An Electrically Controlled Elbow Locking Mechanism for an Upper Limb Prosthesis

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Abstract

The electromyogram from the biceps muscle as used to lock and unlock the elbow mechanism in the prosthesis fitted to a unilateral above-elbow amputee. The electrically powered lock is only slightly heavier than the mechanically operated lock which it replaces and current consumption is small.

1. Prosthetic Background

The cable operation arm and hand prosthesis is by far the most commonly fitted to unilateral above-elbow amputees. The amputee is extremely limited in the variety of independent movements which he can perform using the remaining skeletal structures on the amputated side and frequently only a single cable can be usefully exercised. For this reason the active articulations are almost invariably restricted to two: those of the elbow joint and the terminal device. Arrangements may also be incorporated for "passive" articulations, for example to provide rotation at the wrist and at a "humeral joint", proximal to the elbow, substituting for the internal/external rotation at the shoulder which is largely lost due to restraints imposed by the socket and suspension. The user of the prosthesis has only one of the active functions available to him at any one time; selection between the two is obtained by means of a locking mechanism incorporated with the elbow joint which allows the arm to be fixed at any one of several angles of flexion. If a voluntary opening terminal device is fitted a spring maintains the artificial hand (if such is used) in a closed position. If the elbow is free to move the action of the motivating cord will, therefore, produce flexion at the elbow. If the mechanism is locked, as Fig (1) illustrates, the available work output from the motivating cord is transferred to the hand and will open it against the spring force. Although the locked elbow is useful in carrying heavy loads (the maximum weight-lifting ability of the prosthesis positioned by the motivating cord and with the elbow free(1) is typically less than 2 kg) its essential function is this transfer of the available work output, and of control, from one function to the other. It may be thought of therefore as a functional switch.

Many mechanical devices of varying ingenuity, complexity and effectiveness have been developed to provide the required switching action.(2) The design is made difficult by the limited repertoire of independent movements of the shoulder girdle. At best only a low force, small displacement movement of the clavicle and scapula is available; this may be harnessed to give control via a single pull cord. A toggle mechanism is incorporated to give a pull-to-lock/pull-to-unlock characteristic. Sadly, the majority of users of this type of prosthesis find themselves unable to master this type of control and find it necessary, therefore, to use the "good" hand to operate the lock. Obviously this detracts considerably from the functional improvement which the prosthesis brings.

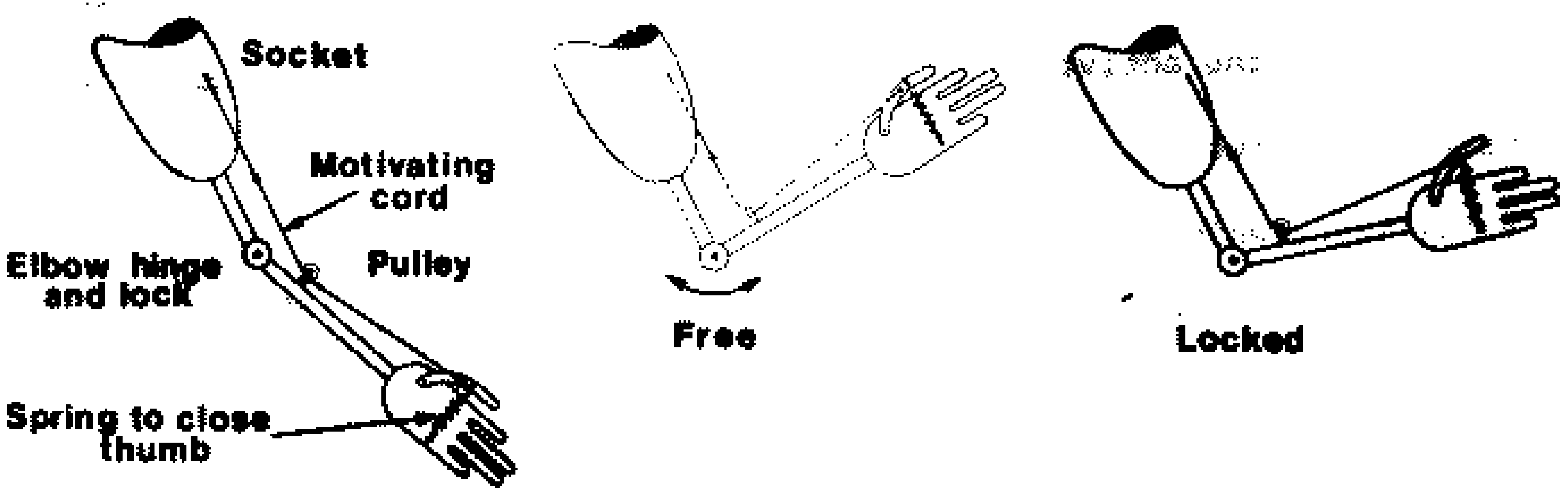


Fig (1)

2. The Electromyographically Controlled Elbow Lock

The muscles of the upper arm (biceps, triceps) in an above-elbow amputee show clearly differentiated e.m.g. signals of good amplitude. This can be used to control an electrically powered locking mechanism. The idea has several attractive features:

1. No movements of the prosthesis itself have to be powered so that the energy requirements are small Good endurance from lightweight batteries can be expected.
2. The prosthesis is not made unuseable in the event of failure of the electronic package, the electrical mechanism or the power supply. Means for reversion to manual operation is easily incorporated.
3. Positional feedback (via the motivating cord) is entirely independent of the e.m.g. controlled lock. No loss of proprioceptive sense is involved.
4. Control by biceps/triceps activity is physiologically appropriate, since these muscles power the movements of the natural elbow.

The new lock is shown in Fig (2) with its mechanical precursor (a design developed at the Princess Margaret Rose Orthopaedic Hospital) shown in Fig (3) for comparison. The mechanical toggle mechanism is replaced by a permanent magnet DC electric motor (ESCAP Type 16-M11-210-0), driving the detent into engagement with the locking quadrant by means of a lead screw. The weight of the elbow assembly is increased slightly (from 400 g to 435 g) by this change.

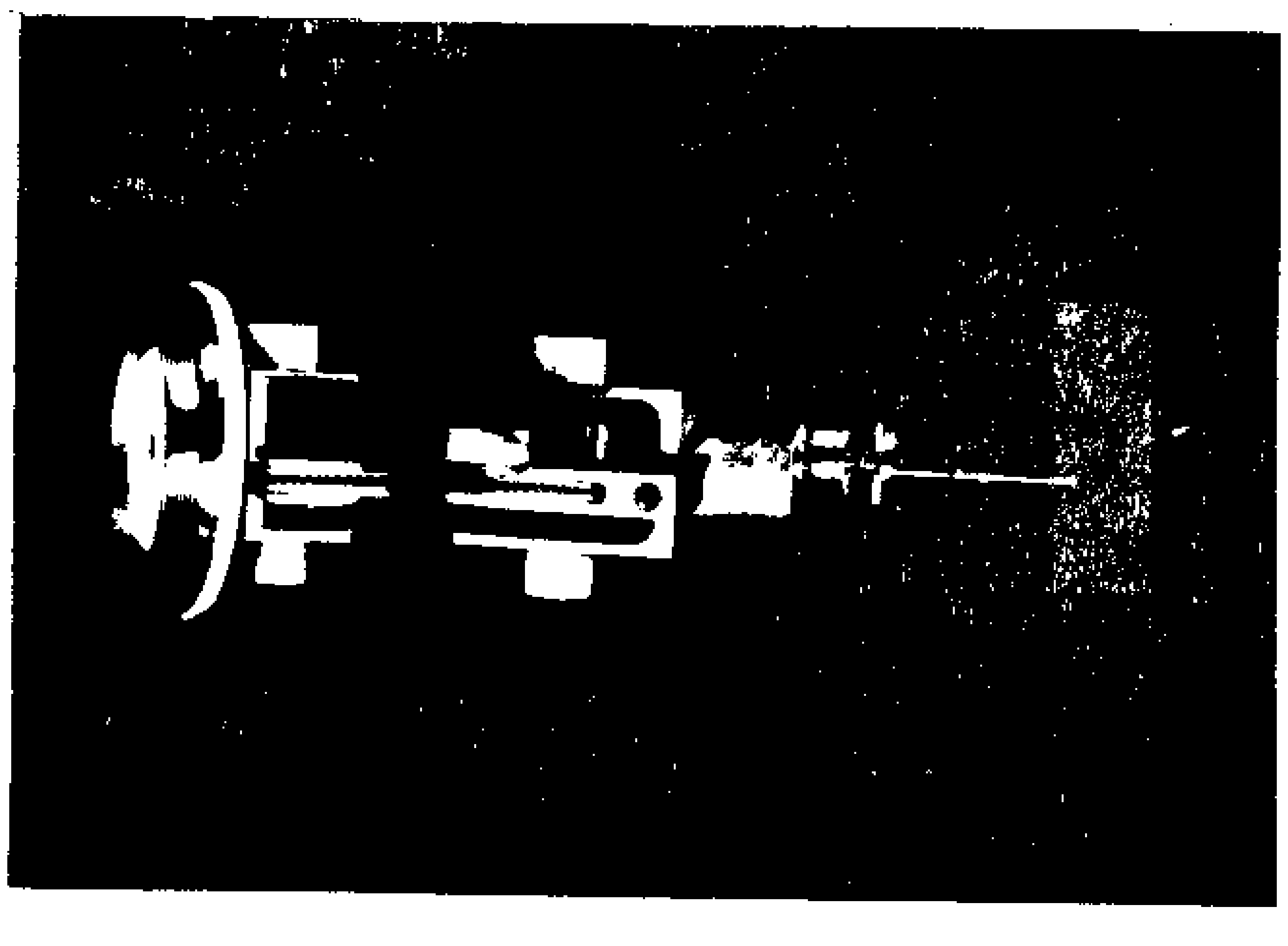


Fig (2)

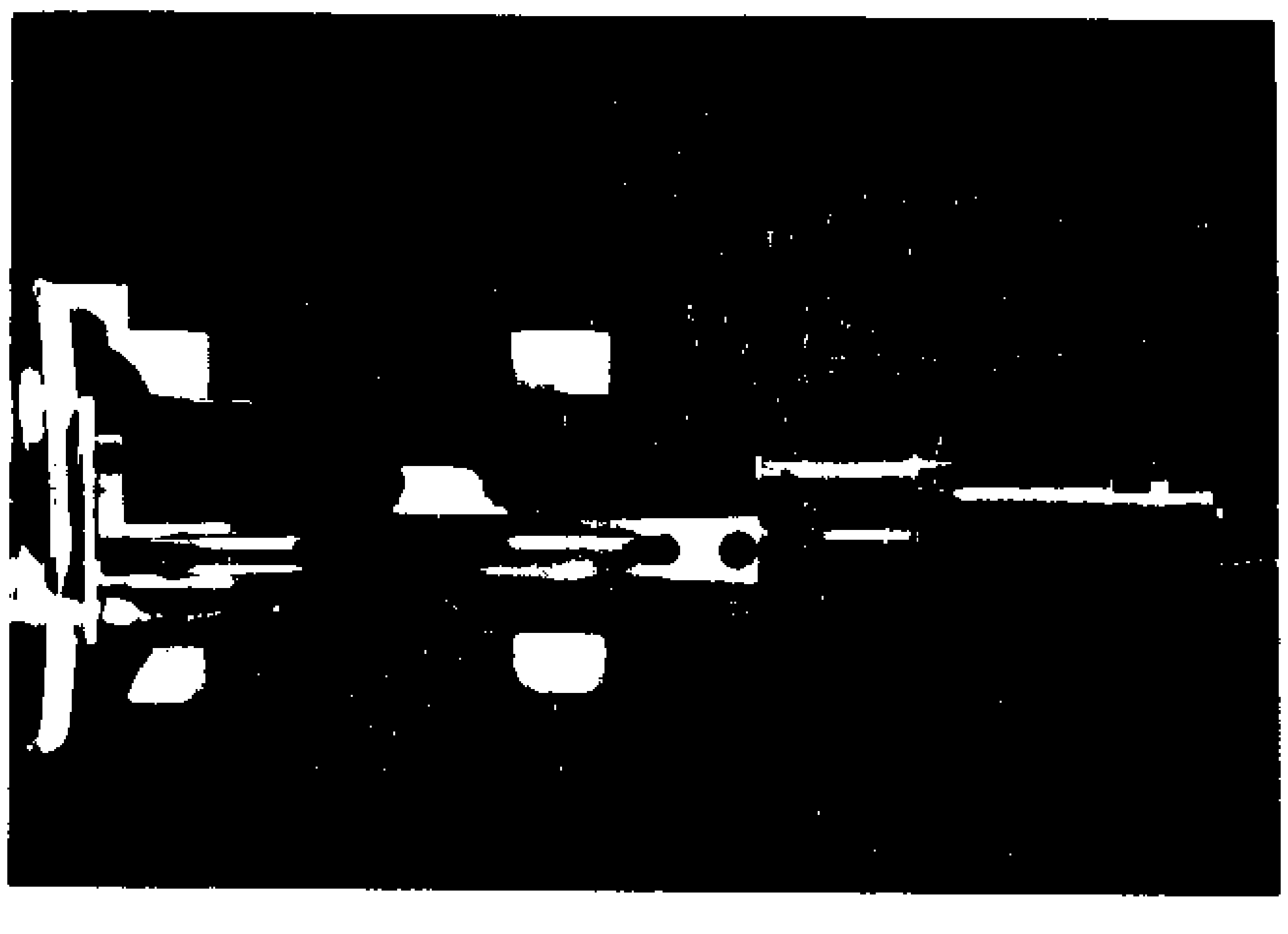
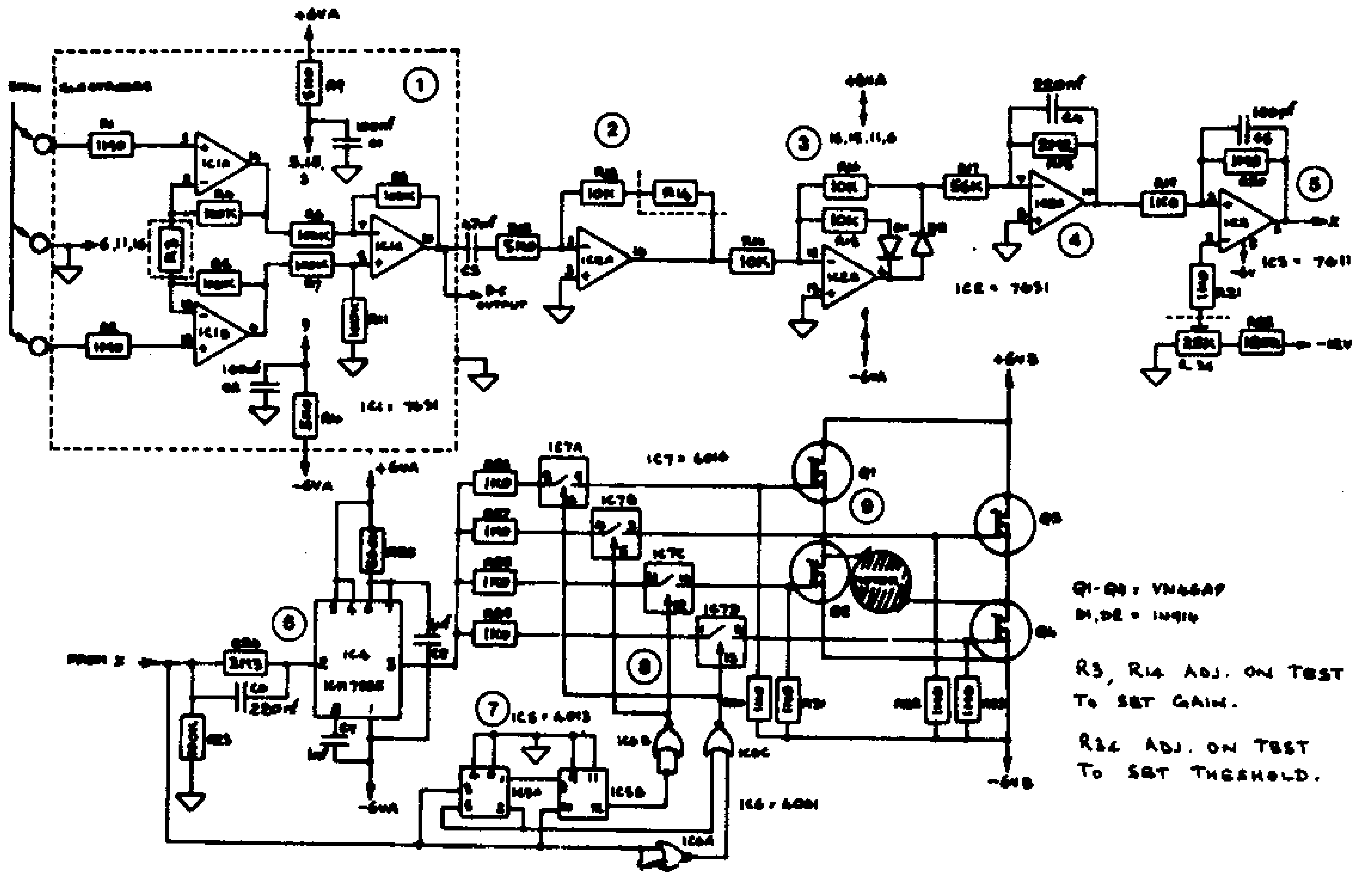


Fig (3)

3. The Electronic Control Circuit

The complete electronic circuit is shown in Fig (4). Its function is as follows. (Numbers relate to the sections of the circuit similarly identified in the figure.)



Q1-Q4 : VN66AF
D1,D2 = 1N914

R3, R14 ADJ. ON TEST
TO SET GAIN.

R36 ADJ. ON TEST
TO SET THRESHOLD.

Fig (4) The e.m.g. amplifier and control circuit

1. An instrumentation amplifier used as the e.m.g. preamplifier. The gain is set by R3 (trimmed to value). For biceps e.m.g. a gain of 100 (R3 = 1000 ohms) is suitable, giving an output of about 10 mV r.m.s.
2. A variable gain amplifier stage (gain $\frac{1}{3}$ to 10).
3. The rectifier.
4. An integrator (down-going time constant ~ 0.5 s).
5. A threshold-crossing detector.
6. Timing circuit.
7. Flip-flop.
8. Decoding.
9. Motor and switching transistors.

An input to the e.m.g. preamplifier of sufficient amplitude and duration will cause the output from IC3 to switch high, initiating the timing circuit and changing the state of the flip-flop. The motor will run for a preset time in the direction determined by the flip-flop. The lock is thus engaged and disengaged by successive, voluntary, brief contractions of the same (biceps) muscle. This action is similar to that of the mechanical locks and most easily learned by an established user of a prosthesis. Other control formats are possible. Using two e.m.g. preamplifiers, for instance, triceps contraction could be used to initiate elbow locking, biceps elbow unlocking. Clinical assessment is continuing to determine the control system which is physiologically the most appropriate.

4. Power Requirements and Battery Duration

The standing current in the electronic circuit is 1.6 mA, the no load motor current is approximately 10 mA rising to 600 mA when stalled. The current waveforms during the lock and unlock events are very similar. Total duration is about 0.5 s, total charge 58 millicoulombs. Use of the prosthesis over a 16 hour day will entail the following energy consumption:

Control circuit, 1.6 mA x 16 h	25.6 mAh
Lock/unlock, each event 58 mA.s, 100 lock/unlock cycles each hour	51.6 mAh
Total	~ 77 mAh

A nickel-cadmium storage battery (2 x 6 volt, 80 mAh, weighing 100 g and volume 30 cm^3) will suffice for a day's use. A mercury primary cell would be smaller and lighter (eg 100 mAh, 14 g, 3.7 cm^3).

5. Hybrid Microelectronics

The advantages which hybrid microelectronic construction brings to this application are considerable. Small size and weight are obvious features (all users are aware of the weight of the prosthesis and critical of any increase), as is reliability. In many ways the environmental conditions are kindly when compared with those specified for (say) military or avionics equipment. The circuits are not required, for instance, to withstand extreme temperatures or high levels of vibration or acceleration. They will, however, be exposed to a formidable variety of pollutants (rain, salt-spray, perspiration, sand, dust ...) and extremely high standards of reliability are needed. The prosthesis is a very personal property, critically assessed. Innovative features which break down frequently will be vigorously rejected.

For hybrid construction the circuit has been divided into three parts:

(i) The e.m.g. preamplifier (section 1, Fig (4)), housed in a ¼ inch square (16 x 16 x 2.3 mm) ceramic/glass/metal flatpack.

(ii) Sections 2-8, in a 1" square (26 x 26 x 3.1 mm) flatpack.

(iii) The power transistors, which are fitted as discrete components.

The e.m.g. preamplifier is separated in anticipation of its use in several other applications under study at the Princess Margaret Rose Hospital and elsewhere. Also, the small, thin dimensions of the package have an important bearing on its performance as it allows good and consistent contact between the electrodes and the skin to be maintained.

6. Clinical Assessment

This is still at an early stage, only one patient having been so far fitted with the new elbow lock. This was incorporated in the Princess Margaret Rose hand and arm prosthesis with cosmetic, functional (voluntary opening) hand.

The patient had, some months prior to fitting, spent approximately 30 minutes learning to generate a biceps e.m.g. "on demand". About 0.2 mV r.m.s. maximum output could be obtained from two surface electrodes spaced 2 cm apart. Dynamic range with other muscles relaxed was in excess of 40 db, a margin of about 10 db remained when other movements of the shoulder were mobilised. With this background, control of the lock was mastered immediately and initially appeared to be reliably dissociated with other movements at the shoulder. Problems arose later as the surface electrode signals are not constant with time with the result that the switching threshold required adjustment from time to time.

Circuit modifications to accommodate this are in hand.

Conclusions

The electrically powered, e.m.g. controlled elbow lock is technically appropriate to modern electronics technology. The limited clinical assessment indicates enthusiastic acceptance by the prosthesis user and learning time is very short.

The device should be of benefit to the many patients who are unable to operate a mechanical elbow lock by movements on the amputated side.

8. Acknowledgement

This work is part of a development programme on electrical control of hand and arm prostheses funded by the Scottish Home and Health Department.

References

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