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Seamone et al.

[11] **3,866,246**

[45] **Feb. 18, 1975**

[54] **SHOULDER DISARTICULATION PROSTHETIC SYSTEM**

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[73] Assignee: **The United States of America as represented by the Secretary of the** Navy, Washington, D.C.

[22] Filed: **Nov. 14, 1972**

[21] Appl. No.: **306,480**

[52] **U.S. Cl.** **3/1.1,** 3/12.3

[51] **Int. Cl.** **A61f 1/00,** A61f 1/06

[58] **Field of Search** 3/1–1.2, 12–12.7

[56] **References Cited**

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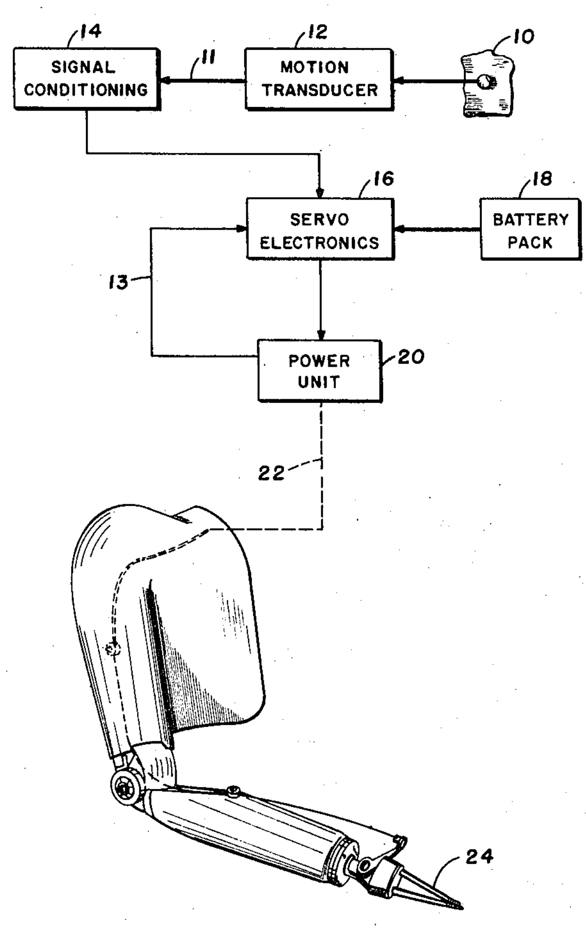
"A Strain Sensor Controlled Orthotic Splint," by Robert P. Patterson et al., Proceedings of the 23rd Annual Conference on Engineering in Medicine and Biology, Washington Hilton Hotel, Washington, D.C., Nov. 15–19, 1970, page 239.

Primary Examiner—Ronald L. Frinks

[57] **ABSTRACT**

The invention is an externally powered prosthesis for shoulder disarticulation amputees. Proportional control of the prosthesis is provided by a displacement sensor preferably comprised of a movable magnet and a stationary semiconductor element which responds to changes in magnetic field strength. The movable magnet is displaced by the transverse motion of the amputee's skin (caused by controlled flexure of a suitably located muscle), thereby producing a signal in the semiconductor element which is proportional to the skin motion. Control of the prosthesis is then accomplished by amplification and utilization of the signal to drive an electric motor powered by an external battery.

7 Claims, 7 Drawing Figures



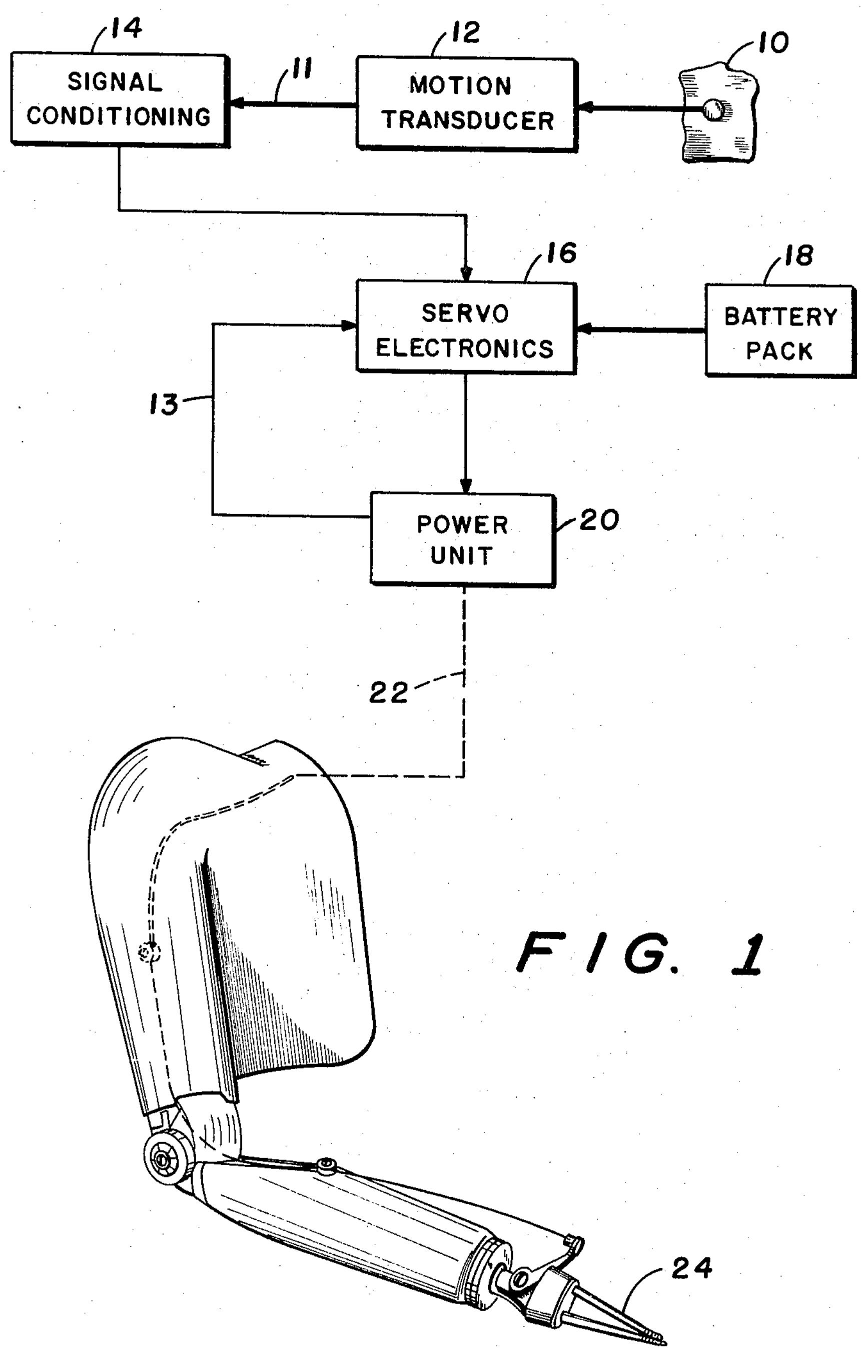

14
SIGNAL CONDITIONING
11
12
MOTION TRANSDUCER
10
16
SERVO ELECTRONICS
18
BATTERY PACK
13
POWER UNIT
20
22
24

FIG. 1

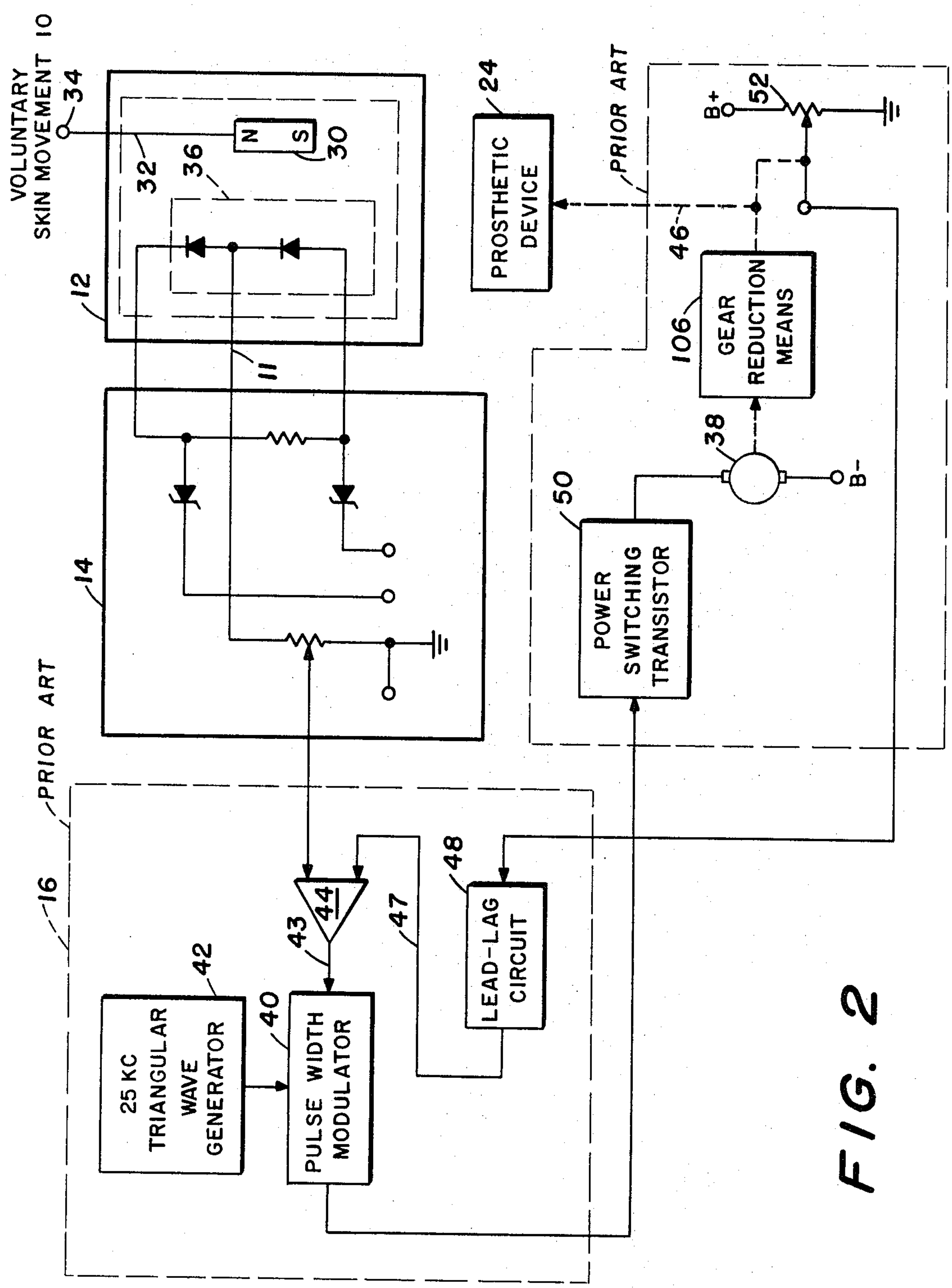
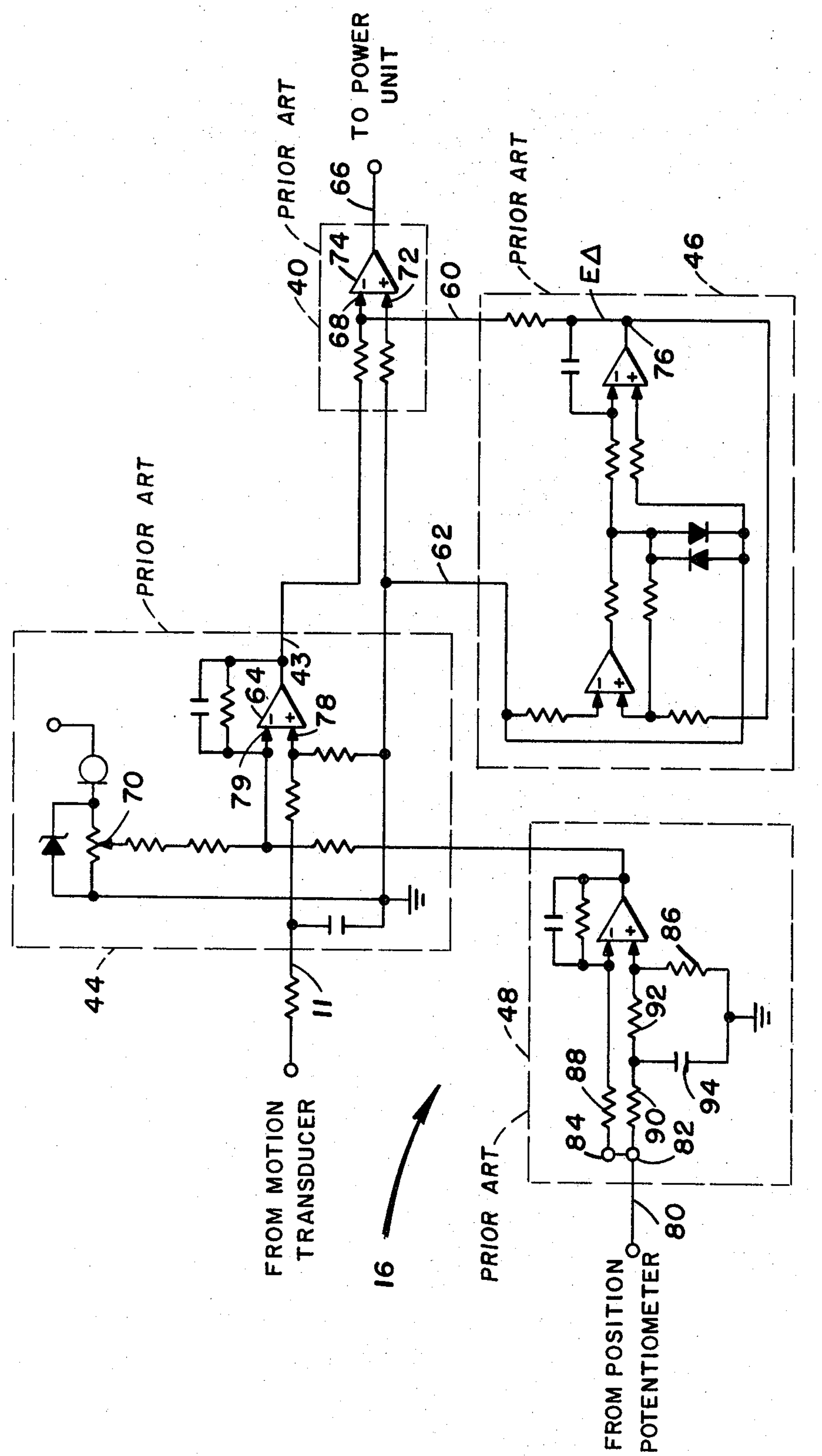

VOLUNTARY SKIN MOVEMENT 10
34
N
S
30
32
36
12
11
14
PRIOR ART
16
25 KC TRIANGULAR WAVE GENERATOR
42
40
PULSE WIDTH MODULATOR
43
44
47
48
LEAD-LAG CIRCUIT
PROSTHETIC DEVICE
24
PRIOR ART
46
B+
52
106
GEAR REDUCTION MEANS
38
B-
50
POWER SWITCHING TRANSISTOR

FIG. 2


TO POWER UNIT
PRIOR ART
PRIOR ART
PRIOR ART
PRIOR ART
EΔ
FROM MOTION TRANSDUCER
FROM POSITION POTENTIOMETER
16
11
40
43
44
46
48
60
62
64
66
68
70
72
74
76
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84
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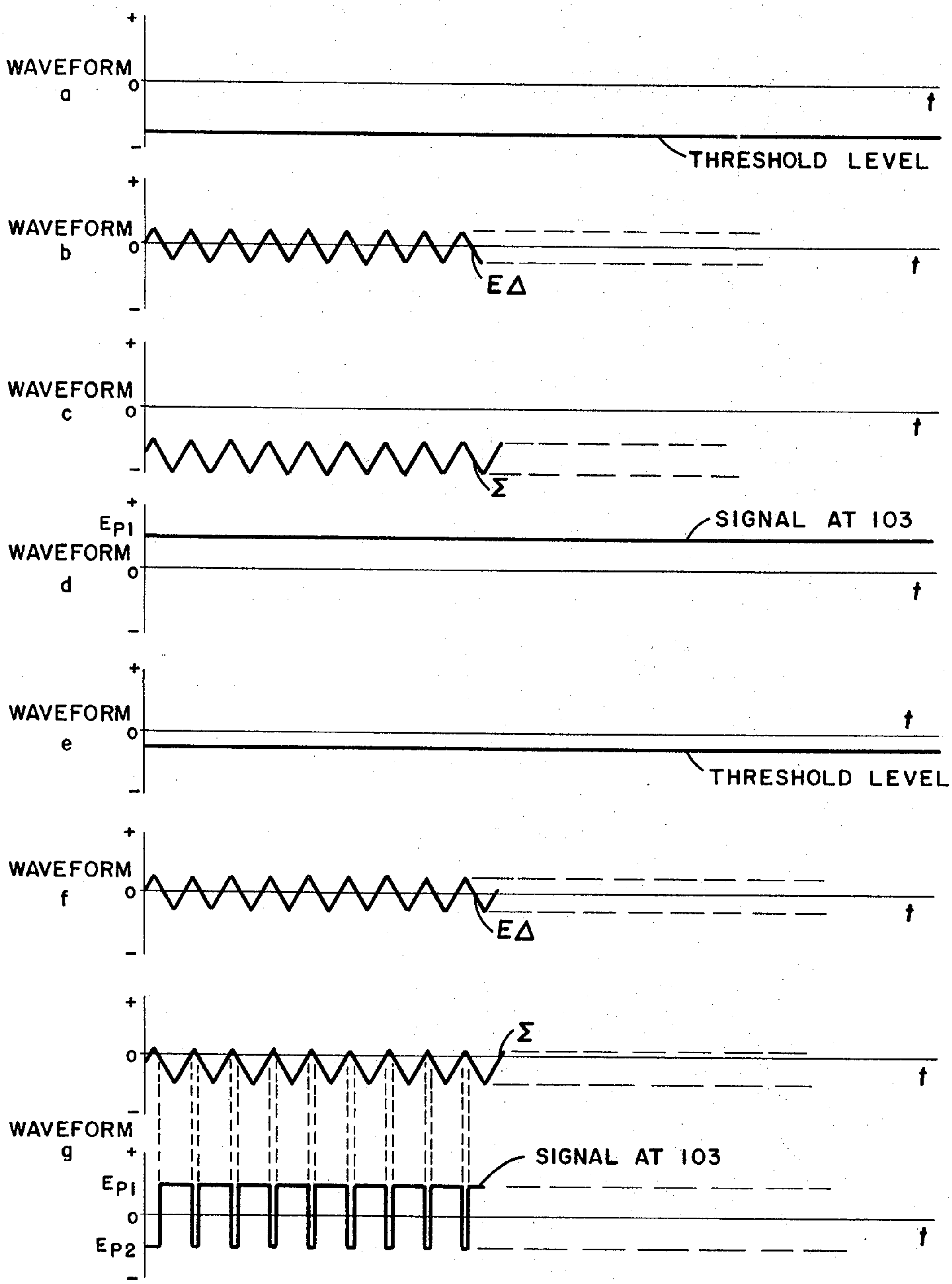
92
94

FIG. 3


WAVEFORM a
THRESHOLD LEVEL
WAVEFORM b
EΔ
WAVEFORM c
Σ
WAVEFORM d
E_{P1}
SIGNAL AT 103
WAVEFORM e
THRESHOLD LEVEL
WAVEFORM f
EΔ
WAVEFORM g
Σ
SIGNAL AT 103
E_{P1}
E_{P2}
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F I G. 4

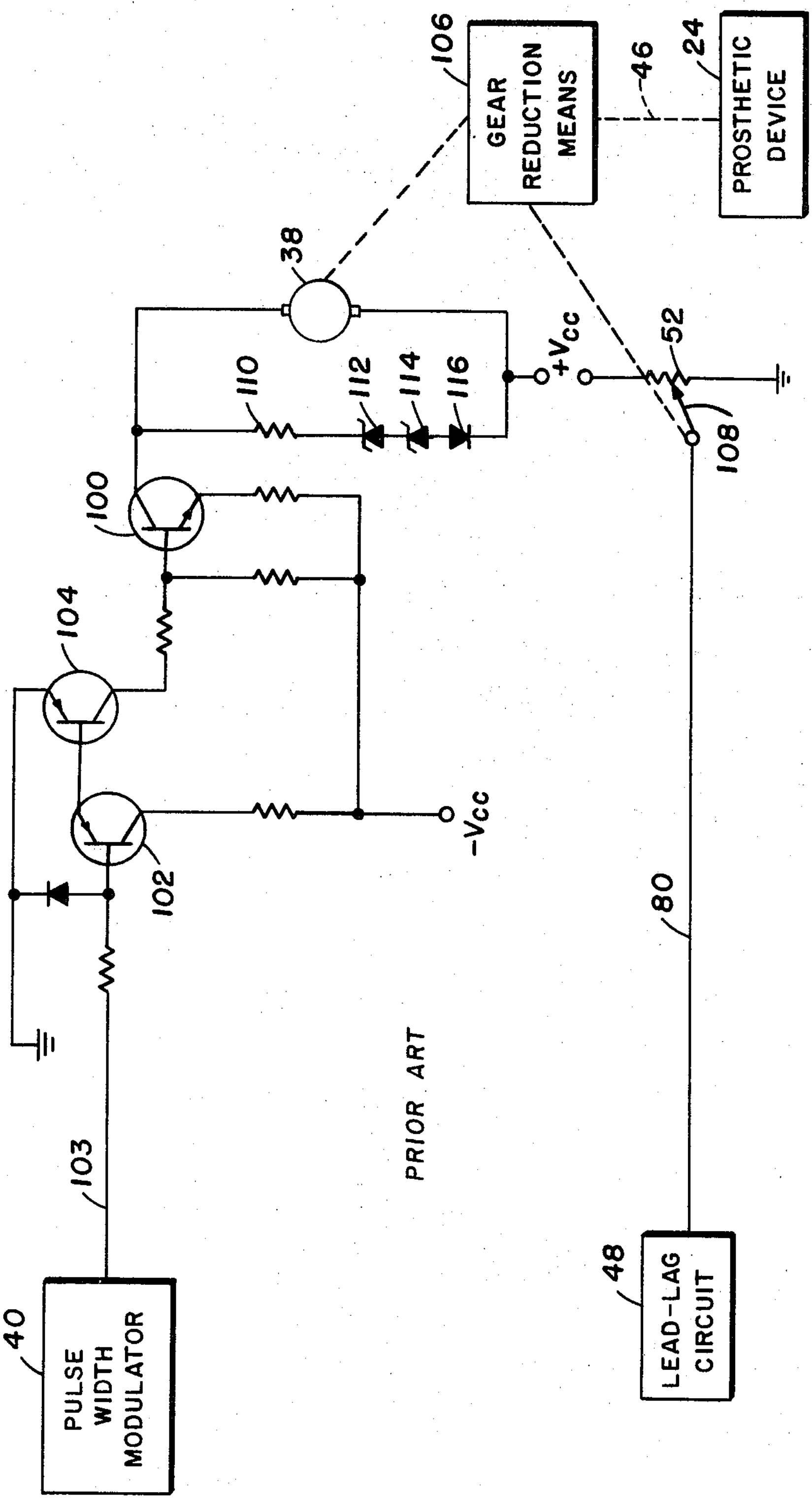
GEAR REDUCTION MEANS
PROSTHETIC DEVICE
PULSE WIDTH MODULATOR
LEAD-LAG CIRCUIT
PRIOR ART
+Vcc
-Vcc
106
24
46
38
52
108
110
112
114
116
100
104
102
103
40
48
80

FIG. 5

PRIOR ART

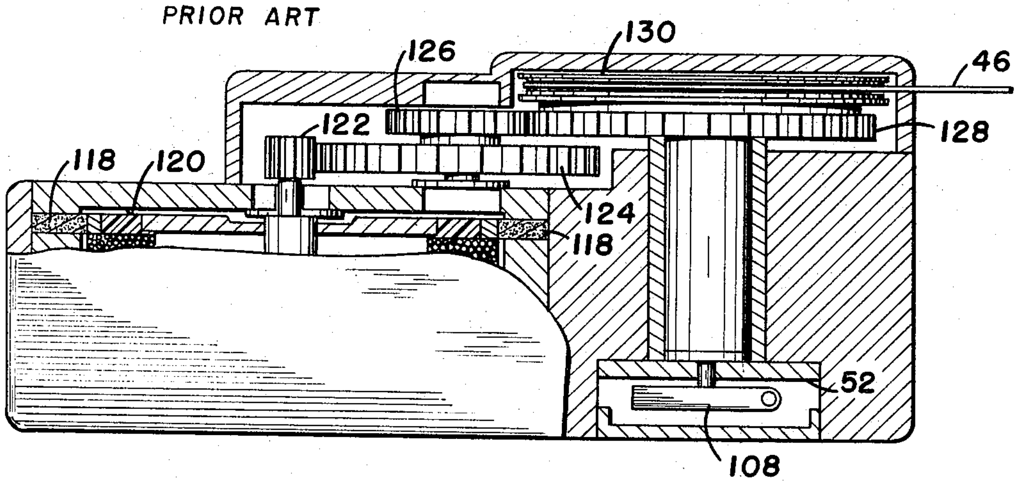

FIG. 6

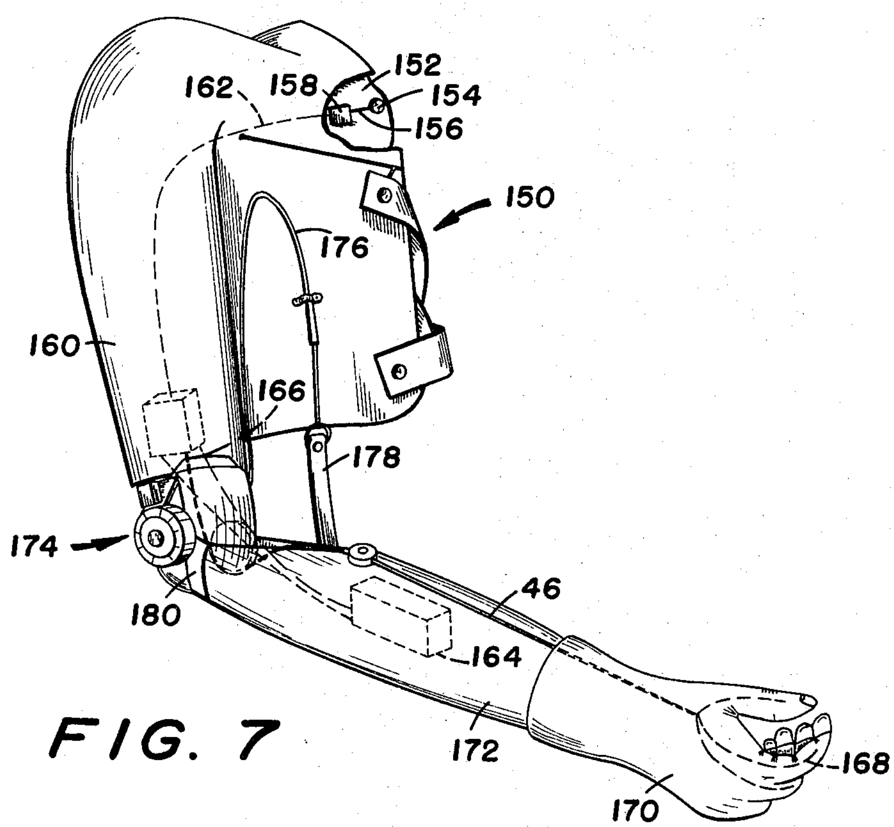

FIG. 7

SHOULDER DISARTICULATION PROSTHETIC SYSTEM

STATEMENT OF GOVERNMENT INTEREST

The invention herein described was made in the course of or under a contract, or subcontract thereunder, with the Department of the Navy.

CROSS-REFERENCE TO RELATED APPLICATIONS

The subject matter of the invention relates to a copending patent application, entitled "Myoelectrically Controlled Prosthesis," Ser. No. 114,262, filed Feb. 10, 1971 and now U.S. Pat. No. 3,735,425.

BACKGROUND OF THE INVENTION

The invention relates to prosthetic and orthotic systems wherein a terminal device is opened in direct proportion to voluntary movement by a user. More particularly, the invention is a prosthesis especially suited for shoulder disarticulation amputees, the prosthesis being controlled by the signal produced by a motion transducer in response to voluntary skin movement. The high-level, essentially DC signal thus produced may then be conditioned and fed into known servo electronics in order to eventually drive a geared-down DC motor which, in turn, drives a mechanical linkage for operating the moving parts of the prosthesis.

SUMMARY OF THE INVENTION

The present invention is particularly useful for prosthetic applications where suitable electromyographic signal sites are not available for "emg" control of a prosthesis. Such situations require that a signal be produced by other means in order to control an externally powered prosthesis. Skin motion on the remaining portion of an amputee's stump is used in the present invention to proportionately control the prosthesis. The motion of the skin is sensed by a motion transducer, the output of which transducer is a signal which may then be conditioned and used to operate a battery-powered servo electronics and motor system. A terminal device on the prosthesis is opened in direct proportion to the signal amplitude as controlled by the user's movement of a particular skin location. Essentially, skin motion produces a control signal which causes a servo control unit to drive a DC motor, consequently opening the prosthesis. The prosthesis begins to open until a feedback voltage proportional to the opened position is equal to the control signal. In this manner, the terminal device of the prosthesis is servo controlled for all positions between fully closed and fully opened. In a similar fashion, elbow motion of the prosthesis may be controlled.

A primary object of the present invention is to provide a prosthetic system suitable for those amputees who do not possess "emg" sites of sufficient strength to control a myoelectrically operated prosthesis.

A further object of the invention is to provide a motion sensor system for a prosthesis whereby voluntary movement of an amputee's skin produces a proportional signal which may be utilized to operate the prosthesis.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic illustrating the major components of the invention;

FIG. 2 is a basic block diagram of the invention;

FIG. 3 is a schematic of the control unit;

FIG. 4 is a chart illustrating the input and output waveforms of the pulse width modulator;

FIG. 5 is a schematic of the power unit;

FIG. 6 is a cross-sectional view of the power unit; and

FIG. 7 is an idealized perspective of a prosthesis configured according to the invention, certain parts being shown in phantom.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a generalized system diagram illustrating the basic elements of the present invention is provided. Voluntary skin movement at **10** is detected by a motion transducer **12**, the signal **11** from the transducer **12** being conditioned at **14** before being fed into a control unit **16**. The control unit **16** comprises servoelectronic mechanisms well-known in the art and will be described in detail hereinafter. External power is provided to the control unit **16** by battery **18**, the control unit controllably supplying power to power unit **20** according to the signal **11** and also according to a position feedback signal **13** generated by power unit **20**. The power unit **20** is comprised of a DC torque motor (not shown) which drives a cable **22** for operation of the prosthesis **24** in a well-known manner.

FIG. 2 provides a more detailed diagrammatical illustration of the present prosthesis system. The system is essentially a closed-loop position servo arrangement with position feedback that follows the signal **11** generated by the motion transducer **12** in response to voluntary skin movement at **10**. The motion transducer **12** preferably comprises a magnet **30** attached to a string **32**, the string **32** being joined to a user's skin by an adhesive tab **34**. Movement of the user's skin causes the string **32** to displace the magnet **30** in a lateral direction, this displacement being sensed by a magnetic-field sensitive semiconductor unit **36**. The semiconductor unit **36** is comprised of semiconductor elements (not shown) which sense changes in the magnetic field experienced by the unit **36**. The unit **36** is known in the electronic arts and, on exposure to a changing magnetic field such as is produced by the movement of the magnet **30**, produces a signal proportional to the change in said field. Therefore, the signal **11** is proportional to the movement of the user's skin at **10**. Electronic excitation is applied to the transducer **12** by signal conditioning circuit **14** which circuit **14** also provides gain control before the signal is applied to the control unit **16**. The signal applied to the control unit **16** is a DC control signal that is approximately proportional in amplitude to the amplitude of the skin movement detected by the motion transducer **12**.

Signal utilization is now accomplished in a known fasion that will be described for convenience. In order to minimize electrical power consumption a pulse-width modulation system is used to control the output torque of a DC torque motor **38** which actuates the prosthetic device **24**. More specifically, a pulse-width modulator **40** utilizes the output of a triangular wave generator **42** and the output **43** of a summing amplifier **44** to provide a pulse-width modulated signal which controls motor current. The DC torque motor **38** is driven in one direction only. The output **43** of the summing amplifier **44** corresponds to the difference between the amplitude of the signal **11** and the position of control cable

46 as represented by a shaped position signal 47 of a lead-lag circuit 48. Since output 43 of the summing amplifier 44 reflects the above mentioned difference, it will hereinafter be referred to as error signal 43. If the amplitude of error signal 43 is small, current in the motor 38 flows for a small part of the duration of the output of the triangular wave generator 42. Accordingly, the "on" time of the motor 38 is a function of the magnitude of the error signal 43. By operating a power switching transistor 50 in a power switching mode and causing the motor 38 to operate only when the output of the lead-lag circuit 48 is less than the signal 11, relatively little power is dissipated. When the motion transducer 21 is not sensing skin displacement, standby power consumption in the electronic component is quite low, i.e., less than 300 milliwatts. No mechanical switches or special power cutoff relays or circuits are required to switch from "standby" to "operate" condition.

A potentiometer 52 supplies the shaped position signal 47 via the lead-lag circuit 48 to the summing amplifier 44. This feedback arrangement provides high gain at low frequencies and less gain as frequency is increased. Such signal processing makes opening of a terminal device on the prosthetic device 24 relatively easy to control at all elbow flexion positions with or without an object in the terminal device. This control technique facilitates a simple interface between the amputee and his prosthesis. The amputee need generate only one signal when he desires to open the terminal device on the prosthesis, the terminal device being automatically closed by spring or elastic action when the user's skin is relaxed and returned to normal position. Thus, an amputee maintains a grasp force without additional effort or attention on his part. When the amputee wishes to disengage the terminal device, he again moves his skin, which motion is detected by the transducer 12. The signal 11 thus produced provides the voltage needed for opening of the terminal device, thereby freeing the object being grasped.

Referring now to FIG. 3, a schematic diagram is shown of the control unit 16. The control unit 16 is known in the art, having first being described in the copending patent application referenced hereinabove. Due to the differing inputs into the control unit 16 of the present invention when compared to the aforementioned patent application, a brief description of said unit 16 follows. The signal 11 generated by the motion transducer 12 in response to movement of a user's skin is passed to the summing amplifier 44 and then to the pulse width modulator 40. The output of the pulse width modulator 40 is subsequently applied to the power unit (not shown) which ultimately actuates the prosthetic device (e.g., a hand or an elbow). In order to minimize electrical power consumption within the power unit, the pulse width modulation system is employed. The pulse width modulator 40 utilizes the outputs 60 and 62, respectively, of the triangular wave generator 42 and the output of a servo amplifier 64 to provide a pulse-width modulated signal 66 which regulates motor current.

In order to more clearly describe the operation of the control unit 16, discussion of the lead-lag circuit 48 and the associated feedback loops will be temporarily omitted. The output signal 62 of summing amplifier 44 represents a DC signal that is proportional to skin movement. This DC signal is applied to input 68 of the pulse width modulator 40. Also, the output 60 of the triangular wave generator 42 is received at input 68. The operation of the pulse width modulator 40 can best be explained by additional reference to FIG. 4. The DC output 43 of the servo amplifier 64 is shown by waveform (*a*) of FIG. 4. In this condition, there is no sensed signal being received from the motion transducer. The DC output signal as shown in waveform (*a*) is obtained from a potentiometer 70 and applied to input 72 of operational amplifier 74. The output, EΔ, from output terminal 76 of the triangle wave generator 42, shown by waveform (*b*) of FIG. 4, is applied to the negative input 68 of the operational amplifier 74. Waveforms (*a*) and (*b*) are combined within the amplifier 74 to produce the summed waveform (*c*) of FIG. 4. As long as the summed waveform is less than 0 volts, the output of the pulse width modulator 40 is as illustrated by waveform (*d*) which represents the control unit 16 in the "off" condition. Thus, the prosthesis does not respond since there is no effective enabling signal. When the motion transducer senses movement of the skin, there is applied to input 78 of the amplifier 64 a positive DC signal. When combined with the threshold level signal as produced by the potentiometer 70, the signal as represented by waveform (*e*) is thus applied to input 68 of amplifier 74. When waveform (*e*) is combined with the EΔ-waveform (*f*), the resultant signal as shown by the upper half of waveform (*g*) is produced. Whenever the upper peak of waveform (*g*) exceeds 0 volts, the pulse width modulator 40 shifts from the non-enabling Ep_1 voltage level to the enabling Ep_2 level. In this manner does the prosthetic device actuate only when the sensed skin motion exceeds a predesignated (and variable) threshold. As the prosthesis is being actuated its physical position is indicated by the wiper arm of a position potentiometer (not shown). The feedback position signal 80 is applied to the lead-lag circuit 48 at terminals 82 and 84. The function of the lead-lag circuit 48 is to prevent actuation of the prosthesis by a short term, high gain signal, e.g., noise. Via resistors 86, 88, 90 and 92 and capacitor 94, the prosthesis will only respond to a long term signal, thereby preventing the prosthetic device from continually opening and closing upon every sensed signal.

Referring to FIG. 5, there is shown a schematic diagram of the power unit. The power unit is also known in the art but is briefly described hereinafter to provide a more complete description of the system used to operate a prosthesis according to the present invention. Emergent from the pulse width modulator 40 is a series of enabling pulses 103, as shown by the lower portion of waveform (*g*) of FIG. 4. These pulses are applied to the motor 38 after being amplified by power transistor 100. Transistors 102 and 104 serve as driver transistors for the transistor 100. Upon energization, the rotation of the armature of the motor 38 causes like rotation in gear reduction means 106. After the necessary gear reduction is accomplished the control cable 46 is connected to a pulley that is attached to the last gear element (not shown). Attached to the end of the control cable 46 is the prosthetic device 24. In this manner, rotation of the motor shaft causes activation of the prosthetic device 24. Also connected to the gear means 106 is the wiper arm 108 of the potentiometer 52. In this manner, position feedback signal 80 is provided for the lead-lag circuit 48. A transient suppression circuit is provided for the power unit for inhibiting undesired interference with power transistor **100** and driver transistors **102** and **104** when the motor **38** is switched on and off. The transient suppression circuit consists of resistor **110**, zener diodes **112** and **114**, and diode **116**.

The gear box reduction means **106** is shown in the cross-sectional drawing of FIG. **6**. The output signal of power transistor **100** is applied to brush assembly **118** causing rotation of the rotor **120**, and thus rotor pinion **122**. Rotation of rotor pinion **122** induces rotation in spur gear **124** and pinion gear **126**. Final gear reduction is accomplished by spur gear **128** to which is attached at its upper end pulley **130** and at its lower end potentiometer **52**. Trained around pulley **130** is the control cable **46** which actuates the prosthetic device. The position feedback signal is provided by the potentiometer **52** and wiper arm **108**, as previously described.

FIG. 7 illustrates an embodiment of the present prosthetic system which is capable of elbow movement. The prosthesis **150** is particularly suited to individuals who have shoulder disarticulation amputations. In such situations, the signal to be controllably generated by the amputee for the purpose of driving the prosthesis is derived from voluntary movement of the skin surface **152** near the amputation site. As has been described previously, an adhesive tab **154** disposed on the skin surface **152** holds a string **156** which is connected to a magnet (not shown). The magnet comprises a portion of a motion transducer **158** which senses the movement of the skin surface **152**. The output signal of the transducer **158** is directed to a control unit **160** via signal cable **162**. Control signals from the control unit **160** to the power unit **164** as well as position feedback signals from the power unit **164** to the control unit **160** are transmitted via signal cable **166**. Upon receiving energization commands from the control unit **160**, a motor within the power unit **164** causes the control cable **46** to retract (as described previously), consequently opening the fingers **168** on a prosthetic hand **170** or the digits of a prosthetic hook. Since the operation of the prosthetic hand **170** is well-known in the art, description of this mechanical process has been deemed unnecessary. Retraction of the cable **46** causes forearm **172** to move upwardly if the elbow joint **174** is unlocked. When the forearm **172** is in the desired position, the amputee pulls on a locking cable **176** by means of a shoulder harness **178**, thereby causing lever arm **180** to lock the forearm **172** into position. When the forearm **172** is locked into position via the lever arm **180**, further retraction of the control cable **46** causes the fingers **168** of the hand **170** to open. The motor and power supply may be placed within the physical confines of the prosthesis **150** or may be disposed on a special belt to be worn about the amputee's waist to reduce prosthesis weight.

We claim:

1. A control system for actuating a prosthesis from voluntary skin movement of a user, comprising:
- a prosthesis;
- displacement sensing means for measuring the amplitude of movement of a point on the skin of a user of the prosthesis, the sensing means comprising
  - a magnet,
  - connecting means joined to the magnet and adapted to be connected to a point on such user's skin, and
  - magnetic field sensitive means for sensing a change in the magnetic field on displacement of the magnet by motion of that point on such user's skin to which the connecting means is joined;
- means for actuating said prosthesis in response to said sensed skin movement; and
- means for providing a position feedback signal to said actuating means for identifying the degree of actuation imparted to said prosthesis.

2. The control system of claim **1**, and further comprising means for delaying in time said position feedback signal.

3. A control system for actuating a prosthesis from voluntary skin movement of a user, comprising:
- a prosthesis;
- means for sensing displacement of a point on the skin of a user of the prosthesis, said means comprising,
  - a magnet,
  - connecting means joined to the magnet and adapted to be connected to a point on such user's skin, and
  - magnetic field sensitive means for sensing a change in the magnetic field occurring on displacement of the magnet relative to said magnetic field sensitive means, the displacement of the magnet occurring due to voluntary motion of that point on such user's skin to which the connecting means is joined;
- means for converting the sensed skin displacement into a DC level signal having an amplitude proportional to the magnitude of the skin displacement;
- means for identifying the exact physical position of said prosthetic device and for producing therefrom a position feedback signal;
- means for actuating said prosthesis in response to said sensed skin displacement, said actuation means providing an electrical signal sufficient to actuate said prosthesis and including a summing amplifier for producing said electrical actuation signal when the resultant threshold output amplitude of said means for converting the sensed skin displacement into a DC level signal is greater than the amplitude of said position feedback signal;
- means for converting said electrical signal into mechanical energy; and,
- means for producing a control signal effective to actuate said prosthetic device only when the sensed skin displacement is above a predetermined threshold level, said degree of prosthetic actuation being proportional to the amplitude of said sensed skin displacement, said means for producing said control signal comprising a standard waveform generator producing a predetermined amplitude signal, said electrical actuation signal being generated when said output amplitude of said summing amplifier is greater than said predetermined amplitude of the standard waveform signal.

4. The control system of claim **3** wherein the magnetic field sensitive means is a semiconductor.

5. The control system of claim **3** wherein said means for producing a position feedback signal comprises a potentiometer whose wiper arm is mechanically actuated in direct proportion to the degree of actuation imparted to said prosthesis, the voltage sensed by said wiper arm being received by said actuating means.

6. The control system of claim **3** and further comprising means for delaying in time said position feedback signal.

7. The control system of claim **3** wherein said means for converting said electrical signal into mechanical energy comprises a DC motor.

* * * * *