US00RE35598E

United States Patent [19]

Sadoff et al.

[11] E **Patent Number: Re. 35,598**

[45] **Reissued Date of Patent: Sep. 2, 1997**

[54] **STRENGTH ANALYZER AND METHOD OF USING SAME**

[76] Inventors: **Armin M. Sadoff**, 465 N. Roxbury Dr., Beverly Hills, Calif. 91210; **Richard C. Nelson**, 411 Park La., State College, Pa. 16803; **Gerald A. Smith**, 31739 Barlow Rd., Philomath, Oreg. 97370; **Joseph Johnstonbaugh**, 113 Harvard Ct., Rt. 1, Port Matilda, Pa. 16801; **Steven J. Sadoff**, Merrill Lynch Japan Inc. Ote Center Boulevard 1-1-3 Otemachi, Chiyoda-ku, Tokyo 100, Japan

[21] Appl. No.: **551,692**

[22] Filed: **Nov. 1, 1995**

Related U.S. Patent Documents

Reissue of:

[64] Patent No.: **4,884,445**
Issued: **Dec. 5, 1989**
Appl. No.: **276,716**
Filed: **Nov. 28, 1988**

U.S. Applications:

[63] Continuation of Ser. No. 329,678, Oct. 26, 1994, abandoned, which is a continuation of Ser. No. 69,453, Jun. 11, 1993, abandoned, which is a continuation of Ser. No. 575,920, Aug. 31, 1990, abandoned.

[51] **Int. Cl.**[6] **G01L 3/24**

[52] **U.S. Cl.** **73/379.01**; 73/379.02

[58] **Field of Search** 73/379.01, 379.02, 73/379.03; 482/46, 49, 50, 112, 113, 5, 901

[56] **References Cited**

U.S. PATENT DOCUMENTS

3,442,132	5/1969	De Mare	73/379
3,670,573	6/1972	Kroemer	73/379
3,672,219	6/1972	Van Patten	73/379
4,050,310	9/1977	Keiser	73/379
4,231,255	11/1980	Haski et al.	73/379
4,235,437	11/1980	Ruis et al.	272/134
4,566,692	1/1986	Brentham	272/130
4,650,183	3/1987	Mc Intyre	272/96
4,705,271	11/1987	Mondloch et al.	272/130
5,184,628	2/1993	Shah et al.	128/774

FOREIGN PATENT DOCUMENTS

2027901	2/1980	United Kingdom .

OTHER PUBLICATIONS

"Simple Method to Determine Sincerity of Effort During a Maximal Isometric Test of Grip Strength", Gilbert et al, *Amer. Jour. of Physical Medicine,* vol. 62, No. 3, pp. 135–144 (1983).

"Muscle Strength Assessment from EMG Analysis", Chaffin et al, *Medicine & Science in Sports & Medicine,* vol. 12, No. 3, pp. 2–5–211, 1980.

"Grip Strength as Measured by the Jamar Dynamometer", Archives of Physical Medicine & Rehabilitation, Jun. 1970, pp. 321–327.

Primary Examiner—Richard Chilcot
Assistant Examiner—Elizabeth L. Dougherty
Attorney, Agent, or Firm—Cislo & Thomas

[57] **ABSTRACT**

An otherwise conventional Jamar dynamometer is provided with a force transducer. The analog output of the force transducer is sampled at regular intervals and converted to a sequence of digital values by a conventional analog-to-digital converter. The digital output of the converter is processed by a conventional computer in real time to produce an output that clearly indicates the maximum force exerted by the subject and whether or not the subject was sincerely attempting to exert a maximum force while the test was in process. Preferably the output comprises both a graphic display of the forces exerted by the subject over a predetermined interval of time and a statistical analysis of those forces. The output data includes calculated discriminator variables which indicate with a high statistical accuracy whether the subject was sincerely exerting a maximal force on the dynamometer when instructed to do so. In an exemplary embodiment, the computer is a MS™ DOS compatible microcomputer and the analog-to-digital converter is a conventional accessory device that is adapted to be mounted in an expansion slot of such a microcomputer.

37 Claims, 6 Drawing Sheets

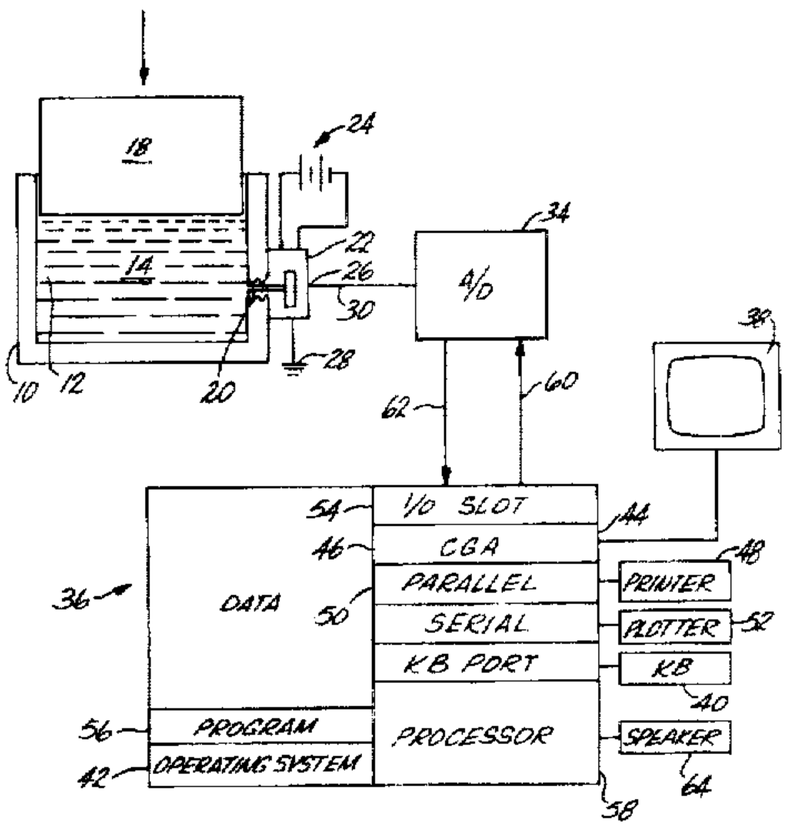
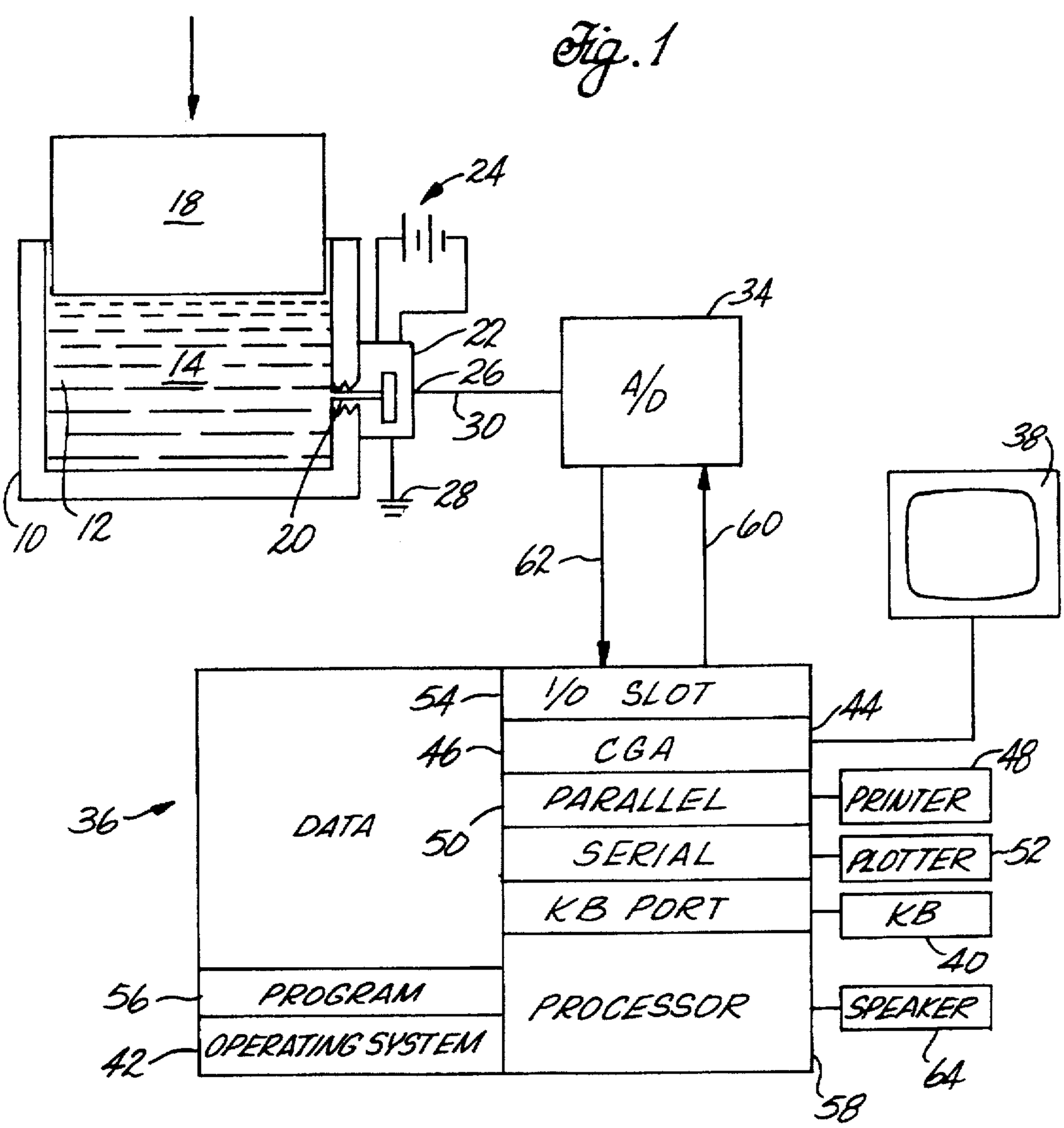


Fig. 1


18
24
14
22
26
30
34
A/D
28
10
12
20
62
60
38
I/O SLOT
44
CGA
46
PARALLEL
48
PRINTER
36
DATA
50
SERIAL
PLOTTER
52
KB PORT
KB
40
PROGRAM
56
PROCESSOR
SPEAKER
64
OPERATING SYSTEM
42
54
58

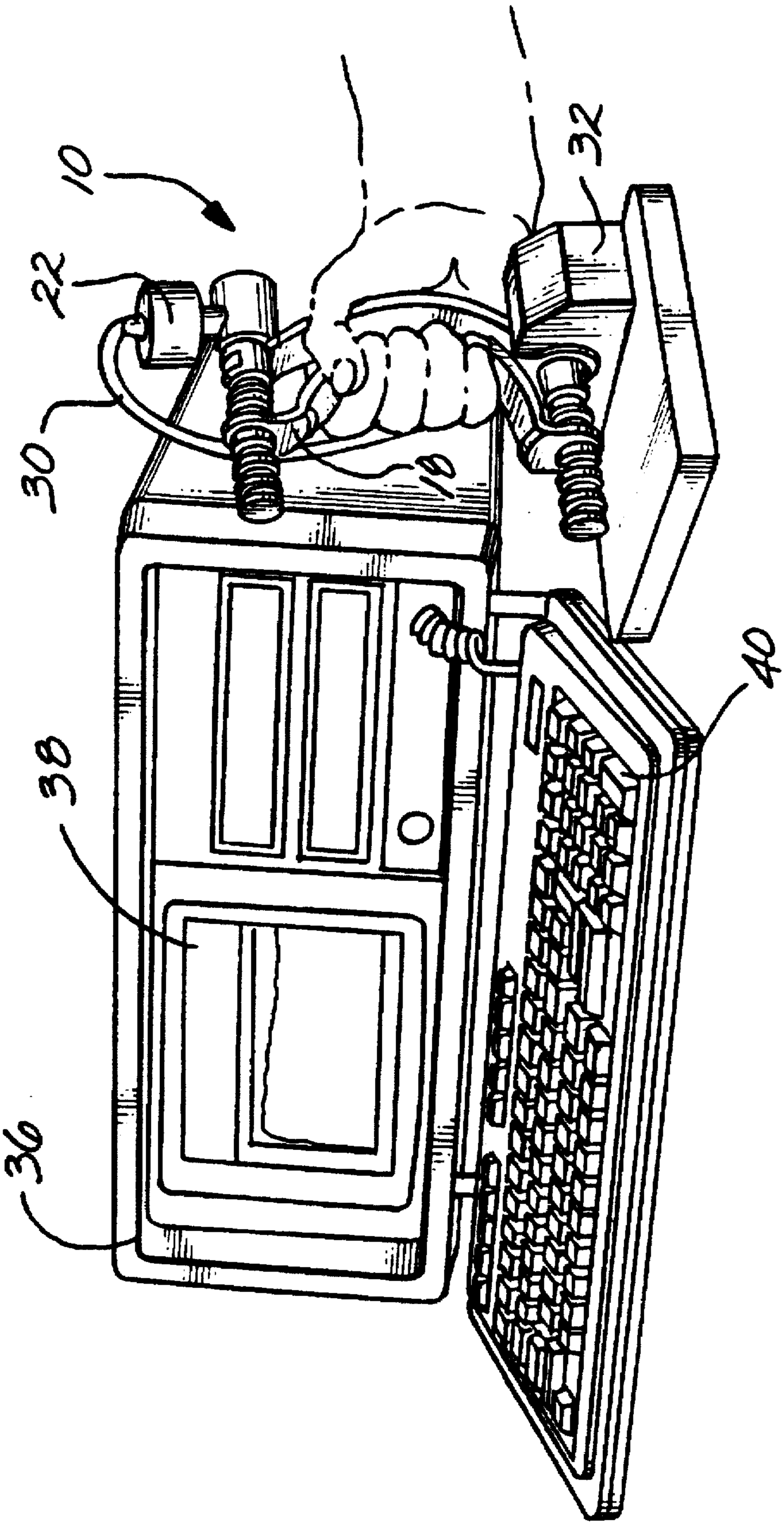


Fig. 2

Fig. 3

```
Choose the Operation Mode:
    1.  Test Subject
    2.  Calibrate Equipment
    3.  Output Results from a Previous File
Type Number of Choice:  1
```

Fig. 4a

```
Information about the Subject:

Subject Name = GERALD SMITH
Social Security Number = 287 44 4908
California ID Number = 314159

Is the above information correct ?  (Y/N)
```

Fig. 4b

```
Gender (M/F) = M
Age = 37
Which is the major hand ? (R/L/A) R
Which hand is injured ? (R/L/B/N) N

Is the above information correct ? (Y/N)
```

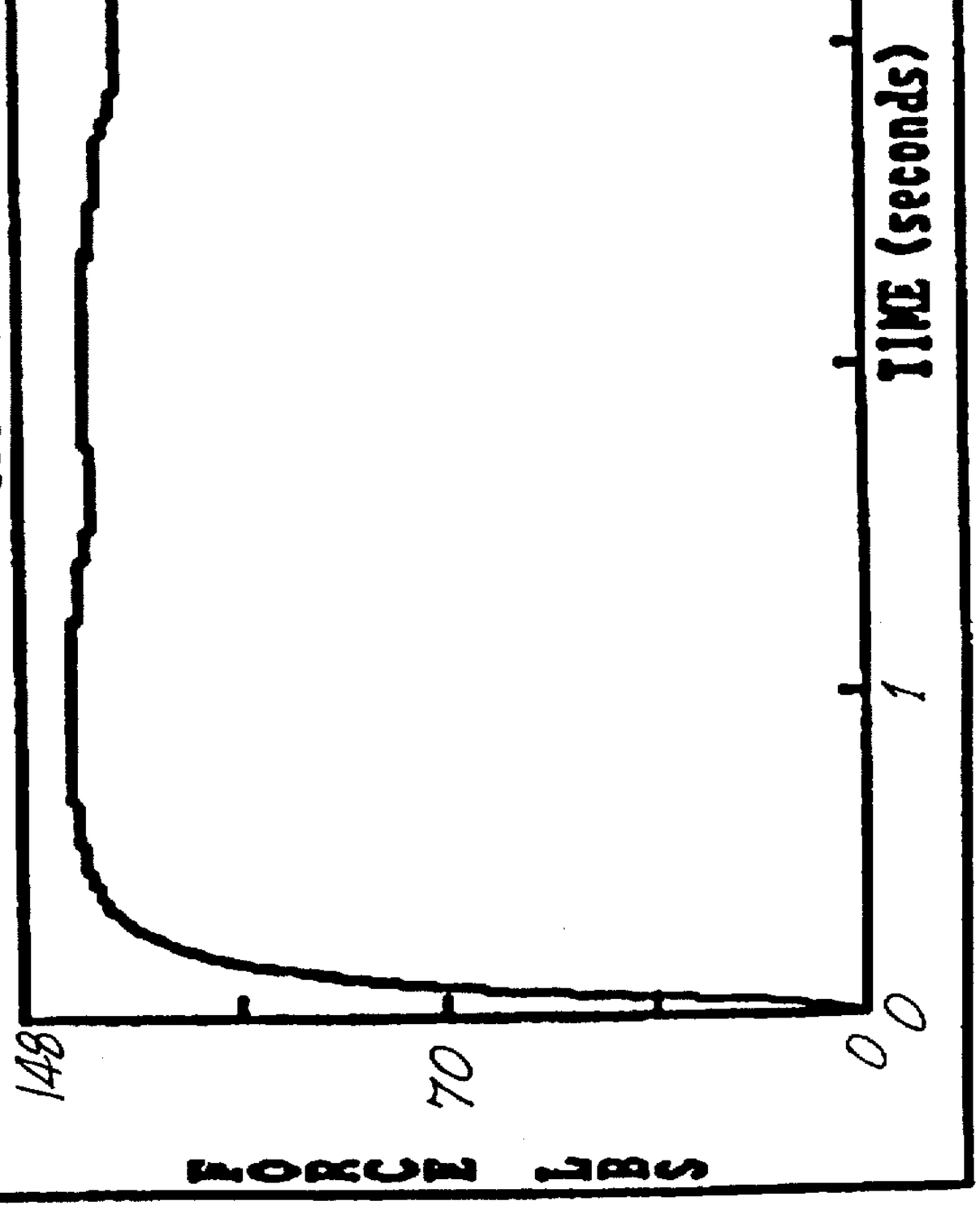
Fig 5

NAME: GERALD SMITH
ID NUM: 314159
DATE: 10-09-1987
HAND: RIGHT
INJURY: NEITHER

FORCE IN LBS:
PEAK FORCE = 132.89
AVERAGE FORCE = 125.21
AF/PF = 94.2%
DIF = 2.05

TIME IN SECONDS:
PEAK : 0.88
90% : 0.26
50% : 0.09
D2: COEFF VAR = 2.2%
D5: ROOT DIF = 0.02

D1: RATIO AF/PF = 94.2%
D4: RATIO DIF = 0.02



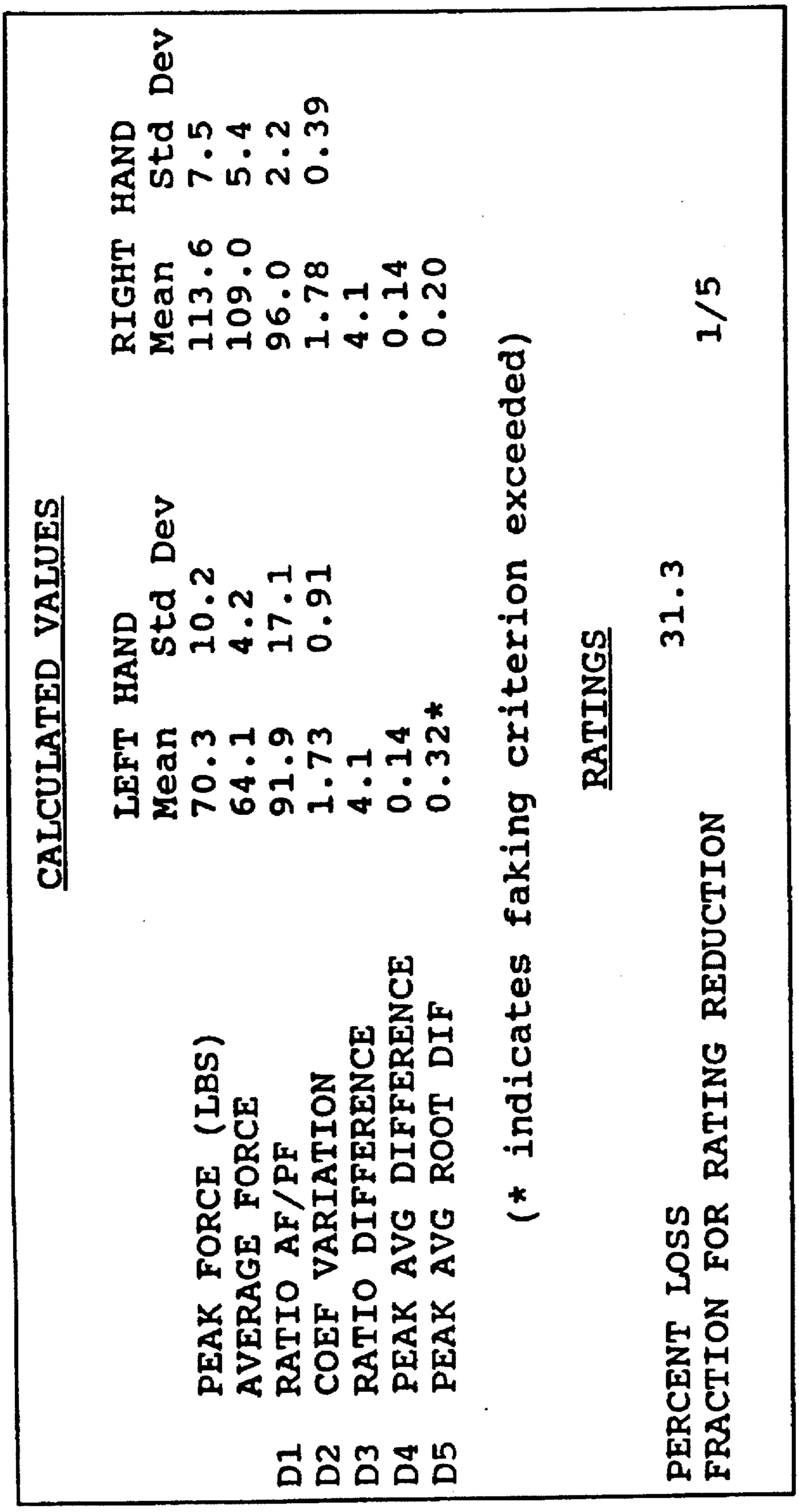
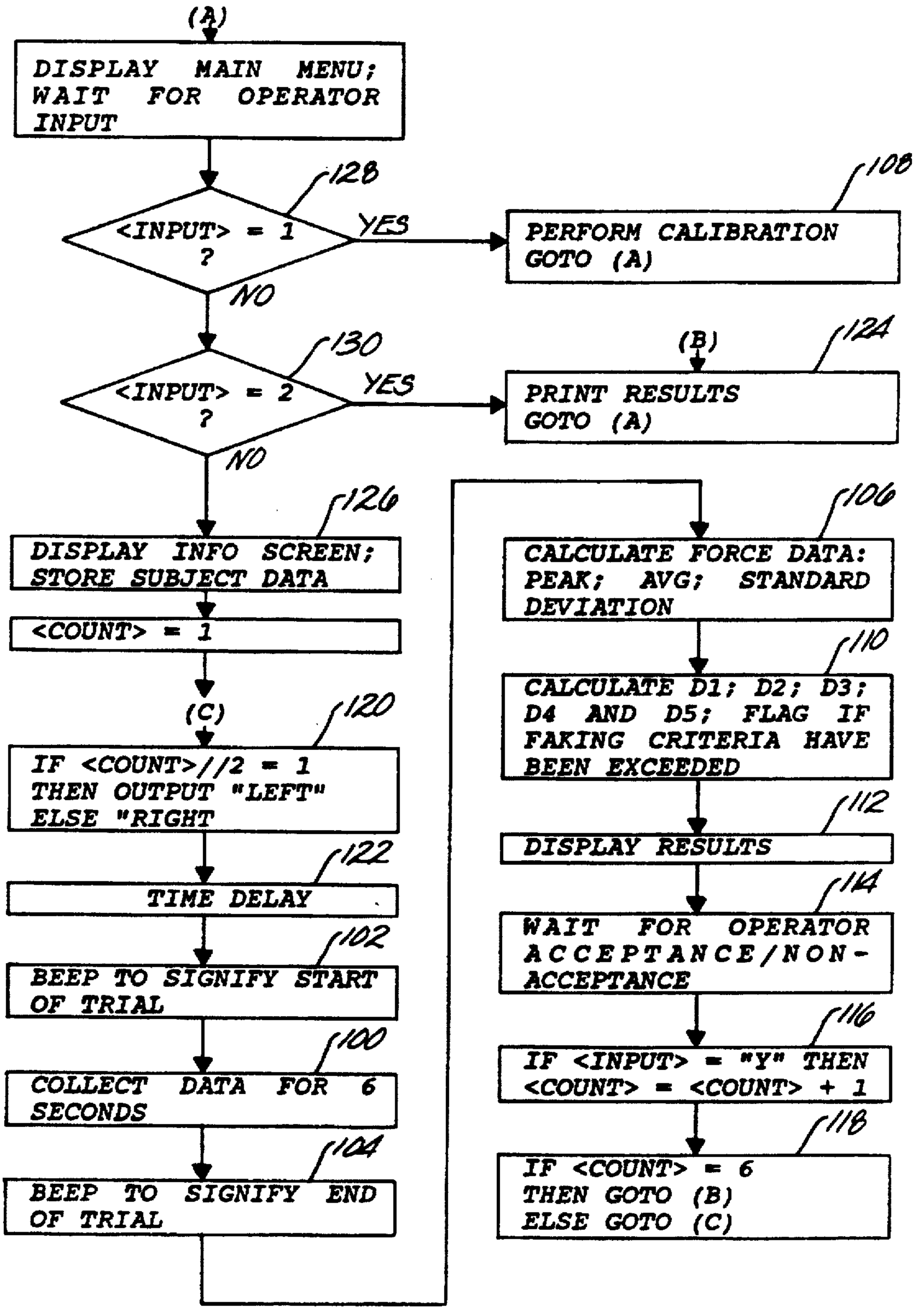

HAND
Std Dev
7.5
5.4
2.2
0.39
CALCULATED VALUES
LEFT HAND
Mean Std Dev
70.3 10.2
64.1 4.2
91.9 17.1
1.73 0.91
4.1
0.14
0.32*
RIGHT HAND
Mean
113.6
109.0
96.0
1.78
4.1
0.14
0.20
PEAK FORCE (LBS)
AVERAGE FORCE
D1 RATIO AF/PF
D2 COEF VARIATION
D3 RATIO DIFFERENCE
D4 PEAK AVG DIFFERENCE
D5 PEAK AVG ROOT DIF
(* indicates faking criterion exceeded)
RATINGS
31.3
1/5
PERCENT LOSS RATING REDUCTION
FRACTION FOR

Fig. 6

Fig. 7


(A)
DISPLAY MAIN MENU; WAIT FOR OPERATOR INPUT
128
<INPUT> = 1 ?
YES
NO
108
PERFORM CALIBRATION
GOTO (A)
130
<INPUT> = 2 ?
YES
NO
(B)
124
PRINT RESULTS
GOTO (A)
126
DISPLAY INFO SCREEN; STORE SUBJECT DATA
<COUNT> = 1
(C)
120
IF <COUNT>//2 = 1 THEN OUTPUT "LEFT" ELSE "RIGHT
122
TIME DELAY
102
BEEP TO SIGNIFY START OF TRIAL
100
COLLECT DATA FOR 6 SECONDS
104
BEEP TO SIGNIFY END OF TRIAL
106
CALCULATE FORCE DATA: PEAK; AVG; STANDARD DEVIATION
110
CALCULATE D1; D2; D3; D4 AND D5; FLAG IF FAKING CRITERIA HAVE BEEN EXCEEDED
112
DISPLAY RESULTS
114
WAIT FOR OPERATOR ACCEPTANCE/NON-ACCEPTANCE
116
IF <INPUT> = "Y" THEN <COUNT> = <COUNT> + 1
118
IF <COUNT> = 6 THEN GOTO (B) ELSE GOTO (C)

STRENGTH ANALYZER AND METHOD OF USING SAME

Matter enclosed in heavy brackets [ ] appears in the original patent but forms no part of this reissue specification; matter printed in italics indicates the additions made by reissue.

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of application Ser. No. 08/329,678, filed Oct. 26, 1994, abandoned, which is a continuation of application Ser. No. 08/069,453, filed Jun. 1, 1993, abandoned, which is a continuation of application Ser. No. 07/575,920, filed Aug. 31, 1990, abandoned, which is a reissue application of application Ser. No. 276,716, filed Nov. 28, 1988, now U.S. Pat. No. 4,884,445.

TECHNICAL FIELD

The present invention relates to apparatus and method for assessing [grip] strength in an ergonomic or clinical setting, as well as for determining whether the test subject's response is sincere when he is instructed to apply a maximum contraction force to the test apparatus.

BACKGROUND ART

An article by Schmidt published in 1970 in Archives of Physical Medicine & Rehabilitation, June 1970 pp 321–327 is exemplary of the use of a so-called Jamar dynamometer with adjustable hand spacing and a sealed hydraulic system as a standardized instrument for determining grip strength, and notes that grip strength has been correlated with hand dominance, overall "physical fitness", normal growth, seriousness of upper extremity injuries, and the success of physical rehabilitation programs.

Van Patten (U.S. Pat. No. 3,672,219) discloses a handgrip dynamometer equipped with an electric transducer which is connected to a volt meter. Kroemer (U.S. Pat. No. 3,670,573) shows a digit dynamometer with a strain gauge transducer whose output is applied to a chart recorder.

A paper by Gilbert et al. published in 1983 in American Journal of Physical Medicine, vol 62 No. 3 pp 135–144 discloses the desirability of providing a graphical record of force in response to a single request for maximal voluntary contraction using a force transducer whose electrical output is recorded on a strip chart, for the purpose of determining whether an apparent inability to produce a normal gripping force is faked, or is genuine. The authors concluded that the ratio of average force to peak force is statistically correlated to the subject's sincerity, and suggested that a "minimum standard indicative of a sincere effort" should be that the average force during the final three seconds of a 5 second contraction should be at least 90% of the peak force. However, such a ratio is not believed to discriminate between a sincere and insincere subject with sufficient reliability to serve as the sole basis for determining a claim for workman's compensation.

Ruis et al. (U.S. Pat. No. 4,235,437) discloses a microcomputer having among its inputs electrical signals indicative of user exerted force from respective transducers and analog-to-digital converters. The microcomputer samples the measured values including various force values and uses that information to calculate the required counterforce to constrain the group of muscles being exercised to a particular path/resistance profile. The force information is also

stored for possible subsequent (unspecified) use. Brentham (U.S. Pat. No. 4,566,692) shows another complex computerized exercising device which includes a microprocessor and an analog-to-digital converter which may be used in the rehabilitation field, which has an electrical input provided by a pressure transducer with the data being either stored for "observation at a later date" and/or illustrated graphically to the user.

A study of Chaffin et al published in 1980 in Medicine and Science in Sports and Exercise, vol 12 No. 3, pp 205–211 concerns the use of electromyography in connection with force measurements of both a "maximum" and an extended submaximal contraction to estimate the subject's true maximum voluntary contraction. In theory such a procedure would be applicable to the measurement of grip strength, but the accurate collection of EMG data presents considerable technical difficulty.

It is to be noted that none of known prior art discloses a simple and accurate apparatus for automatically converting the forces exerted by a subject into a reliable indication of whether the subject is sincerely exerting a true maximal contraction.

DISCLOSURE OF THE INVENTION

It is thus an overall objective of the present invention to facilitate an easily administered analysis of possible loss of [grip] strength including the sincerity of the subject when using a grip strength dynamometer *or other similar means for measuring the force exerted by a contracted muscle (or related group of muscles) in a human subject.* It is another related overall objective to record and display the exerted "maximal" contraction in a way that permits convenient assessment of the subject's sincerity and a ready comparison of the strength of [the] *an* injured hand with the other (uninjured) hand of the subject.

According to *a preferred embodiment of* the present invention, an otherwise conventional [grip] *muscle contractive force* dynamometer (for example, the above mentioned Jamar apparatus) is provided with a force transducer. The analog output of the force transducer is sampled at regular intervals and converted to a sequence of digital values by a conventional analog-to-digital converter. The digital output of the converter is processed by a conventional computer in real time to produce an output that clearly indicates the maximum force exerted by the subject and whether or not the subject was sincerely attempting to exert a maximum force while the test was in process. Preferably the output comprises both a graphic display of the forces exerted by the subject over a predetermined interval of time and a statistical analysis of those forces. In an exemplary embodiment, the computer is a portable MS™ DOS compatible microcomputer and the analog-to-digital converter is a conventional accessory device that is adapted to be mounted in an expansion slot of such a microcomputer.

In accordance with one specific aspect of the invention, a number of variables—each having a statistical correlation with the sincerity of a representative cross section of typical subjects—are individually calculated and then combined into a "discriminant" which is a more reliable indicator of the sincerity for a given individual than any single component thereof. To that end, the computer is preferably programmed to calculate each of the following variables:

Peak Force

Average Force (from threshold +2 seconds to threshold +5seconds, i.e., over the last three seconds of the trial)

Ratio of Average Force to Peak Force

Coefficient of Variation (standard deviation of the Average Force over the last three seconds, divided by the Average Force)

Elapsed Times from threshold to

50% of Peak,

90% of Peak and

100% of Peak.

Peak-Average Difference (proportional to the difference between the inverses of the maximum and average forces, i.e., the ratio of the difference of the two forces to their product), and

Peak-Average Root Difference (similar to the Peak-Average Difference, but forming the numerator from the difference of the fourth root of the two forces)

The data for each hand is stored and compared to calculate

Ratio Difference (an additional discriminator of subject sincerity formed by subtracting the Ratio of the two forces for one hand from the corresponding Ratio for the other hand; this has been found to be particularly useful for female subjects)

Obviously, such a two-handed calculation will not be meaningful for a subject not having a "normal" hand, for example, a subject with a bilateral injury.

The computer has the capability to summarize the test results as

Faking or sincere

Percent Loss, and

Rating Reduction Fraction.

In accordance with another more specific aspect of the invention, the programmed microcomputer not only analyzes the output data from the transducer, but also ensures that the entire test is conducted and documented in accordance with a standardized test protocol and to that end preferably:

generates a beep to indicate the subject should immediately try to exert the maximum force

verifies that there is zero force prior to the beep

samples for six seconds after the beep

analyzes the force output for a five-second interval starting when a threshold force value has been reached.

Such an automated procedure thus produces output data in the form of a standardized snapshot.

BRIEF DESCRIPTION OF DRAWINGS

For a better understanding of the present invention and how to make and use what is presently considered to be the best mode thereof, reference should be made to the appended drawings of an exemplary embodiment in which

FIG. **1** is a block system diagram of the various system components;

FIG. **2** shows the hardware used to practice the invention ready for use;

FIG. **3** shows the main menu as it appears to the operator;

FIG. **4** comprising FIGS. **4**a and **4**b shows the two information screens used to input subject information;

FIG. **5** shows a screen plot of a single test trial;

FIG. **6** shows a printed summary of a full test sequence for a single subject; and

FIG. **7** is a flowchart of the computerized test procedure.

BEST MODE FOR CARRYING OUT THE INVENTION

Referring to FIGS. **1** and **2**, it will be seen that a standard Jamar Dynamometer **10** includes a chamber **12** filled with hydraulic fluid **14** which is responsive to pressure **16** applied by means of an adjustable handle **18**. Chamber **12** has an outlet port **20** to which is normally attached a mechanical pressure gage (not shown) which measures the peak force applied to the handle, which is linearly proportional to the pressure of the fluid inside the dynamometer. Such a standard Jamar instrument is easily modified by removing the usual pressure gage and replacing it with a conventional force transducer **22** connected to a battery **24** (or a small transformer) to provide at an output **26** a voltage relative to ground **28** ranging from 0 to 5 volts, thereby producing an electric signal on an output line **30** having an amplitude proportional to the pressure and thus to the applied force. A supporting stand **32** may be constructed to hold the dynamometer **10** loosely in an upright position on the table top such that the dynamometer remains freely moveable. The handgrip dynamometer is preferably supplied with two accessory support stands: one relatively rigid (not shown) for calibration procedures and another more flexible stand **32** for the normal grip testing.

The analog dynamometer output is sampled at a frequency of 200 Hz using a Metrabyte DAS-8 analog-to-digital board **34** in an MS-DOS™ compatible microcomputer **36** (for example, a Compaq™ Portable II) having a screen **38** and a keyboard **40**. The computer is equipped with the MS-DOS™ operating system **42**, CGA graphics **44**, a parallel port **46** for an Epson™ compatible printer **48**, a serial port **50** for a Hewlett-Packard Graphics Language compatible plotter **52**, and an expansion slot **54** in which is mounted the analog-to-digital converter **34**. Such an arrangement provides a force measurement accuracy of better than ±0.2 pounds. A computer program **56** controls the analog-to-digital board as well as the testing protocol and data analysis. A program listing for a preliminary version of such a program (written in Microsoft QuickBasic) has been submitted to the Register of Copyrights in the Library of Congress under the title "Grip Test Program Version 3" by Armin M. Sadoff and is hereby incorporated by reference.

Although this application is believed to set forth sufficient information for the average artisan to make and use what is presently considered to be the best mode of the invention claimed herein, a copy of that commonly owned program is also being filed concurrently herewith in the file wrapper of this application and members of the public are hereby given a limited license to obtain single copies of the program listing from either the Commissioner of Patents or from the Library of Congress for the purpose of obtaining any additional information it may provide which may be of assistance in understanding the use and function of the present invention.

Prior to use, the handle **18** of the dynamometer **10** is adjusted to the subject's preferred spacing and several practice contractions are made to acquaint the subject with the feel of the device during a test.

At this point, reference should also be made to the exemplary screen layouts of FIGS. **3**, **4** and **5**, to the examplary printout layout of FIG. **6** and to the program flowchart of FIG. **7**.

Under the control of the program **56**, the microprocessor **58** contained in the computer **36** commands the converter **34** via control line **60** to sample the output **30** from the transducer **22** and to output via data line **62** digital data signals 200 times each second which correspond to the analog output of the transducer **22**. This is done for six seconds (block **100**) following an audible signal generated by the processor (block **102**) and output from a speaker **64**

contained within the computer which indicates the start of the test. A second such beep (block **104**) indicates the end of the data collection for a particular trial.

The sampled data is converted to force units in pounds (block **106**) using a calibration constant previously obtained in the conventional manner (block **108**) by applying a known force to the dynamometer **10**. The individual data for each trial are analyzed (block **110**) to determine several characteristic parameters:

T_0=time when the force first reaches an arbitrarily set threshold of 3 pounds (the beginning of the 5 second contraction)

F_{max}=peak force throughout the trial

F_{avg}=average force through the final 60% of the trial (the final 3 seconds for a 5 second contraction)

T_{90}=time to 90% of peak (time 90)

F_{fin}=average force during the "plateau" region of the curve (defined as T_{90} until the end of the contraction period)

σ=Standard deviation of the force data during the "plateau" region of the curve

Each trial results in a screen display of test results (block **112**; FIG. **5**) which is validated by the operator (block **114**); if the operator does not accept the results of a given trial, the data collection process is repeated without incrementing the trial counter (blocks **116**, **118**, **120**).

The results of six such trials (block **122**) (one "round") are pooled together (block **118**), in which case a single mean value for each of the previously described parameters can be determined for the entire round and used in any subsequent analysis. At the end of each round, the alphanumeric printer optionally may be commanded to print (block **124**, FIG. **6**) summary information, including the above-defined characteristic values and further "discriminator" values which are derived therefrom, as well as identified information which is input (block **126**; FIG. **4**) by the computer operator (subject's name, social security number; right or left hand) and time/date information derived from a clock internal to the computer **36**.

The computer generated force-time plots for each trial which are displayed on the screen **38** (block **112**; FIG. **5**) may also be recorded on the plotter **52** to permit qualitative comparisons to be made between the various conditions. These plots therefore bear the relevant identifier and time/date information.

The first discriminator (D1) involves a fractional comparison of average (A) and peak (P) forces, and is defined as follows:

$$D1 = \frac{100 \cdot F_{avg}}{F_{max}} \text{ (Ratio)}$$

The second discriminator assesses the variability of the plateau region and is defined as:

$$D2 = \frac{100 \cdot \sigma}{F_{fin}} \text{ (Coefficient of Variation)}$$

A third discriminator variable called the Ratio Difference (D3) uses data from both hands. It is calculated by subtracting the above defined Ratio measured for the other hand. Preferably, it is output as part of the summary data which is normally printed after both hands have been tested.

Two other discriminator variables which are also based on the mean peak and mean average forces may be conveniently calculated for each test trial to spread the characteristic ranges upon which discrimination between sincere and faking maxima was observed:

$$D4 = \frac{(F_{max} - F_{avg}) \cdot 100}{(F_{max} \cdot F_{avg})} \text{ (Peak-Average Difference)}$$

$$D5 = \frac{\sqrt[4]{F_{max}} - \sqrt[4]{F_{avg}}}{(F_{max} \cdot F_{avg})} \cdot 10^8 \text{ (Peak-Average Root Difference)}$$

The five discriminator variables, D1=Ratio, D2=Coefficient of Variation, D3=Ratio Difference, D4=Peak-Average Difference, and D5=Peak-Average Root Difference, have been subjected to extensive statistical analysis in an experiment involving a number of male and female subjects who were instructed to fake a submaximal contraction at certain points in the above-described procedure. The frequency distributions were estimated for each discriminator from the mean and standard deviation of the variable for the various conditions (assuming each distribution was approximately normal). Based on the "sincere" distribution, criterion values (Table 1) were determined for each discriminator such that 95% of the sample would be included in the sincere distribution (thus establishing a theoretical type I error level of 5%). Finally, several multiple variable prediction relationships were determined. These were derived by first calculating a z score for each discriminator value (based on the standard deviation of the sincere distribution of each variable). A mean z score was obtained from the variables involved in each relationship. The 95% z score (1.645) was used as a criterion value for discrimination into sincere and faking designations. The true sincere and true faking percentages were determined for each single and multiple variable relationship (Tables 2 and 3).

TABLE 1

CRITERION VALUES TO DETERMINE FAKING (95% CONFIDENCE LEVEL):

	MALE	FEMALE
D1. (RATIO):	<84.9	<75.5
D2. (COEF. VARIATION):	>8.85	>14.14
D3. (RATIO DIFFERENCE):	>6.88	>8.46
D4. (PEAK-AVE DIFF.):	>0.18	>0.53
D5. (PEAK-AVE ROOT DIFF.):	>0.28	>3.13

TABLE 2

PREDICTION ACCURACY FOR EACH DISCRIMINATOR VARIABLE*:

	MALE		FEMALE	
	SINCERE:	FAKING:	SINCERE:	FAKING:
D1. (RATIO):	90.0%	95.0%	93.5%	58.7%
D2. (COEF. VARIATION):	90.0%	92.5%	95.7%	52.2%
D3. (RATIO DIFFERENCE):	100%	100%	96.0%	78.3%
D4. (PEAK-AVE DIFF.):	97.5%	100%	95.7%	71.7%
D5. (PEAK-AVE ROOT DIFF.):	95.0%	97.5%	97.8%	87.0%

TABLE 3

PREDICTION ACCURACY FOR MULTIPLE DISCRIMINATOR VARIABLES*:

	MALE		FEMALE	
	SINCERE:	FAKING:	SINCERE:	FAKING:
D1 + D3 + D4 + D5:	92.5%	100%	95.7%	87.0%
D1 + D4 + D5:	90.0%	97.5%	95.7%	76.1%
D3 + D4 + D5:	95.0%	100%	95.7%	89.1%
D3 + D5	95.0%	100%	97.8%	93.5%
D4 + D5	92.5%	97.5%	95.7%	84.8%

*Based on criterion values established using a normal distribution approximation (confidence level = 95%)

Referring specifically to Table 3, it may be seen that several combinations of discriminators were found to result in improved detection of faking over any one single discriminator—this notably enhanced the possibility of detection of faking, particularly for females and only slightly increased the risk of labeling a sincere trial as faked.

Each of the 5 discriminators was found to yield quite divergent distributions for sincere and faking conditions of the male population. Because of the relatively large separation between the distributions in these cases, each variable provided good discrimination between the sincere and faking conditions and thus proved to be highly sensitive tests of faking while being conservative in falsely categorizing sincere trials. However, the values for the female population exhibited less separation between the sincere and faking distributions and were also more variable. This widened each of the distributions in comparison to the male population. The greater variability resulted in criterion values more distant from the sincere means for each variable. Consequently, smaller proportions of the faking distribution were beyond the criterion resulting in less sensitivity in faking detection.

Subject by subject analysis indicated that the 5 discriminators were often "catching" different faking subjects. A combination of variables thus increased the successful detection rates. The coefficient of variation was found to duplicate the results of the ratio variable and was not included in the multiple variable predictions. Table 3 lists five of the combinations tested. The inclusion of the ratio variable (D1) was found to decrease the female detection rate below the levels of D5 alone. The combination of D3 and D5 proved to be the best predictor. It maximized the female "true faking" detection to about 93% while maintaining a relatively conservative error rate with sincere trials of about 2–3%. Discriminator D3 used in this combination involved the comparison of ratios between hands. In the case of a bilateral injury where faking might be expected on both hands, the use of this variable would not be appropriate. In such cases, the best predictive combination was found to be D4 and D5.

For the male population slight improvement in an already high level of predictive ability was found with the various discriminator combinations; however, the female predictions were found to improve substantially. The best combination of variables was D3 and D5 which yielded a correct prediction of female faking of 93.5%.

It will thus be appreciated that for both men and women, the above-described system and method of force-time curve analysis allows for detection of more than 92% of insincere grip force maxima.

Reference should again be made to FIG. 7. The program file itself is under the filename GRIPTEST.EXE. Another file (GRIPPER.CAL) contains calibration information used by the program. In the process of testing a patient's grip strength a data file (whose filename is the subject ID number plus an optional extension) is stored at the completion of the test on a previously formatted floppy disk.

The program is loaded by typing the name of the program: GRIPTEST, whereupon an opening title screen will appear. After the program title screen, typing any key takes the operator to the main program menu (FIG. 3). Three choices are presented. The operator can (1) test the subject, (2) calibrate the equipment (blocks **128**, **108**), or (3) print or plot results (blocks **130**, **124**) from previous files (stored on disk). While testing will be the primary mode of operation, calibration of the equipment is a necessary prerequisite to testing.

CALIBRATION

When doing normal testing the program accesses the information in the calibration file (GRIPPER.CAL) on the program disk. If for some reason that calibration file is not available (perhaps inadvertently erased, or the disk was removed from the drive), the program will automatically go into the calibration mode to generate a calibration file before testing.

The calibration mode provides the means of relating the electrical signals produced by the dynamometer to the real world forces exerted on it. A baseline reading with zero force application is initially taken, followed by a reading with some known force application. The known difference in forces is input into the computer where it is divided by the measured difference in signals to form a conversion factor which can be used during subsequent tests as the required multiplier to convert the subsequently measured difference between the baseline signals and those generated during the testing of a subject into corresponding force values.

The actual calibration procedure preferably begins with the dynamometer **10** placed in the bottom half of a conventional calibration support (palmar grip surface down). The computer **36** activates the analog-to-digital convertor **34** to sample the output signal (for six seconds) and uses the arithmetical average of the corresponding digital output **62** from the converter to determine a baseline signal value. Then the upper half of the calibration support is placed on top of the dynamometer and a reference weight on top of this upper support. The program prompts the operator to input the amount of weight put on the device and then samples the resultant signal (again for six seconds). A calibration file will then be created on the disk in drive A. The Jamar dynamometer **10** and the transducer **22** exhibit a relatively linear signal output; however, for most accurate calibration, the reference weight chosen should be near the upper end of the expected forces (probably 75 to 150 pounds). Also the operator should include the weight of the upper half of the calibration support in the reference weight (about 4 pounds). Thus, if a 75 pound weight is put on the calibration stand, the reference weight value input into the computer should be 79 pounds.

TESTING GRIP FORCE

Testing the subject is the primary mode of operation of the program and is the first choice listed on the main menu (FIG. 3). Choosing this mode from the main menu begins a strict testing protocol. Initially the operator is prompted for certain subject information: Name, Social Security number, Cali-

fornia ID number, gender, age, major hand and injured hand (block **126**). Following this is a set of six grip trials, alternating right and left hands. The computer prompts the operator in each case (block **120**) for the proper hand the subject should be using. The subject is alerted to the beginning of each trial by a "beep" from the computer (blocks **122**, **102**. A second beep (block **104**) signals its completion. To be meaningful, each trial should begin with zero force on the dynamometer (i.e., the sampled digital signal exceeds the baseline value by at most a nominal amount, such as three pounds). If the computer senses more than a nominal initial force, it will immediately respond with a series of warning beeps and the test will be re-initialized. The subject should be instructed to respond after the starting beep completes sounding. The time between beeps is six seconds. The program samples the data for the whole time (block **100**) but only displays the force output for the five second interval beginning from when the calculated force exceeds a threshold value of 3 pounds.

After recording the force-time data from the dynamometer, several variables are calculated (block **106**) and the force-time curve is graphically displayed (block **112**) on the monitor **38**. Each of these variables is displayed at the top of the trial results screen (FIG. **5**).

The tester can scan the trial results screen and judge whether the trial was satisfactory. Pressing any key will open a small window on the graphical display with the message "Accept Last Trial? (Y/N)." Responding with "Y" for yes (block **116**) will then continue with the testing of the subsequent hand, while "N" will redo the previous trial (entry point "C" to block **120**). At the completion of six acceptable trials, three on each hand, the data is available for printing. At this time, the data should be stored on the disk in drive B.

After storage of the data on disk, the operator is prompted (block **124**) to indicate whether output is desired immediately or later. In either case, printed or plotted results can be obtained as described below.

OUTPUT OF RESULTS

The selection of main menu choice three (Output of Results from a Previous File) or an indication that immediate output (after testing) is desired will display the Final Results Output menu. From this menu several choices of output mode are available:

a printed summary table;

a plotted summary table;

a plotted summary table and right/left hand force curves. The distinction between output modes is one of time, complete data and perhaps aesthetics. The printed output includes the individual trial variables as well as means and standard deviations across the three trials (FIG. **6**), but no force-time graphs. Printed output takes less than 30 seconds to produce. The plotted outputs are somewhat slower to produce (about 10 minutes for the three pages) but present a complete record of each trial in a standard report format (FIG. **5**).

Whichever the operator's choice from the output menu, a prompt is then given to prepare the appropriate device for output. In the case of the plotter, if at the end of a page's output the results are unacceptable (pen ran dry, paper wrinkled, etc.), the plot may be repeated by typing "R" from the screen's prompt. Otherwise, output will be continued with the subsequent page, or if complete, return to the Output menu.

Two other menu choices are available. Number 4 will restart the program ready for testing the next subject, while No. 5 will terminate the program, returning to the computer's operating system.

SUBJECT INFORMATION

Two screens of information (FIGS. **4**a and **4**b) are requested for each test subject. The name entered must be less than 16 characters total. For names longer than this, some appropriate abbreviation will be necessary (such as first initial, or perhaps truncating a particularly long last name). The capitalization used will carry over to the output, therefore capitalize as desired for the output format.

The hand information (FIG. **4**b) gives several choices. The major hand (dominant hand) entry allows designation as (R/L/A) which stand for Right, Left, and Ambidextrous. The injured hand selection allows choices of (R/L/B/N) which stand for Right, Left, Both and Neither.

SCREEN PLOT OF FORCE-TIME

Each trial is presented graphically on the screen with subject information and calculated variables (FIG. **5**). The Peak Force is the greatest force observed throughout the 5 second sample. Average Force is the mean of the force data over the last 3 seconds samples. Ratio is the calculated percent of the Average Force to the Peak Force. The Coefficient of Variation is a measure of the variability of the force over the last 3 seconds. It is calculated based on the standard deviation of the force data during the last 3 seconds divided by the average force during that interval. Several times are also displayed on the screen. These are measured to the nearest hundredth of a second beginning from the sample immediately prior to the crossing of the threshold force.

FINAL RESULTS OUTPUT

The final results output can be of several forms. Printed output goes just to the printer **48**. The plotter **52** may also be used to generate a similar summary table (FIG. **6**) as well as force graphs for each of the individual trials which are similar to the graphical display on the screen (FIG. **5**) shown at the end of each trial. The graph scaling is determined by the maximum obtained on any of the six trials.

The present invention has been described above with regard to the structure, function and use of a presently contemplated specific embodiment of the invention. It should be appreciated by those skilled in the art that many modifications and variations are possible. Accordingly the exclusive rights afforded hereby should be broadly construed, limited only by the spirit and scope of the appended claims.

What is claimed is:

1. A method for measuring grip strength of a subject, comprising the steps of:

(a) providing a grip strength dynamometer with a transducer having an electrical output which produces an analog signal representative of the force with which the dynamometer is gripped;

(b) coupling the electrical output from the transducer to an input of a digital computer via an analog to digital converter;

(c) having the subject grip the dynamometer with a maximal contraction effort for a first predetermined period of time using a designated first hand;

(d) inputting to the computer digital data representative of samples of the gripping force applied to the dynamometer during the first predetermined period;

(e) calculating for the first hand from the sampled force data a first value for a first discriminator;

(f) inputting to the computer digital data samples of the applied force while the subject is gripping the dynamometer with a maximal contraction effort for a second predetermined period of time but with his other hand;

(g) calculating a second value for said first discriminator from the sampled second hand force data;

(h) comparing the calculated first and second hand values of the first discriminator to calculate a value for a second discriminator based on the difference thereof;

(i) combining the calculated second discriminator value with the calculated value of another discriminator having a different statistical distribution to that of the second discriminator to form a combined discriminator value; and

(j) determining whether the combined discriminator value is within a range that has been previously determined experimentally to indicate with a predetermined level of confidence the sincerity of the subject.

2. The method of claim **1** wherein said calculated value of another discriminator is calculated from only data samples that are input while the subject is gripping the dynamometer with his first hand.

3. The method of claim **1** wherein

said computer determines the beginning and end of each said predetermined period and a value for the average force applied to the dynamometer during a defined portion of each said predetermined period, and

at least one of said first discriminator and said another discriminator is a function of both the thus-determined value for the average force and of a calculated value of a peak force.

4. The method of claim **3** wherein said first discriminator is the ratio of the calculated average force value to the calculated peak force value.

5. The method of claim **4** wherein

said another discriminator is also a function of said calculated average force value and of said calculated peak force value, and

said another discriminator has a different distribution than that of said first discriminator.

6. The method of claim **3** wherein each said predetermined period is a five second period commencing with the application of a threshold force and said defined portion is the terminal 60% of said five second period.

7. The method of claim **1** further comprising the step of

(k) outputting the sampled force data in graphic form.

8. Apparatus for determining **[**grip**]** strength comprising:

a **[**grip strength**]** dynamometer *responsive to a force applied thereto by a subject*;

an electrical transducer attached to the dynamometer and having an analog output which produces an analog signal representative of the force **[**with which**]** *applied to* the dynamometer **[**is gripped**]**;

an analog to digital converter having an analog input for receiving analog data and a digital output for outputting digital data corresponding to the analog data at said analog input, said analog input being coupled to said analog output *of said electrical transducer*;

a digital computer having a digital input for digital data coupled to said digital output from the analog to digital converter, said digital computer further comprising:

timer means for establishing a first predetermined period of time, and

calculating means for deriving from the digital data applied to said digital input during said first predetermined period of time:

a first calculated value corresponding to the average force applied to the dynamometer during a defined portion of said first predetermined period,

a second calculated value corresponding to the peak force applied to the dynamometer during said first predetermined period,

third and fourth calculated values for respective first and second discriminator functions, said first and second discriminator functions each being a function of the average force and the peak force, but having different statistical distributions for sincere and faking subjects, and

a fifth calculated value for a combined discriminator function which is derived from said first and second discriminator functions, said combined discriminator function being such that it more reliably differentiates between sincere and faking subjects than either of said first or second discriminator functions.

9. The apparatus of claim **8** *wherein said dynamometer is adapted to be gripped by either hand of the subject, said apparatus* further comprising means for inputting to the computer digital data samples of the applied force while the subject is gripping the dynamometer with a maximal contraction effort for a second predetermined period of time but with his other hand.

10. The apparatus of claim **9** further comprising means for determining a sixth calculated value corresponding to said first discriminator function but using the second hand force data sampled during said second predetermined period of time.

11. The apparatus of claim **10** further comprising means for using the difference between said third calculated value and said sixth calculated value in determining said fourth calculated value.

12. The apparatus of claim **11** further comprising means for combining said fourth calculated value with a seventh calculated value corresponding to a third discriminator function having a different statistical distribution than that of the second discriminator to form a combined discriminator value.

13. The apparatus of claim **9** further comprising

recording means coupled to said computer and responsive to said calculating means, for providing a permanent record of the use of the apparatus for measuring the grip strength of both hands of a single subject, including graphical data representative of force applied by the subject, and alphanumeric data presenting the test results in summary form.

14. The apparatus of claim **13** further comprising

display means coupled to said computer and responsive to said calculating means, for providing a display of selected data while the apparatus is being used to measure the grip strength of said single subject, including graphical data representative of the variations of the force applied by the subject over said first and second predetermined periods of time and alphanumeric data presenting the test results.

15. The apparatus of claim **8** further comprising means for determining whether the calculated value of said combined discriminator function is within a range that has been previously determined experimentally to indicate with a predetermined level of confidence the sincerity of the subject.

16. The apparatus of claim **8** further comprising

display means coupled to said computer and responsive to said calculating means, for providing a display of

selected data while the apparatus is being used to measure the grip strength of a single subject, including graphical data representative of the variations of the force applied by the subject over said first predetermined period of time and alphanumeric data presenting the test results in summary form.

17. The apparatus of claim 8 wherein

said fifth calculated value is substantially equal to said third calculated value and said combined discriminator function is substantially equal to said first discriminator function if the subject is male, and

said fifth calculated value is substantially equal to said fourth calculated value and said combined discriminator function is substantially equal to said second discriminator function if the subject is female.

18. The apparatus of claim 17 wherein

said first discriminator function is substantially proportional to the ratio of the difference of the peak and average forces to their product, and

said second discriminator function is substantially proportional to the ratio of the difference of the n^{th} root of the peak and average forces to their product.

19. The apparatus of claim 18 wherein n is equal to 4.

20. Apparatus for determining muscle strength comprising:

a dynamometer responsive to a force applied to the dynamometer by a contracted muscle of a human subject;

an electrical transducer attached to the dynamometer and having an analog output which produces an analog signal representative of the force applied to the dynamometer;

an analog to digital converter having an analog input for receiving analog data and a digital output for outputting digital data corresponding to the analog data at said analog input, said analog input being coupled to said analog output;

a digital computer having a digital input for digital data coupled to said digital output from the analog to digital converter, said digital computer further comprising:

timer means for establishing a first predetermined period of time, and

calculating means for deriving from the digital data applied to said digital input during said first predetermined period of time;

a first calculated value corresponding to the average force applied to the dynamometer during a defined portion of said first predetermined period,

a second calculated value corresponding to the peak force applied to the dynamometer during said first predetermined period,

a third calculated value for a respective first discriminator function substantially proportional to the ratio of the difference of the peak and average forces to their product,

a fourth calculated value for a respective second discriminator function substantially proportional substantially proportional to the ratio of the difference of the nth root of the peak and average forces to their product,

wherein said third calculated value is used to differentiate between sincere and faking male subjects and said fourth calculated value is used to differentiate between sincere and faking female subjects.

21. The apparatus of claim 20 wherein n is equal to 4.

22. A method for determining whether or not a human subject is making a sincere effort to apply maximum force, the method comprising the steps of:

(a) having the subject apply force to a dynamometer with a purported maximal effort for a predetermined period of time;

(b) determining a maximal force and an average force applied during a designated portion of the predetermined period of time;

(c) calculating at least one of a first discriminator value proportional to a ratio of a difference of the maximal and average forces and a product of the maximal and average forces, and a second discriminator value proportional to a ratio of a difference of nth roots of the maximal and average forces and the product of the maximal and average forces, wherein the first discriminator value is calculated according to the following equation:

$$D4=K_1\cdot(F_{max}-F_{ave})/(F_{max}\cdot F_{ave}),$$

and the second discriminator value is calculated according to the following equation:

$$D5 = K_2 \cdot \left(\sqrt[n]{F_{max}} - \sqrt[n]{F_{ave}} \right) /(F_{max} \cdot F_{ave}),$$

where D4 and D5 are the first and second discriminator values, respectively, and F_{max} and F_{ave} are the maximal and average forces, respectively, and K_1 and K_2 are constants; and

(d) comparing at least one of the first and second discriminator values to a corresponding one of first and second predetermined discriminator values, respectively, and determining whether the subject is making a sincere effort based on the comparison,

wherein the first and second predetermined discriminator values are previously obtained by performing steps (a) to (c) for members of an experimental group.

23. The method of claim 22 wherein both the first and second discriminator values are calculated and compared to the first and second predetermined discriminator values in the step of comparing for male and female subjects.

24. Apparatus for determining strength comprising:

a dynamometer responsive to a force applied to the dynamometer by a human subject;

an electrical transducer attached to the dynamometer and having an analog output which produces an analog signal representative of the force applied to the dynamometer

an analog to digital converter having an analog input for receiving analog data and a digital output for outputting digital data corresponding to the analog data at said analog input, said analog input being coupled to aid analog output of said electrical transducer;

a digital computer having a digital input for digital data coupled to said digital output from the analog to the digital converter, said digital computer further comprising:

timer means for establishing a first predetermined period of time, and

calculating means for deriving from the digital data applied to said digital input during said first predetermined period of time;

a first calculated value corresponding to the average force applied to the dynamometer during a defined portion of said first predetermined period,

a second calculated value corresponding to the peak force applied to the dynamometer during said first predetermined period,

third and fourth calculated values for respective first and second discriminator functions, said first and second discriminator functions each being a function of the average force and the peak force, but having different statistical distributions for sincere and faking subjects, wherein the first discriminator value is calculated according to the following equation:

$$D4=K_1\cdot(F_{max}-F_{ave})/(F_{max}\cdot F_{ave}),$$

and the second discriminator value is calculated according to the following equation:

$$D5=K_2\cdot\left(\sqrt[n]{F_{max}}-\sqrt[n]{F_{ave}}\right)/(F_{max}\cdot F_{ave}),$$

where D4 and D5 are the first and second discriminator values, respectively, and F_{max} and F_{ave} are the maximal and average forces, respectively, and K_1 and K_2 are constants,

wherein the computer comprises means for comparing at least one of the third and fourth calculated values to a corresponding one of first and second predetermined stored discriminator values, respectively, and for determining whether the subject is making a sincere effort based on the comparison,

wherein the first and second predetermined discriminator values are obtained for members of an experimental group and stored in the computer.

25. The apparatus of claim 24 wherein the means for calculating calculates both the first and second discriminator values, and the means for comparing compares these values with a combination of the first and second predetermined discriminator values.

26. The method of claim 22 wherein the force applied to the dynamometer is by the subject gripping the dynamometer.

27. The apparatus of claim 24, wherein the dynamometer comprises a grip strength dynamometer.

28. The apparatus of claim 22, wherein n equals 4.

29. The method of claim 24, wherein n equals 4.

30. A method for determining whether or not a human subject is making a sincere effort to apply maximum force using a contracted muscle group, the method comprising the steps of:

(a) having the subject apply force to a dynamometer with a purported maximal effort for a predetermined period of time;

(b) determining a maximal force and an average force applied during a designated portion of the predetermined period of time;

(c) calculating at least one of a first discriminator value (D4) proportional to a ratio of a function of a difference of the maximal and average forces and a function of a product of the maximal and average forces, and a second discriminator value (D5) proportional to a ratio of a function of a difference of nth roots of the maximal and average forces and a function of the product of the maximal and average forces, and

(d) comparing at least one of the first and second discriminator values to a corresponding one of first and second predetermined discriminator values, respectively, and determining whether the subject is making a sincere effort based on the comparison,

wherein the first and second predetermined discriminator values are previously obtained by performing steps (a) to (c) for members of an experimental group.

31. The method of claim 30 wherein both the first and second discriminator values are calculated and compared to the first and second predetermined discriminator values in the step of comparing for male and female subjects.

32. Apparatus for determining sincerity of effort comprising:

a dynamometer responsive to a force applied to the dynamometer by a contracted muscle of a human subject;

an electrical transducer attached to the dynamometer and having an analog output which produces an analog signal representative of the force applied to the dynamometer;

an analog o digital converter having an analog input for receiving analog data and a digital output for outputting digital data corresponding to the analog data at said analog input, said analog input being coupled to said analog output of said electrical transducer;

a digital computer having a digital input for digital data coupled to said digital output from the analog to digital converter, said digital computer further comprising:

timer means for establishing a first predetermined period of time; and

calculating means for deriving from the digital data applied to said digital input during said first predetermined period of time:

a first calculated value corresponding to the average force applied to the dynamometer during a defined portion of said first predetermined period,

a second calculated value corresponding to the peak force applied to the dynamometer during said first predetermined period,

third and fourth calculated values for respective first and second discriminator functions (D4, D5), said first and second discriminator functions each being a function of the average force and the peak force, but having different statistical distributions for sincere and faking subjects, wherein the first discriminator value is proportional to a ratio of a function of the difference of the peak and average forces to a function of a product of the peak and average forces, and

the second discriminator value is proportional to a ratio of a function of the difference of nth roots of the peak and average forces to a function of a product of the peak and average forces,

wherein the computer comprises means for comparing at least one of the third and fourth calculated values to a corresponding one of first and second predetermined stored discriminator values, respectively, and for determining whether the subject is making a sincere effort based on the comparison,

wherein the first and second predetermined discriminator values are obtained for members of an experimental group and stored in the computer.

33. The apparatus of claim 32 wherein the means for calculating calculates both the first and second discriminator values, and the means for comparing compares these values with a combination of the first and second predetermined discriminator values.

34. The method of claim 30 wherein the force applied to the dynamometer is by the subject gripping the dynamometer.

35. The apparatus of claim 32 wherein the dynamometer comprises a grip strength dynamometer.

36. The method of claim 30 wherein the nth roots are the 4th roots.

37. The apparatus of claim 32 wherein the nth roots are the 4th roots.

* * * * *