ELECTROMYOSTIMULATION, CIRCUITS AND MONITORING

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INTRODUCTION

Electromyostimulation (EMS) is a procedure in which electrical currents are applied externally to a human with the intent of causing particular muscle groups to contract. The procedure has a history that seems to be long on anecodotal results and short on very specific and quantitative data. The electrical current is generated by a stimulator which is nothing more than an oscillator creating a waveform that is routed to an isolated power amplifier. The signal is applied via conductive electrodes attached to the skin. Appropriate location of these electrodes will cause a desired muscle or muscle group to contract. This contraction will generally cause some form of body motion. An example is the contraction of the thigh (quadricep) muscle which causes the leg to extend.

One method to determine the benefit of electromyostimulation requires an accurate strength assessment of the muscle of interest using a muscle force testing device. Several commercial devices are available. After a pre-EMS muscle assessment, a protocol with accurately controlled stimulation parameters must be applied and monitored. Both the actual current and the resultant muscle force must be measured throughout the study. At the conclusion of the study, a reassessment of the muscle strength must be gathered.

In our laboratory, electromyostimulation is being studied as a possible countermeasure to the muscle atrophy (degeneration) experienced in space. This muscle loss not only weakens the astronaut, but adversely affects his/her readaptation to 1-g upon return from space. Muscle atrophy is expected to have a more significant effect in long term space flight as anticipated in our space station.

METHODS

Our studies have concentrated on stimulating the four major muscle groups in the leg. These muscles were stimulated sequentially to allow individual muscle force quantification about the knee and ankle. The leg must be restrained in an instrumented brace to allow this measurement and preclude muscle cramping.

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Signal Generation

The generation of a stimulation waveform is not particularly difficult. Nearly 200 different devices are commercially available and listed with the FDA. None, however, allow four or more channel sequential operation at power levels that are sufficient to perform maximal muscle stimulation. Selection of a unit must also consider the waveform appropriate for optimum stimulation of the muscle of interest. Most devices are two channel and allow little variation in signal parameters, other than amplitude. The device used in our laboratory was a modified off-the-shelf 8 channel unit of which 4 channels were used. The frequency, pulse width, and duration of the pulse wavetrain were adjustable. After considerable experimentation, parameters were chosen that caused the best overall contractions of the four muscle groups in the leg. The amplitude of each was individually adjusted to elicit the maximum force without undue subject discomfort.

The waveform used in our studies was a biphasic pulse train that had a pulse width of 150 usec and a repetition rate of 30 hertz. The pulses ramped up from zero requiring approximately 6 cycles to reach the peak amplitude. Amplitude was adjusted until maximal tolerable contraction was achieved. Figure 1 shows the waveform used in our studies.

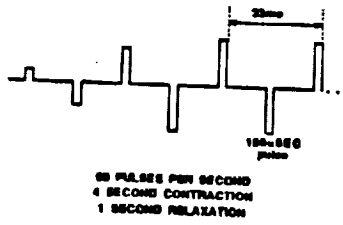

Figure 1 - Stimulation Waveform

The stimulator was battery powered to provide safety and isolation from power lines. Futhermore, the output was transformer coupled to provide additional isolation. This isolated signal was then passed through a sequencer and current monitor.

Sequencer/Current Monitor

The sequencer applied the stimulation signal subsequently to each of the four muscle groups. The signal was on for 4 seconds and off for 1 second at which time the switching occurred. A complete cycle took 20 seconds. Figure 2 shows a block diagram of the sequencer. The trigger pulse originates in the stimulator. Relays allow only one channel to output an EMS signal at a time.

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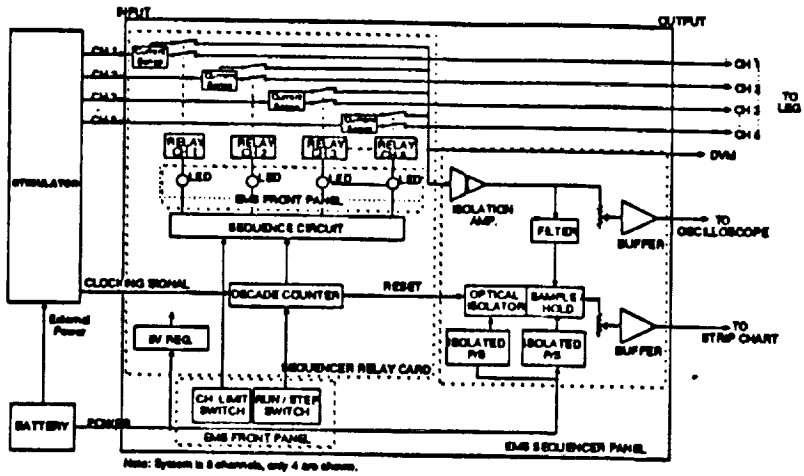

Figure 2 - Sequencer/Current Monitor Block Diagram

The sequencer also contains a current monitor circuit. It is important to monitor the current during the actual time of stimulation. An RMS current measurement does not give a reasonable representation of the effective current being delivered to the muscle. This current monitor read the voltage across a precision 10 ohm resister. A peak detector and hold circuit was necessary as the waveform took six cycles to build up to its full value. This peak voltage is held and scaled to indicate current.

Protocol

Studies conducted thus far in our laboratory have employed EMS in two positions. In the first, muscle atrophy was introduced to one leg of each subject by applying a fiberglass leg cast. This removable cast was worn continuously except during daily EMS sessions. EMS was applied for one hour while the subject sat in a chair with his leg restrained in an instrumented brace.

The second study introduced muscle atrophy by bedresting subjects for 30 days. Subjects received stimulation on a schedule of three days on and one day off throughout the study. Since the subject was supine, a different brace was developed to be clamped to the bed for the twice daily sessions.

Force Quantification

Both braces immobilized the leg so that muscle contraction would be isometric, i.e., the leg could not move. The leg was held in a position of 55 degrees flexion. The foot was restrained with a footplate which could rotate about an axis in line with the ankle. A load cell was attached to the bottom of the footplate to measure forces applied during contraction of the calf muscles (in the down direction) and the anterior tibialis (in the up direction). The foot, lower leg, and the assembly just mentioned was allowed to pivot about an axis in line with the knee.

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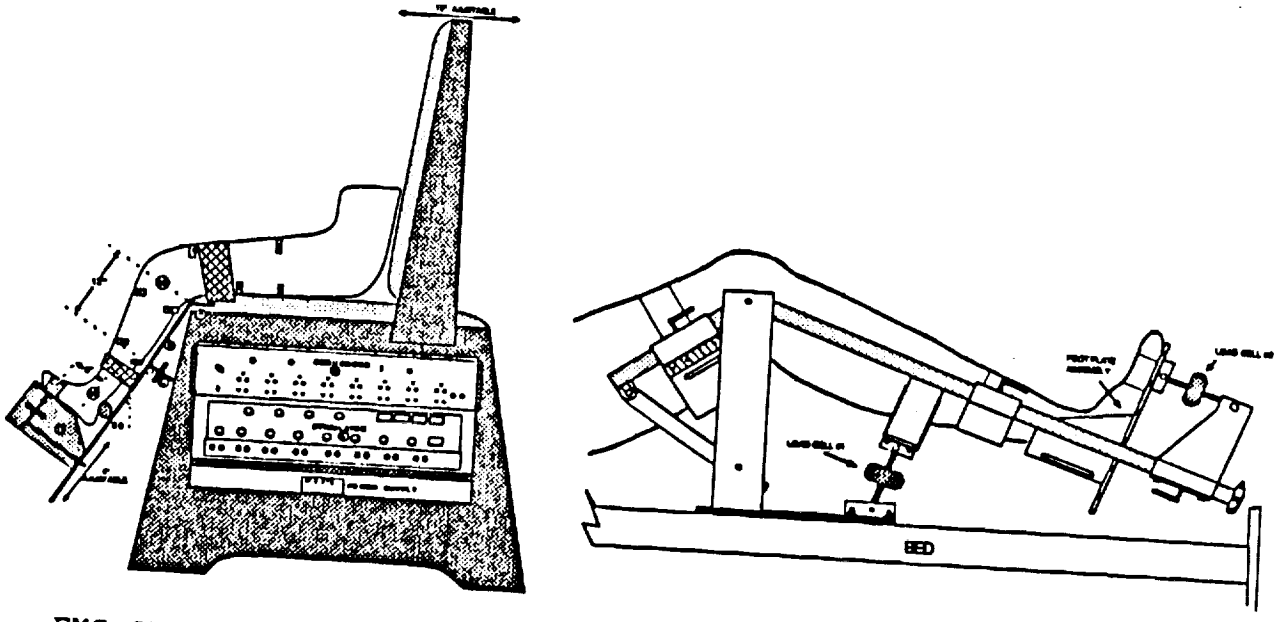
Another load cell was attached to this assembly. Contraction of the quadricep caused the leg to pull up on the load cell. Contraction of the ham strings caused the leg to pull down, therefore compressing the load cell. Figure 3 shows the basic layout of the two braces.



EMS Chair Brace

Supine Brace

Figure 3

Data Acquisition

The current data was available on a single output channel from the sequencer as the measurement channel rotated with the stimulation signal. The voltage across the precision 10 ohm resistor in each channel was buffered, isolated, and available as an analog signal. This was recorded on a strip chart recorder with the sensitivity of 1 volt/100 ma. The same analog signal was also fed to a computer A/D card resident in a Compaq computer. The average of each muscle's current level over a minute's time was calculated, displayed, and written to memory. Generally, this was the average of three readings.

The outputs from the two load cell signal conditioners was a plus or minus analog voltage proportional to the force applied by the muscle group. The sequencer split the plus outputs from the minus outputs so that each of the four muscle groups could be displayed seperately on four channels of a strip chart recorder. Each channel was scaled to allow maximum readability. Stronger muscle groups, such as the quadriceps, were initially scaled to 90 ft-lb full scale. Smaller groups, such as the anterior tibialis, were scaled to 45 ft-lb full scale.

RESULTS

The circuitry described was used during two studies. The prototype equipment was used for the seated EMS study involving leg casting. Four systems were subsequently fabricated and used throughout the summer of 1987 during a Bedrest study conducted at the AMES Research Center in California. Operation was reliable and stable.

The only problem encountered was that eventually all of the bedrest EMS subjects were able to tolerate the maximum level of stimulation available from the stimulator. A modification to the power supply of the output stage doubled the available output current from 200 ma to approximately 400 ma. The application of this higher current elicited stronger muscle contractions. In fact, one subject was able to create torques about the knee of 133 ft-lb.

One of the advantages of using load cells was the ability to remove them and have them calibrated to National Bureau of Standards values. They were also stable and provide repeatable data.

CONCLUSION

The support to principal investigators pursuing the physiology involved with electromyostimulation can be challenging and rewarding. The quantification of EMS parameters in the detail described here has seldom been accomplished. Absolute stability of the leg in the measurement brace is not possible, especially when higher forces are being developed. This leg movement can cause errors in that the knee or ankle axis moves off from the brace axis. Considerable efforts are expended to preclude or at least minimize this. It is, therefore, important to assure accurate repositioning of the leg from day to day to enhance repeatability of the measurements. Since comparision of pre and post test data will be made, relative changes are important to the confirmation of the study hypothesis.