AN INSTRUMENT FOR TESTING ISOMETRIC STRENGTH AND ENDURANCE

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16. Abstracts

This report contains a technical description of a versatile instrumentation system designed to obtain, monitor, and process human static strength and isometric endurance data. The system includes in-house designed mechanical and electronic apparatus as well as commercially available apparatus. Examples of the system's utilization with human subjects are presented.

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Abstract

An in-depth technical description of a versatile instrumentation system designed to obtain, monitor, and process human static strength and isometric endurance data is described. Examples of the systems utilization with human subjects is presented.

Introduction

For many years human strength and isometric endurance testing in the laboratory has been generally implemented utilizing the techniques of dynamometry and/or electromyography (EMG). The use of myography has become increasingly more important as recent research has shown that with increased muscular activity there appears a corresponding shift of the general frequency spectrum of the muscle under test towards the lower frequencies.[8,9] This downward shifting of the EMG spectrum might possibly be useful as one indicator of fatigue, especially among those industrial workers whose jobs involve prolonged muscular exertion.

In the past, investigators have reported the results of their experiments of strength and endurance testing but it was difficult if not impossible for others to duplicate their experiments. Recently. unified and consistent testing techniques have been proposed[7,13] so as to allow direct comparison of research conducted in various laboratories. In our view, another inadequacy found in a large portion of the aforementioned reported literature is the lack of attention paid to the technical description of the apparatus used in the various experiments. It is certainly recognized that some of the apparatus utilized in this type of research can be commercially purchased and thus sufficient technical data is available from manufacturers; however, more often than not, we feel adequate technical description of crucial portions of, for example, in-house designed instrumentation (not available commercially) appears neglected.

It is the purpose of this paper to describe an instrumentation system consisting of in-house designed apparatus and commercially available apparatus,* developed primarily to assess human isometric endurance and secondarily static strength (defined as a maximal voluntary isometric exertion[7]). Furthermore, it is our hope that those who view this apparatus useful in their own work will find sufficient information contained herein to duplicate it without much difficulty. It is not the purpose of this paper to report extensive results of the research conducted utilizing this apparatus; it is expected to be reported in the near future after completion.

General System Description

This instrumentation system serves the following main functions: (1) allows measurements of static strength and isometric endurance, and obtains EMG measurements of human subjects in a repeatable and definable manner; (2) provides EMG signal conditioning with analog display and EMG spectrum analysis using a variety of storage and display devices; (3) provides a means of assessing human static strength, isometric endurances and displaying same in analog format; (4) provides a digital display of these strength and endurance measures thus functioning as a subject error analysis system compatible with digital computer processing.

Referring to Fig. 1, the strength and endurance testing system consists of: (I) a versatile human restraining seat and positioning frame which restricts the subject movement to a predetermined and definable position thus

* Mention of commercially available apparatus, instrumentation, or devices herein does not necessarily imply endorsement by the U.S. Government.

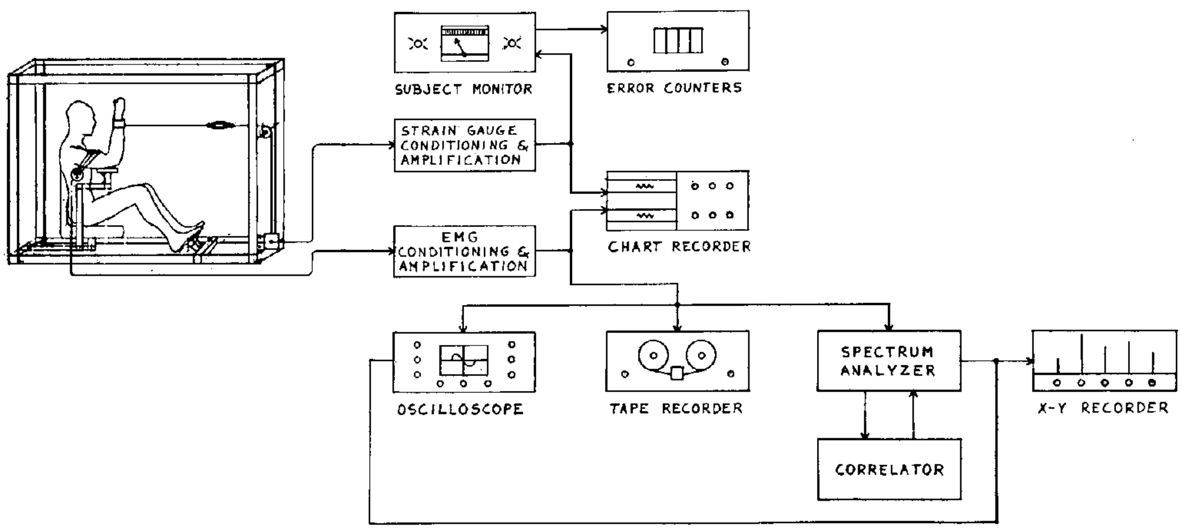


FIGURE 1. HUMAN STRENGTH AND ENDURANCE INSTRUMENTATION SYSTEM

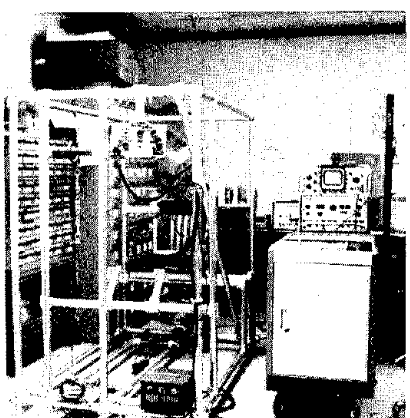


FIGURE 2-A

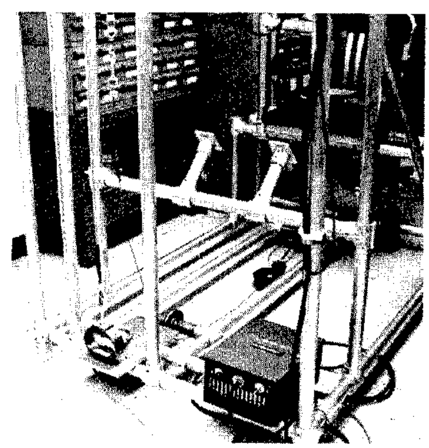


FIGURE 2-B

allowing repeatable strength and endurance measurements; (II) a movable pulley and cable arrangement attached at one end to a full bridge strain gauge, the other end attached to the subject; (III) EMG surface electrodes; (IV) independent signal conditioning of the strain gauge output and the multichannel EMG signals; (V) readout devices of the EMG data channel consisting of: (1) a analog multipen chart recorder; (2) a multitrack FM instrumentation tape recorder; (3) a spectrum analyzer (with associated X - Y recorder output); (4) a correlator; (5) a multichannel oscilloscope (with associated camera); (VI) readout devices of the strain gauge data channel consisting of: (1) an analog pen chart recorder; (2) an analog strength-endurance monitoring instrument with adjustable upper and lower limits used as a feedback device to the human subject; (3) a digital readout system consisting of timers, event counters, and associated control logic. This digital system functioning as an error analysis unit in conjunction with the analog strength monitoring instrument.

For the sake of discussion, the entire system may be thought of as consisting of two distinct parts: (1) a subject strength and endurance testing apparatus and (2) an EMG signal conditioning, monitoring, and data processing system.

Strength Testing Apparatus

The entire strength testing apparatus is shown in Fig. 2A. To insure repeatable isometric contractions of the muscles under test, a restraint system was designed to restrict and define the body positions of the subject.

A four arm active Wheatstone bridge was used as the nucleus of a "muscle force loading system" used to be obtain a measure of subject strength. A frame support structure was constructed to combine the restraint and loading systems, which would limit the direction of the isometric contractions to the sagittal plane and provide a rigid support structure that would insure the maintenance of the desired anatomical relationship. A subject display monitor was designed in-house to measure relative strength and provided a means of feedback to the subject. This monitor will be described later.

It was estimated mainly from Caldwell's work [1,2,3,4,6] that the maximum muscular forces encountered in this type experiment could reach as much as two hundred pounds. The frame support structure was rectangular, approximately 4 ft x 5 ft x 6 ft holding all the experimental attachments and allowing easy access to the contained restraint system. Light-weight, high strength aluminum was chosen for this frame; standard 1 1/4 inch I.D. aluminum pipe was selected (Alcoa 60-61-T6 alloy). Cast aluminum fittings (Hollander standard 1 1/4 inch) were used to interconnect the pipes and other attachments. The use of these fittings enabled total adjustability and adaptation to any additional configuration desired.

The restraint system consisted of a modified single aluminum office-type chair with fixed arm rests and a two-way auto safety belt (Kangel Type LD-3) bolted to a small frame. This small frame, was attached to the larger frame by means of sliding fittings and was adjustable fore/aft and vertically. An adjustable arm rest and two foot rests were constructed of materials similar to the frame and attached as shown in Fig. 2A.

To measure the isometric forces generated by the restrained subject, a fixed mechanical resistance in the form of a steel cable attached a steel "D" shaped ring[10] was bolted to an aluminum plate at the front of the frame as shown in Fig. 2B. The "D" ring contained an electrically balanced, four arm active Wheatstone Bridge (Micromeasurements Type CEA-06-500-UW-350). Force exerted by the subject against the resistance is transmitted through the steel cable, which is attached to the subject via a nylon webbed cuff, to the "D" ring causing a distortion in the ring. Strain gauge characteristics were matched to the steel characteristics of the "D" ring and then mounted on the "D" ring in pairs (using Micro-measurements Bonding Kit GAK-200). Tension on the steel cable changes the resistance of the strain gauges, thus unbalancing the bridge. The degree of unbalance being proportional to the change in resistance and therefore proportional to the force originally exerted by the subject and hence a direct measure of subject strength.

Any description of torque generated in elbow flexion or knee extention must include magnitude, direction, and moment arm involved[14]. The Wheatstone Bridge on the "D" ring enables magnitude to be determined (to be discussed later). The moment arm for each subject was the distance from the point of rotation (elbow or knee) to the center of the cuff. Since the instantaneous force in a torque movement lies perpendicular to the rotating arm, it was decided that the steel cable would be placed along this line perpendicular to the subject's upper or lower limb. To orient the cable perpendicular to the upper or lower limb in the sagittal plane, a series of pulleys were designed as shown in Figs. 3 and 4. Each of the pulleys was a pressed steel unground ball bearing sheave (NICE-2025) and 1/2 inch hollow collar, fitted

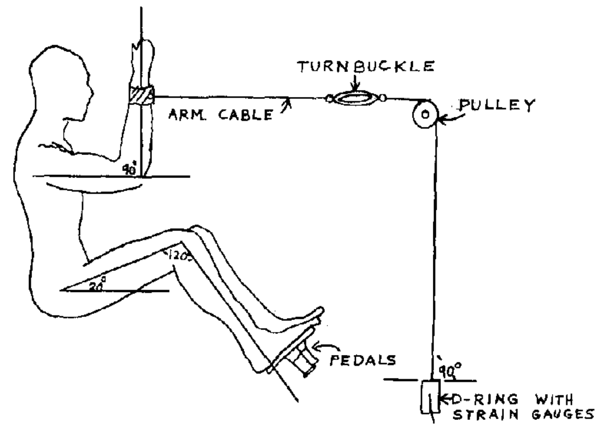


FIGURE 3. BODY POSITIONS FOR ELBOW FLEXION
RELATIONSHIP TO LOAD SYSTEM

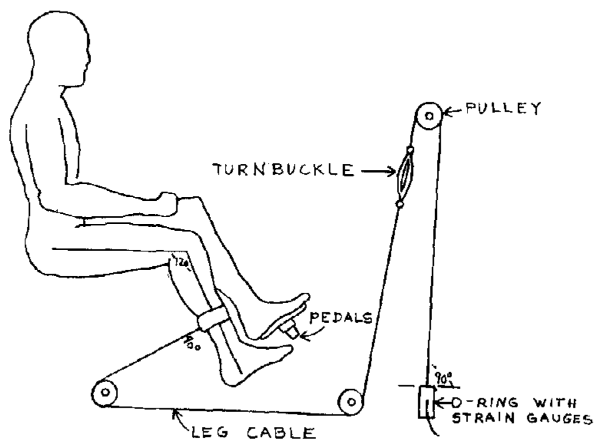


FIGURE 4. BODY POSITIONS, KNEE EXTENTION
RELATIONSHIP OF LOAD SYSTEM

to 1/2 inch steel shafts (Crucible Steel Company, Maxel 3.5 Rockwell "C") which were tooled into drilled 1 3/4 inch shafts to fit the aluminum fittings. In other words, the shafts were inserted into larger shafts which were tooled to fit the sliding aluminum fittings, and thus were adjustable. The pulleys are capable of withstanding perpendicular forces up to 200,000 lbs/sq. in. without yielding. The pulley positioned over the "D" ring was used in all determinations and was adjusted so that the cable formed a 90° angle with the ring. Interchangeable turnbuckles provided adjustments in the length of the main cable and two were set for each subject (one for the arm, one for the leg). Two shorter cables were connected to nylon webbed cuffs. One was used in elbow flexion, and the longer was used in knee extension, as shown in Figs. 3 and 4.

The strain gauge was calibrated using a series of suspended lead weights ranging to 200 pounds, and a calibration curve was determined; corresponding signal outputs from subjects could then be converted easily into pounds of force.

Fig. 5 depicts the signal flow of the strength and endurance measuring and monitoring system. In general, after the subject has exerted tension on the steel cable leading to the "D" ring, the Wheatstone Bridge becomes unbalanced due to the corresponding deformity of the "D" ring to which said cable is attached. A shielded 10 ft. cable brings this signal to one channel of a six channel Beckman R-911 Dynograph Recording System. This particular signal channel consisted of a Beckman strain gauge conditioning coupler (Type 9803) followed by a preamplifier (Type 481-B) followed by a power

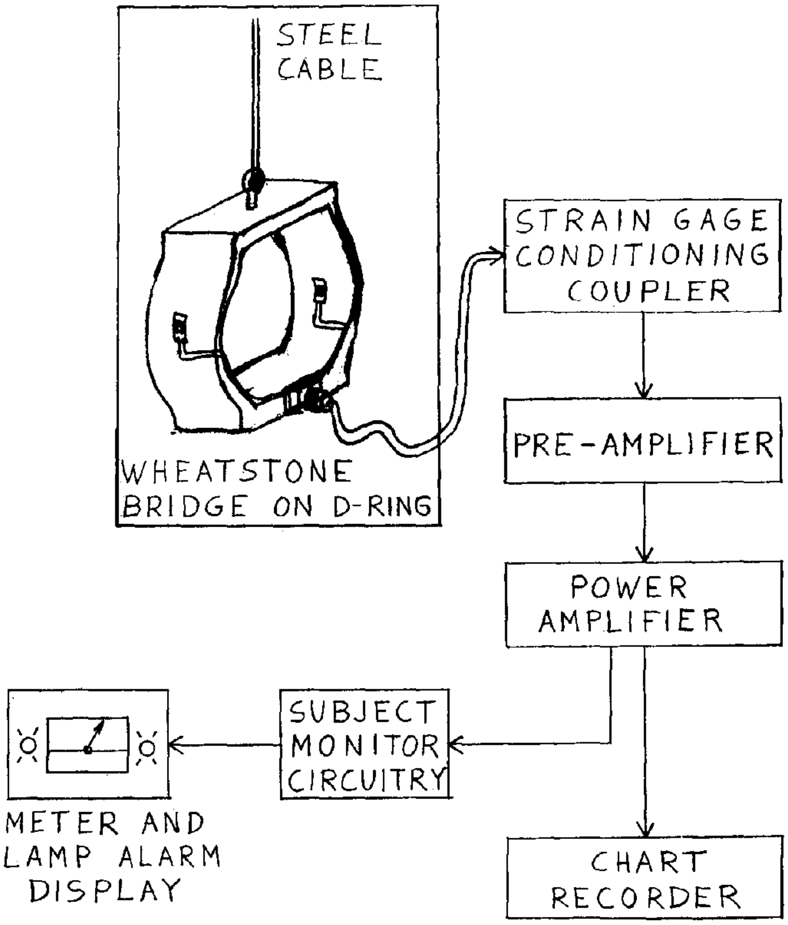


FIGURE 5. SIGNAL FLOW CHART STRENGTH AND ENDURANCE MEASURING AND MONITORING SYSTEM

amplifier (Type 411) whose signal output in turn is presented to: (1) the chart pen circuitry for permanent recording, and to (2) the subject display monitor.

The completely solid state subject display monitor was designed in-house and gave visual feedback to the subject during his relative endurance contractions. The unit consists of the following: (1) a large (5 inch) meter display with associated circuitry, (2) signal normalization circuitry, (3) comparison circuitry, and (4) alarm readout circuitry and display. Fig. 6A is a schematic diagram of the monitor circuitry. This circuitry functions in the following manner. Basically the system employs three integrated circuit operational amplifiers; A_1 and A_2 operating as comparators, comparing simultaneously the strength input signal (obtained from the Beckman 411 Power Amplifier output, ± 2 volt maximum deflection) to two preset voltages established by R_9 (the "highest" set desired) and R_{10} (the "lowest" set desired). If the high set voltage is exceeded or if the strength signal is lower than the lowest set voltage, the appropriate comparator turns on its lamp driver (Q_1 or Q_2) which in turn lights the corresponding lamp. A_3 functions as a unity gain voltage follower acting as a buffer and meter driver. In particular, the input strength signal is applied to a two stage filter network (R_1, C_1 and R_2, C_2) designed to remove high frequency noise as well as any possible residual carrier signal from the Beckman 411 demodulator. This strength signal is then summed with an adjustable voltage bucking network composed of R_8 (zero adjust) , R_7, R_{11}, R_{12}, R_{13}, and R_{14}. This network allows the signal on the output meter to read zero in the event that it is

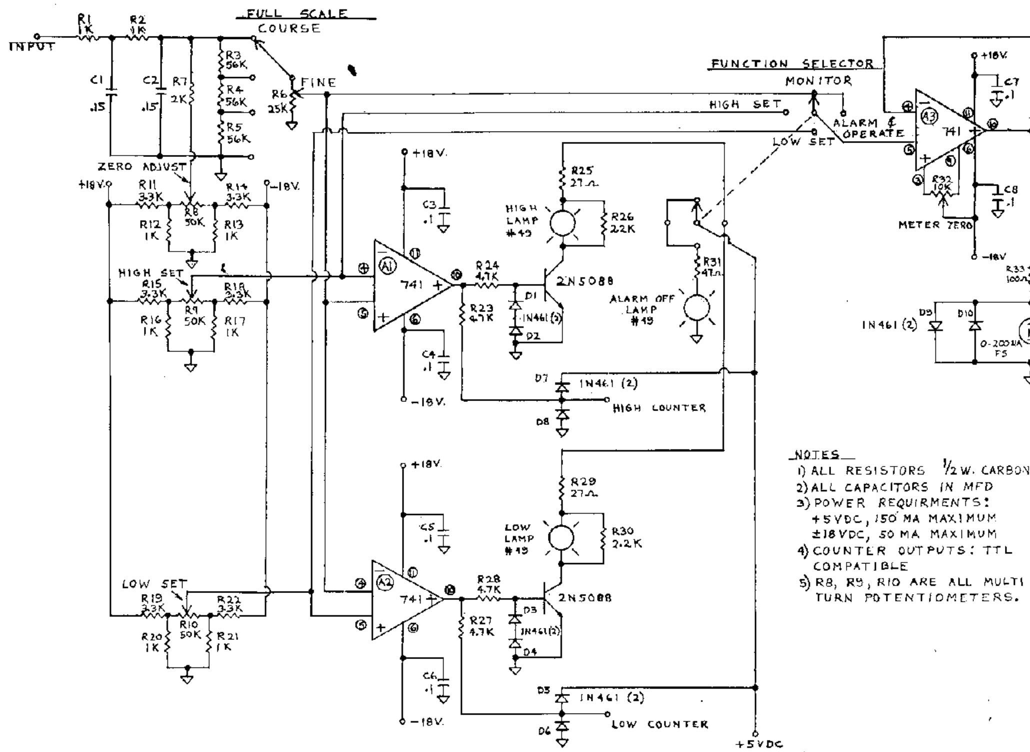


FIGURE 6-A. HUMAN ENDURANCE AND STRENGTH MONITOR

desirable to operate the initial pen position of the Dynograph at a position other than at the center of its excursion. This circuit then established the "zero position" of the strength meter to that of the pen position. An input strength signal applied next may be normalized or adjusted to read "full scale" on the meter via the attenuator network R_3, R_4, R_5, R_6. For test purposes, this may be artifically created by intentionally unbalancing the Wheatstone Bridge balance on the Type 9803 conditioning coupler. Once the zero and full scale meter conditions have been established the low and high set "alarm window" conditions are next established. The 200 micro-amp meter then functions as an alarm set up device. Rotating the function selector switch to high set allows the meter to read virtually the same voltage as high comparator A_1. Resistors R_9, R_{15}, R_{16}, R_{17}, and R_{18} form the high set voltage divider network. Similarly, rotating the selector switch to "low set" allows the meter to monitor the low set voltage divider network composed of R_{10}, R_{19}, R_{20}, R_{21}, R_{22}. In all conditions (other than monitor) of the function selector switch, the +5 VDC is removed from the lamp driver Q_1 and Q_2 . An operator alarm "off lamp" is lit in all conditions other than monitor, to remind the researcher that the alarm is not activated. Capacitors C_3, C_4, C_5, C_6, C_7, C_8 are used as decoupling capacitors for their respective IC's. R_{24} and R_{28} form base coupling resistors to Q_1 and Q_2. Diodes (D_1 and D_2, D_3 and D_4) form voltage clamps to insure transistor cutoff when the comparators are at their negative voltage excursions. R_{25}, R_{29}, and R_{31} limit the lamp current for their respective lamps. R_{26} and R_{30} keep a small collector current flowing through each lamp driver should either lamp open circuit. Diode pairs (D_5 and D_6, D_7 and D_8)

form level shifting networks which will convert $\pm$ 18 volt swings of each comparator to Transistor-Transistor Logic levels (0 to+5V, TTL-compatible). These outputs are normally at logic zero when the alarm lamps are off. The 10K potentiometer in the A_3 circuit minimizes the IC offset voltage into the meter when no signal is present. R_{33} limits the current through the meter; D_9 and D_{10} act as meter protection by limiting the maximum voltage across the meter to approximately 0.5V.

In our experimental arrangement it was also desirous to know (1) the number of events which the human subject was outside the strength "window" (i.e., how many times he was below or above target) and (2) how long the subject was above, below, and on target. Fig. 6B depicts the TTL interface logic utilized with three clockcounters (Hunter, Model 220C) and up to three event counters (ERC, Model 2303A). In particular SN7400 (1,2,3) and(4,5,6) form modified "antibounce" circuits removing any possible artifacts which may be generated as a result of the long cabling in our system. C_1 and C_2 are used for decoupling purposes. The counter outputs are thus applied to hex inverters SN 7404 (8,9,10,12) which in turn drive the external clocks and counters. R_1, R_2, R_3, R_4, R_5, R_6 are used to insure stable logic zero and one levels to these remote counters. IC, SN 7400 (7) is used to generate the "on target" logic condition: Output = $(\overline{\text{low}}) \cdot (\overline{\text{high}})$. The SN 7404 (11) is used as a driver.

The monitor was utilized in the following manner: The meter, which was visible to the subject, was marked off in percent, from zero to 100%. The normalization circuitry examined the degree of electrical unbalance in the maximal voluntary force and enabled the investigator to adjust

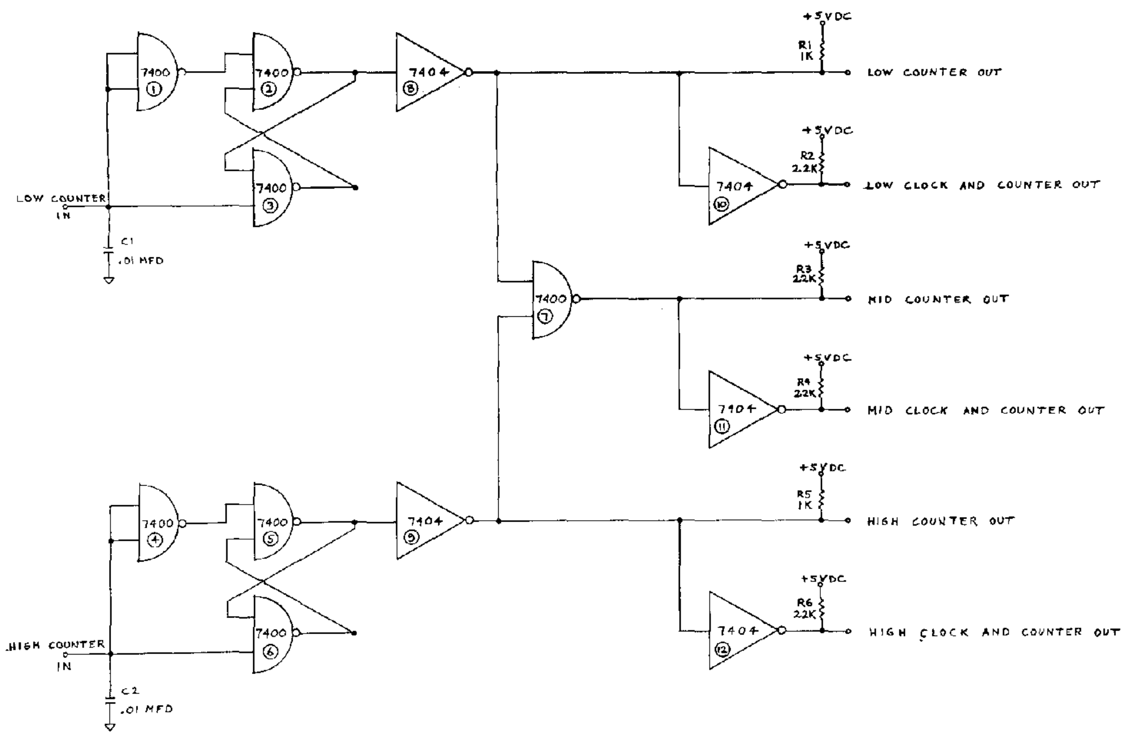


FIGURE 6-B. STRENGTH MONITOR LOGIC

the monitor so that this unbalance read full scale (100%) on the meter. The comparison circuitry enabled the investigator to manually establish the upper and lower limits of the electronic "window" around the "target relative load" (i.e., this load was some given percentage of a maximum voluntary contraction (MVC) which he was asked to maintain for a period of time).

Once a signal was normalized to 100%, all subsequent signals were normalized and shown as some percent of the original signal. In addition, this signal was simultaneously presented to the upper and lower limit circuits for comparison to their previously established limit settings. When the signal fell outside the target zone, the appropriate alarm circuit was activated. If the normalized signal fell below the pre-set "low" limit, a green light was activated next to the meter. If the signal was above the "high" limit, a red light was activated.

During the endurance exercise, the visual meter display was continually presented to the subject, reflecting the percent of maximum force that he was exerting. The system was designed so that only the investigator knew how wide the window was. The meter, circuits, and lights were assembled into a aluminum box (7"x10"x6") and suspended from the top front rail of the frame. A lazy-susan bearing was used to allow free rotation for best visibility to the subject.

EMG Conditioning, Monitoring, and Data Processing

In our present work we are presently examining the spectral characteristics of electromyograms obtained from two muscles, the biceps brachii and rectus femoris. It is to be pointed out that the system to be decribed is not limited to analyzing those particular muscles, but is directly applicable to any EMG data.

The EMG to be recorded was obtained by placing three surface electrodes (Bectin-Dickinson Type "Dispos-El") on each muscle and were arranged in an "in-line" fashion as shown in Figs. 7 and 8. Fig. 9 depicts the EMG data collection and monitoring scheme employed. The action potential signal sensed by the aforementioned elecrodes was passed via 9 ft. shielded cable (Bectin-Dickinson Model BD-6-7915) to another channel of the Type R-411 Dynagraph Recorder. In particular, the signal entered a Type 9852-A, EMG Conditioning Coupler used in the "direct" mode. This output was routed to a Type 481-B preamplifier, then in turn to a Type 411 power amplifier whose output was made available to a variety of readout devices: a Type R-411 chart recorder; a Tektronix 560 series oscilloscope (with associated scope camera); a Teac R-70 Cassette instrumentation data tape recorder (used in the FM mode); and a Saicor-Honeywell Model SAI-51A Real Time Spectrum Analyzer-Digital Integrater Computer (connected to a Hewlett-Packard Model 7004-B, X - Y Chart Recorder). As the actual EMG was taken, "hard-copy" of the raw (direct) EMG signal was recorded by the Dynograph Chart Recorder. Simultaneously this signal was available for "quick viewing" on one channel of the oscilloscope and was recorded on instrumentation quality tape cassettes. The EMG signal was being processed - "on-line" via the spectrum analyzer and thus "spectral" information was immediately available for viewing either on the second channel of the oscilloscope

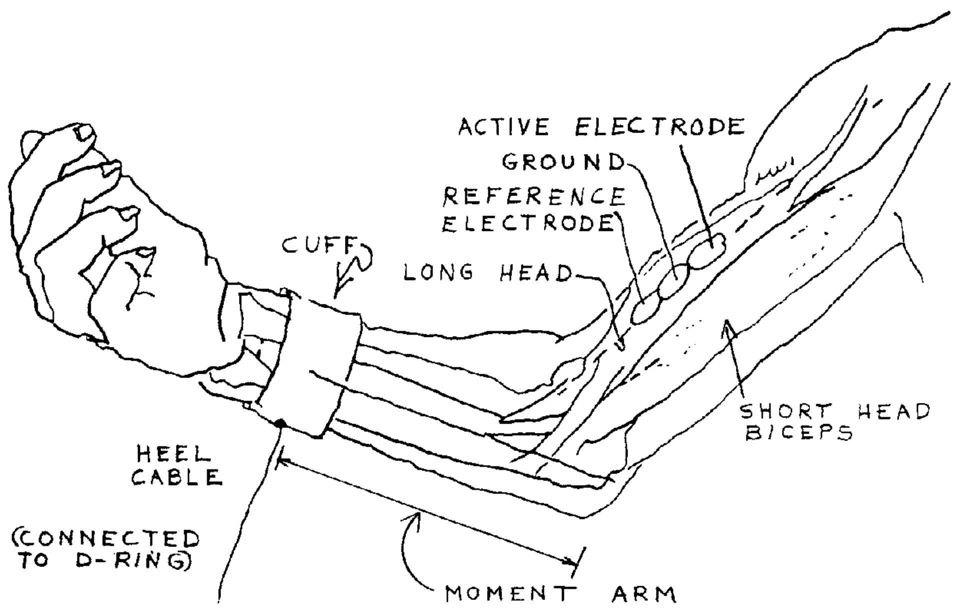


FIGURE 7. ELECTRODE PLACEMENT: RIGHT BICEPS BRACHII

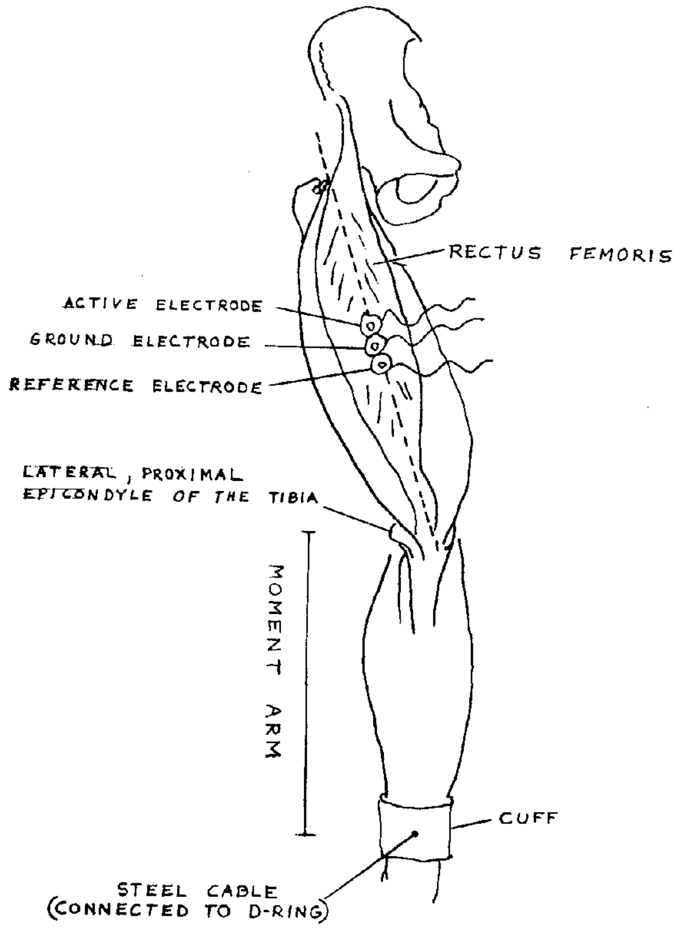


FIGURE 8. ELECTRODE PLACEMENT: RIGHT RECTUS FEMORIS

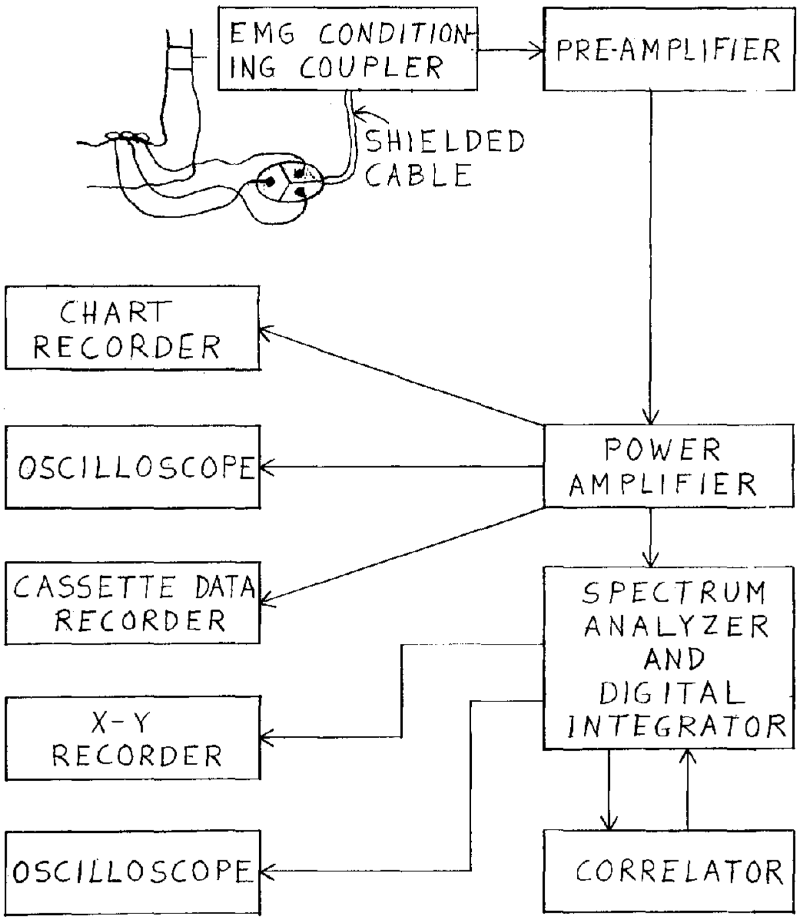


FIGURE 9. SIGNAL FLOW CHART EMG DATA COLLECTION, MONITORING AND DATA PROCESSING

and/or in the form of "hard-copy" on the X-Y chart recorder. Use of the cassette data recorder not only provides a convenient recoverable permanent record of the original EMG data, but also allows for future computer data processing of the EMG information. A Saicor-Honeywell Correlation Computer Model SAI-42 will be used in conjunction with the SAI-51A Spectrum Analyzer in order to perform "cross-power spectrum analysis" should more than a single EMG channel of data be obtained simultaneously. This technique of cross-power spectrum analysis will provide a spectrum analysis of the cross correlation function of two EMG data channels thus yielding the spectrum components which are common to both EMG channels and are thus common to both muscles which generated these original EMG signals.

System Utilization

By way of illustration a procedural approach as to how the two described systems integrally functioned using a human subject during isometric endurance testing will be briefly described[11]. (As aforementioned, it is not the purpose of this presentation to state the results of the research conducted with this instrumentation, this will be presented in the near future).

Prior to each experiment, the loading system was calibrated utilizing known weights. The data collection and processing systems were checked to assure that switch settings were correct and that all connections were proper. All subjects were each given a brief orientation of the system prior to their actual participation.

The muscles to be tested were located via the method of Kendal[12]. EMG electrode sites were prepared by rubbing the proper skin areas with a sponge soaked in isopropyl alcohol. Surface EMG electrodes with adhesive collars were attached in the following manner:

For elbow flexion exercises, the electrodes were attached in such a way as to form a straight line which coincided with one line drawn over the long head of the biceps brachii from the anterior axillary fold to the antecubital fossa. The ground electrode was placed on the skin over the belly of the biceps, midway on the line previously described. The active electrode was placed along the line closer to the axillary fold, the insulated periferal collar of the electrode just butting up to that of the ground electrode. The reference electrode was placed similarly but on the side opposite the active electrode, the collar just touching the ground. The three electrodes thus form a straight line, with the active and reference electrodes equidistant from the ground electrode (see Fig. 7). The skin was marked for easy relocation of electrodes in subsequent tests.

For knee extention exercises, the electrodes were attached in a similar straight line arrangement over the rectus femoris, on a line drawn from the acetabulum to the proximal border of the patella. Again the ground electrode was placed midway on this line and the active and reference electrodes were placed on either side, the reference electrode being the most distal (see Fig. 8). Again the skin was marked for easy relocation.

The following tests are generally performed for each subject: maximum right elbow flexion force and endurance, maximum right knee extension force and endurance.

Tests of right elbow flexion were performed with the subject seated in the chair and restrained by the seat belt, elbow supported by the adjustable padded arm rest to a height even with the shoulder in the sagittal plane. The subject's lower arm with hand in the mid-prone position was connected to the transducer cable by the two-inch wide webbed cuff in the vicinity of the distal epicondyle of the radius, the exact position being that point at which the cable was perpendicular to the lower arm when the elbow angle was 90^{o} (Fig. 3). The elbow angle was fixed by adjusting the cable length by means of a turnbuckle. To facilitate standardization, the turnbuckle was locked into position, labeled, and used in testing by that subject only. The moment arm was measured from the lateral epicondyle of the humerus to the middle of the cuff and recorded. The skin was marked for easy relocation.

The legs were supported by adjustable foot pedals and forced into a knee angle of 120^{o} and a thigh angle of 20^{o} to facilitate body stabilization as recommended by Caldwell[5]. The subject was permitted to grip the fixed arm rest on the left side of the chair for additional stability. The subject was not permitted to see the meter display at this time, since knowledge of his maximal effort might influence retests.

The subject was instructed to take a deep breath, exhale slowly, and create a slight tension in the cable to take up the slack, preventing any tendency to jerk the cable when the contraction began. On command from the investigator, the subject flexed his elbow, achieving his maximum effort in one second. After three seconds of maximal effort, the investigator instructed the subject to cease the contraction. The same procedure was repeated as necessary to establish the subject's Maximal Voluntary Contraction (MVC). A minimum of two minutes was allowed between maximal tests and was considered a sufficient rest period[13].

The MVC was determined for both leg and arm exercises by taking the mean of the registered forces on the chart recorder at the end of the three seconds of maximal effort. Retests were conducted until two values were obtained that were within 5% of each other. When these two values were obtained, their mean became the subject's MVC for that day.

Once the MVC was determined, the subject display monitor was adjusted, normalizing this MVC value to 100%. The electronic window was set around the selected target relative load, either 25%, 50%, or 75% MVC; the monitor rotated so that the meter and alarm lights were visible to the subject.

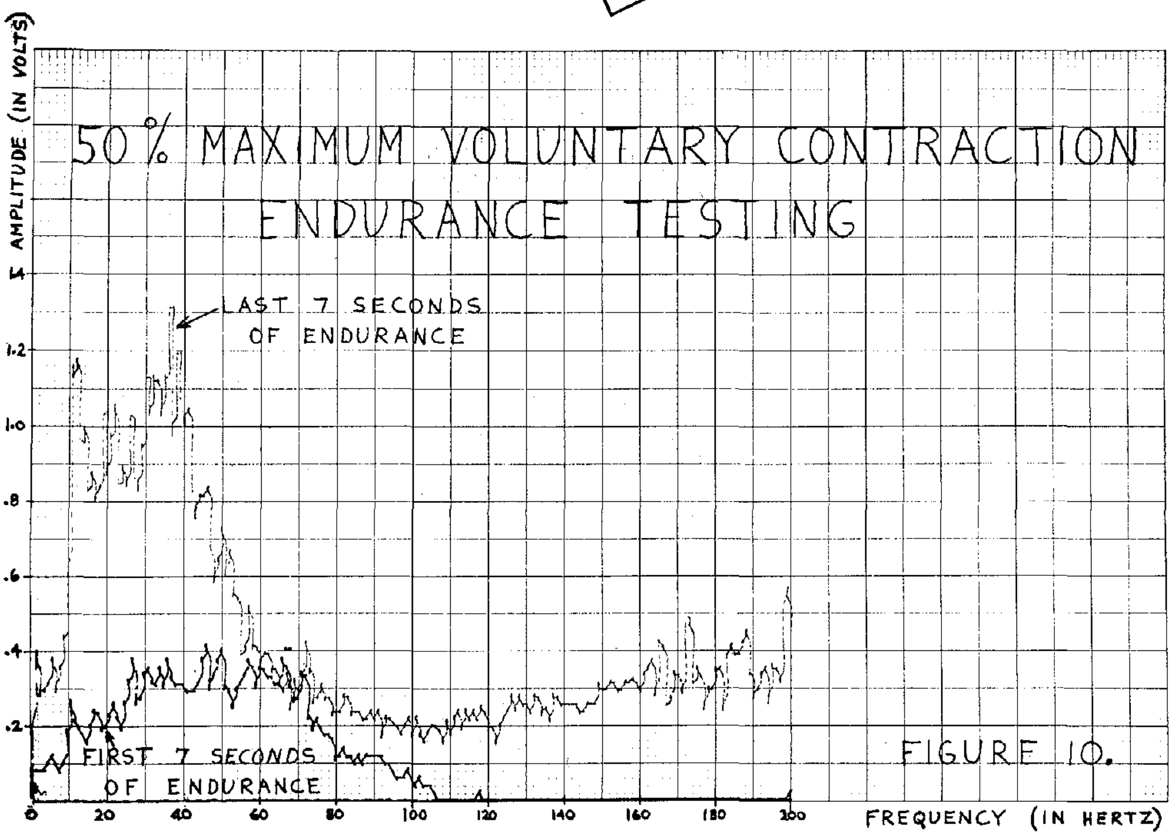
The EMG electrodes were then connected to the shielded cables. A few minor contractions by the subject assisted the investigator in determining whether all connections were satisfactory and if all EMG equipment was functioning properly.

The subject was instructed to breathe normally during the endurance effort and to watch the monitor at all times. The subject was reminded that this was an isometric exercise, therefore any extraneous movement would negate the test. The visual alarm system was explained and the subject told the percentage of his MVC he would be required to exert. The subject was told to maintain this level of exertion by bringing the needle on the meter to the desired position and sustaining the contraction at that point as long as possible. As long as the needle was in the target zone, the alarm lights would not function. The subject was instructed to discontinue the contraction when he could no longer keep the low limit light off.

As the actual test began all recording instruments were turned on and quickly checked to insure proper functioning. The body position of the subject was checked with special attention given to elbow angle. The subject was instructed to prevent jerking at the initiation of the contraction by creating a slight tension in the cable prior to beginning. On command, the subject brought the needle to the target load on the meter, and at the same time the investigator started a stop watch. The event marker channel of the Dynograph recorder emitted a signal which resulted in a pen deflection each second on the chart paper as the other measurements were recorded, affording a permanent record of all contraction times. The subject was verbally encouraged when he appeared to be tiring. When exhaustion was reached, (i.e. the point at which the subject could no longer voluntarily maintain the selected load) the subject ceased the contraction, the stop watch was checked, and the time recorded. After approximately 30 seconds the recording instruments were turned off. The necessary change of cables and switch to a new body position for the knee extention tests was completed and gave the subject about five minutes of rest before the next contractions were made.

Tests of right knee extention were performed with the subject seated in the restraint chair with the left leg in the same position as in the elbow flexion and the subject gripping both fixed arm rests. The subject's lower leg was connected above the ankle to a cable by means of a cuff similar to that used in the elbow flexion tests. This cable, somewhat longer than that used on the arm, was connected to the load cable via a turnbuckle, identical to but not the same one as used on the arm measurement. By adjusting cable length using the turnbuckle and shifting the cuff position, the ideal position was established. The position then described was a knee angle of 120^{o} in the sagittal plane and the cable perpendicular to the lower leg. The turnbuckle was fixed at its length by bolts and labeled. The skin was marked at the distal edge of the cuff and the moment arm was measured from the proximal lateral epicondyle of the tibia to the center of the cuff. The procedures for determining the maximum voluntary contraction and the relative endurance of right knee extention were identical to those described for elbow flexion.

As of this writing, the system has been used with five human subjects; addition experiments using this system are in progress. An example of EMG spectral data obtained using this system with a 25 year old male subject is shown in Fig. 10. The muscle under test was the subject's right biceps brachii at 50% MVC. This figure depicts unintegrated EMG spectral data obtained during the first and last 7 seconds of an endurance run whose total duration is approximately 100 seconds. This graph vividly depicts the shift towards the lower frequencies and increased power at the lower frequencies as the subject reaches exhaustion. Since the EMG signals are continously tape recorded, one may playback into the spectrum analyzer



50% MAXIMUM VOLUNTARY CONTRACTION
ENDURANCE TESTING
LAST 7 SECONDS OF ENDURANCE
FIRST 7 SECONDS OF ENDURANCE
FIGURE 10.
AMPLITUDE (IN VOLTS)
1.4
1.2
1.0
.8
.6
.4
.2
0
20
40
60
80
100
120
140
160
180
200
FREQUENCY (IN HERTZ)

various segments of the experiment, as it progresses with time, and actually view the progression of power spectrum shifting.

Summary

An in-depth description of a versatile instrumentation system designed to obtain, monitor, and process human strength and isometric endurance data has been give. The system includes in-house designed mechanical and electronic apparatus as well as commercially available apparatus. Examples of the system's utilization with human subjects are also presented. No attempt has been made to report the results of data obtained utilizing this system, this is expected shortly.

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