Development of Mono-axial Electrogoniometer

A dissertation

Submitted in partial fulfilment of the

requirements for the degree of

Master of Technology

by

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of

disabled people around us

Dissertation Approval Sheet

Dissertation entitled **"Development of Mono - axial Electrogoniometer"** by Prakash Pandey (Roll No. 94314101) is approved for the award of the degree of **Master of Technology** in Biomedical Engineering.

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Abstract

A goniometer is an instrument for measuring joint angle, and it has many clinical applications, such as diagnostic assistance in knee corrective and reconstructive surgery, in the design of the locomotive assistive devices, and in general study of locomotion (gait analysis).

The objective of this project is to design and build a simple, low cost, light weight, non-interfering in walking, and reliable electrogoniometer to record the angular movement of the knee joint in the sagittal plane (flexion-extension). The necessary mechanical assembly required for proper attachment at the knee joint has been redesigned and fabricated incorporating some additional features to an earlier design. The prototype was packaged with appropriate control knobs in a box designed and fabricated for this purpose. Calibration and testing of the unit has been carried out. The flexon waveforms were recorded using a plotter for various activities such as walking, jogging, cycling, and sitting and rising on the chair for normal knee joint. The developed unit was interfaced with a battery operated portable data logger for digitizing and recording the waveforms. The recorded waveform can be subsequently retrieved for display and spectrographic analysis on a PC. Such an analysis was carried out for the captured flexon waveforms.

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Chapter 1

Introduction

1.1 Problem overview

In clinical application, the treatment decision and monitoring of patients progress are mainly based on assessment of gait cycle. Gait analysis techniques can be used to measure normal walking and other activities such as throwing a base ball, bowling cricket ball, pole vault, etc to develop better sporting skills. It is also used to diagnose the problems of people who have difficulty in walking such as children with cerebral palsy [13], and to investigate problems such as total joint implant loosening or to develop better technologies in prosthetic design for patients who have had limb amputed. The purpose of many of the therapeutic procedures used in rehabilitation is to improve the range of motion (ROM) of the joint. A goniometer, an exoskeleton instrument for measuring joint angle movements, can be helpful in these.

The joint angle can be measured goniometrically as well as photogrametrically. Interrupted light photography and film/ video techniques are the photogrammetric technique of measuring joint angle. In interrupted light photography technique, the person is asked to walk in the dark with his joints marked with reflective fabric. The discrete images reflected from the marker are captured with the help of the shuttered camera and the processed film is viewed frame by frame in a motion analyzer for further analysis. Another photogrammetric technique of angular measurement is film/video technique. In this technique also, the joints of the subject under study is marked with a marker. The photograph of the mark is taken by using more than two cameras from different angles while subject walking. The x-y coordinates of the joints is digitized directly by digitizer. These digital data are fed to the computer for the analysis of the joint angle. These techniques are slow, requiring film to be developed, expensive, and labour intensive. Another technique of angular measurement as mentioned earlier is goniometry. The goniometer is of two types namely manual type and electrical type. In this project electrical type of goniometer will be developed for measuring joint angle. In this electrical type of goniometer, generally a potentiometer is used as sensor, hence the instrument is called electrogoniometer. The main advantage of this technique, compared to other techniques, is that the analogue signal obtained from the potentiometer proportional to the angular movement of the joint can be converted easily to digital form for computer analysis.

1.2 Project objective

The main objective of this project is to develop a portable, low cost, reliable, ergonomic, and user interactive electronic goniometer for monitoring the angular movement of the knee joint. A mechanical assembly for the same has been earlier developed [4]. A prototype mechanical assembly will be redesigned and fabricated for use in the electronic goniometer . The developed unit will be packaged in a box with appropriate control knobs and switches and will be calibrated. Finally, recordings of the goniometric signal will be carried out on normal subjects using a plotter and a battery operated portable data logger.

In this technique of angular assessment adopted in this project, a single turn potentiometer will be mounted to the joint of two shafts which gives output electrical signal proportional to the angular movement. The potentiometer will be connected with the electronic system away from the subject under study through a long flexible cable. The signal obtained from potentiometer will be processed in the electronic circuit provided and displayed to the visual display. The instrument will be interfaced to other recording, storage, and analyzer system for subsequent display and analysis of the angular motion signal. It is further proposed to provide facility for monitoring the movement of two knee joints simultaneously by incorporating two channels of signal conditioning stage.

1.3 Dissertation outline

This project report has been arranged into six chapters. The second chapter reviews some of the different types of electrogoniometer developed and reported earlier in the literature. The third chapter deals with the design and fabrication of mechanical portion of the electrogoniometer developed. The fourth chapter includes instrumentation portion covering hardware design and implementation details. In the fifth chapter, the recording and testing of an electrogoniometer has been carried out on a normal subject. Finally, the sixth chapter concludes the report with the summary of the work done and the suggestions for further work.

Chapter 2

Literature Review

This chapter deals with the literature review of some of the existing electrogoniometers developed earlier. It also covers biomechanics of knee joint and its possible ranges of different kinds of rotation in brief. Finally, the chapter ends with the description of limitations of planar electrogoniometer.

2.1 Historical background

The recording of joint motion in walking by means of electrogoniometry has been used since 1960 when Karpovich and Herden first published their results [1]. The basic design of their instrument was a rotational potentiometer which was attached to two rods applied to limb on either side of the joint under examination. The angular excursion was determined by changes in resistance of the potentiometer. Their device proved goniometry to be a valuable tool in the study of normal as well as pathological gait. However, the fact that motion could only be measured in one plane by means of their goniometry was a disadvantage. In 1969, Johnston and Smidt reported results with a goniometer capable of recording the motion of the hip joint in 3 planes. Ketterkamp et al (1970) used a similar goniometer with slight modification in their studies of motion of knee. In 1971, an electrogoniometric method was further elaborated by Lamoruix. He described an exoskeleton by means of which the motion of three major joints of the leg could be recorded simultaneously. The theoretical aspect of goniometry has been extensively covered by Chao (1980).

Further, a light weight goniometer was designed by Hannah et al in 1979 which was capable of recording the motion of the hip, knee, and ankle joints on both sides simultaneously in three planes [1].

2.2 Different kinds of rotation

The knee joint is a polycentric joint although often modelled as a hinge joint. Knee motions are a combination of rolling and sliding between the contacting tibia and femur condyle surfaces. There are three mutually perpendicular axes about which movements of a joint takes place. The possible movements are flexion/extension, abduction/adduction, and internal/external. Flexion extension is the movement of posterior aspect of thigh towards or away from its surface respectively. Abduction/adduction indicates side to side movement during normal walking. Internal external rotation is also called medial/lateral rotation. It indicates the axial rotation of tibia directed towards or away from the knee joint.

Active knee flexion attains a range of 140^0 with hip flexion and only 120^0 at hip extension. Passive extension attains 5-10^0 from the position of reference. Lateral rotation has a range of 40^0 and the medial rotation has a range of 30^0. This range vary with the degree of knee flexion. Lateral rotation attains a value of 32^0 when the knee is at 30^0 and is 42^0 at knee flexion at 90^0. The maximum value of abduction/adduction angle is 15^0.

During normal walking, flexion extension in swing phase attains around 70^0 while in stance phase it attains around 6 - 20^0. The abduction adduction angle is 2-12^0 and axial rotation in the range of 5.7^0-25.4^0. Again it depends on the speed of walking [4].

2.3 Types of goniometer

The joint motion can be measured goniometrically as well as photogrammetrically. The goniometer has been classified into two types namely manual type and electrical type.

Manual type goniometer is formed by joining two rods/shafts into a point around which the rods rotate. On the top of the moving rod one 360^0 protector is placed which helps to give corresponding readings. It gives accurate measurement but it is restricted only for static angle measurements. Manual goniometers are shown in Fig. 2.1.

In an electrical goniometer the protector of the manual type is replaced by a transducer which gives an electrical signal corresponding to the angle. This signal can be measured by electrical meter, as well as can be recorded for the study of dynamics of angular motion of the joint.

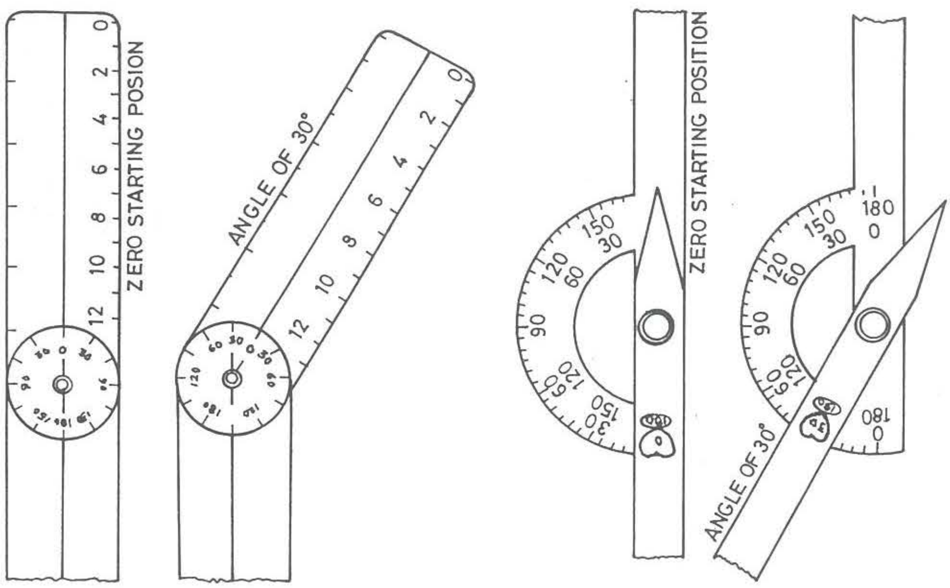


Fig. 2·1 Different types of manual goniometer.

2.4 Different types of electrogoniometer

The recording of joint motion in walking by means of electrogoniometry has been used since 1960, when Karpovich and Herden first used it [1]. After that number of electrogoniometers have been developed. Here, the instrumentation and the performance aspects of some of these will be briefly described.

2.4.1 Electrogoniometer by Mcleod et al, 1975 [6]

They have developed an electrogoniometer as shown in Fig. 2.2 for determining the frequency and type of knee motion such as walking, sitting and rising, ascending, and descending. Activities were determined by the pattern of knee motion.

The instrumentation developed consisted of an electrogoniometer, a miniature tape recorder (worn by patient to record sagittal plane knee motion), tape play back unit, and galvanometric recorder that produces d.c. voltage representative of knee motion as a function of time.

The recording electronic circuits consisted of a voltage controlled oscillator and reference oscillator. The frequency of the voltage controlled oscillator was controlled over the range of 1-2 kHz, by the motion of the tibia relation to the femur. The reference oscillator operated at a constant frequency of 5 kHz. The signals from these two oscillators were electrically added and were recorded on CrO_2 magnetic tape.

In the play back electronic circuit, the frequencies from the two oscillators were separated by the use of two phase-locked loops. The voltage from the phase locked loop that follows the movement of the knee and the voltage from the phase locked loop that view a constant frequency of 5 kHz were applied to the inputs of a difference amplifier which removes all the noise components common to both channels. The difference amplifier was followed by a low pass filter with a flat frequency response from dc to 15 Hz in order to remove high frequency 60 Hz noise from AC line and 120 Hz radiation from fluorescent lighting. The output signal from amplifier was amplified and was recorded by a light beam galvanometric recorder.

The miniature cassette tape recorder demonstrated a sizeable variation in tape speed due to eccentricities within their rolling parts. These fluctuation caused a frequency modulation of the information being recorded. During playback this frequency modulation appeared as noise

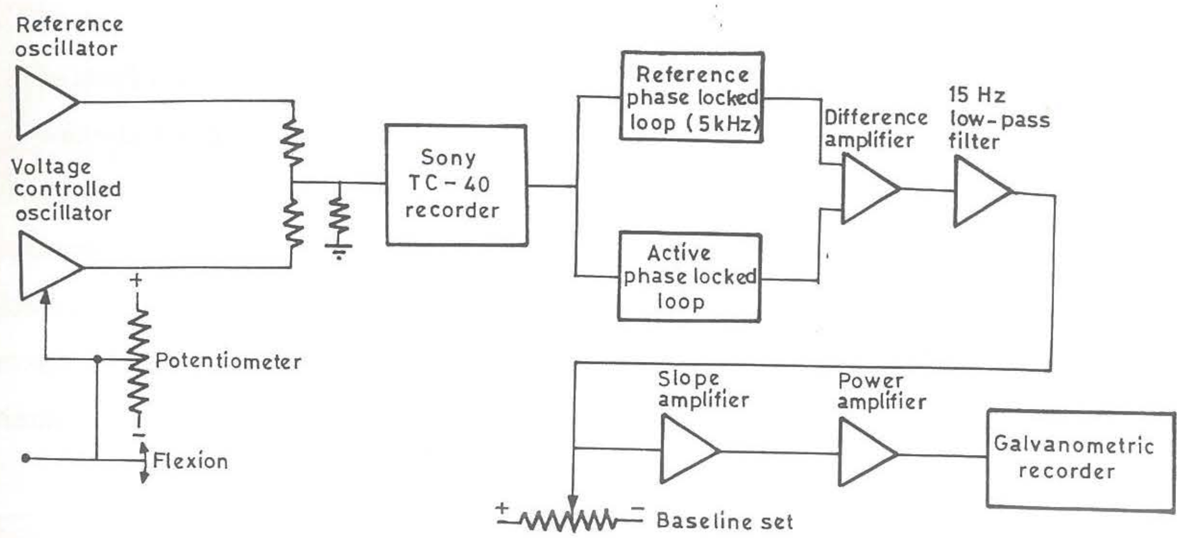


Fig. 2.2 Block diagram of recorder and play back circuit developed by Mcleod [6]

in output. An improved signal to noise ratio was obtained by using two oscillators, a recording network, and two frequency to voltage converters in the playback circuit.

2.4.2 Electrogoniometer developed by Tata et al, 1978 [11]

They have developed a light weight, inexpensive, and easy to attach single plane electrogoniometer for measuring angular movement of knee joint. The main features of a design were a flexing junction bar connecting the two main electrogoniometer arms and the application of a trigonometric relationship for the determination of the actual joint angle.

Applying, then trigonometric relationship the desired joint angle (τ) can be found out. The joint angle is given by $\tau = 180 - (\alpha + \beta)$ where α and β are physically realizable and measurable angles. The mechanical arrangement can be understood from Fig.2.3, 2.4, and 2.5.

The small size high degree of linearity potentiometer (Bourns model 35305-1-502 linearity $\pm 0.5\%$) were chosen for full 360^0 rotation. Each potentiometer was mounted so that the wiper contact was approximately at mid position with angles β and α equal to 0^0 so that there was 180^0 of movement available in either direction. The 2 KΩ trimpots were used to adjust each potentiometer output to exactly 0V when the angles equalled 0^0. The summing and balancing unit was mounted on a waist belt and flexible multiconductor cable connected it with the potentiometer.

2.4.3 Electrogoniometer by Malcolm peat et al, 1976 [5]

They have developed electrogoniometer based on gravity reference principle as shown in Fig. 2.6. It consisted of a potentiometer with a pendulum attached to its shaft. The whole system was mounted in a special bracket with a small bearing. The potentiometer was free to rotate in its mounting bracket about an axis, but the pendulum weight was always vertical even though subjects arm rotate along its long axis during movement. A counter weight was given to the rear side of the potentiometer to balance the weight of the pendulum and the position of the weight was adjusted. Therefore the base of the potentiometer which was mounted on the bracket rotates along with arm movements and the pendulum would always be vertical. A 360^0 protractor was mounted concentric with potentiometer shaft which permits comparison of angle reading with

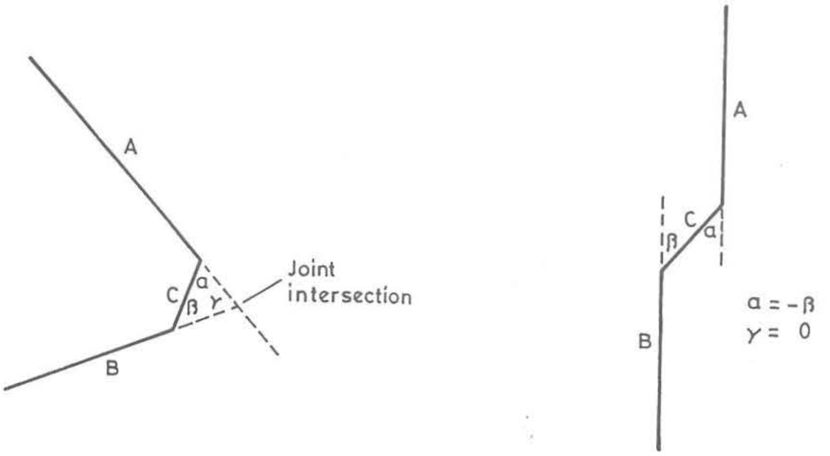


Fig. 2·3 Principle of electrogoniometer developed by Tata et al. [11]

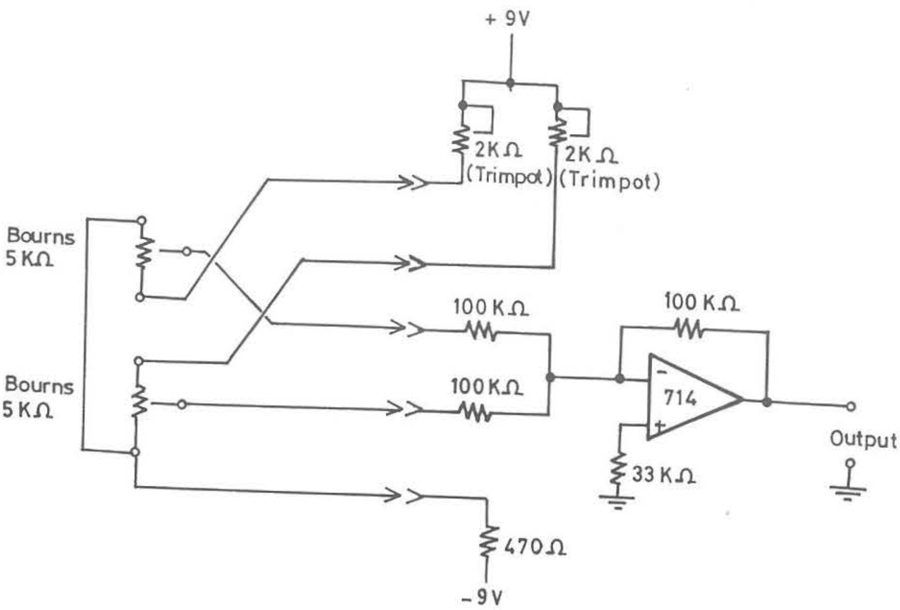


Fig. 2.4 Electrogoniometer developed by Tata et al. [11]

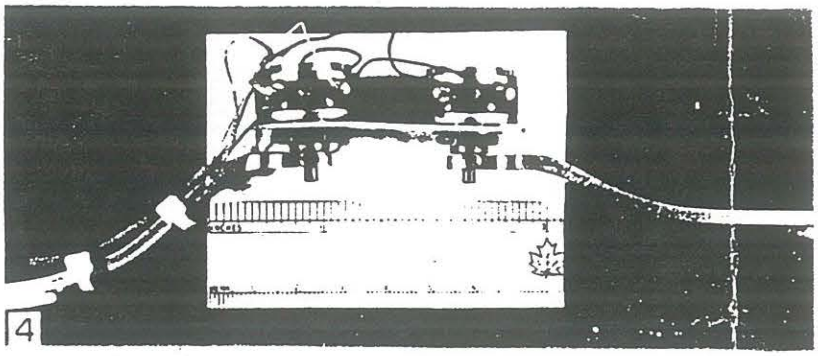


Fig. 2.5 Potentiometer details [11]

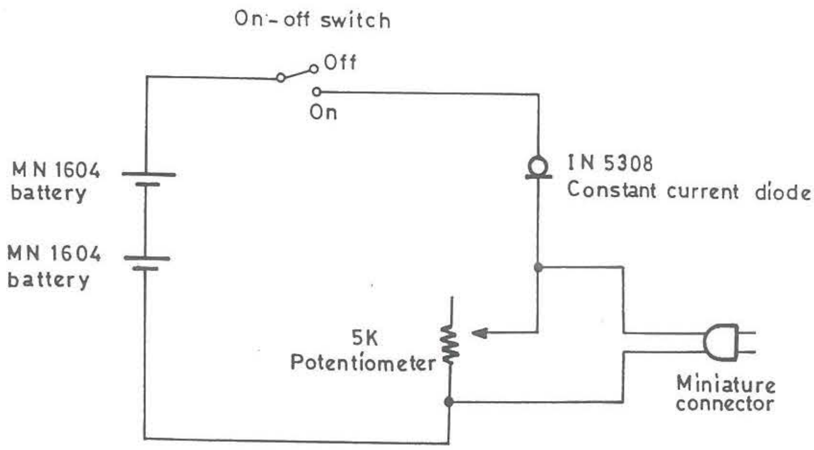


Fig. 2.6 Electrical circuit diagram of electrogoniometer developed by Malcolm et al [5]

electrical output of the potentiometer. With the rotation of base of potentiometer the output voltage was changing, provided a constant input voltage was supplied to it. Then the output voltage was recorded using a chart recorder.

The potentiometer used was low torque, 360^0 rotation type (linear Beckman potentiometer TSP-SK) with a maximum resistance of 5 KΩ. The batteries and other components were mounted directly on the goniometer and its strap as can be seen in figure leaving only a single pair of flexible leads to connect to the chart recorder. The IN 5308 constant current diode was used to ensure linearity between voltage output and angular rotation to this circuit configurations.

The main limitations of this electrogoniometer is that it can measure only relative changes in angle. It measures angle with respect to one fixed body so it couldn't measure the dynamic angle like knee joint motion between tibia and femur where both parts are moving.

2.5 Limitations of planar electrogoniometer

The planar electrogoniometer is frequently used to provide simple measurement of joint motion in one plane. since knee joint motion involves complex three dimensional motion, the application of planar goniometer is limited. The translational motion is usually small and difficult to measure due to instrumentation limitation.

In clinical measurement of joint motion, only two dimensional angular motion in one plane is considered according to the international standard of orthopaedic measurement. Although such simple measurement by mono planar electrogoniometer has clinical importance, it becomes inadequate when objective assessment of joint function and deformity is required in pathological condition.

Chapter 3

Design and fabrication of electrogoniometer

In this chapter, the detailed mechanical design and fabrication of an electrogoniometer has been described. The basic design considerations that have been incorporated in this development will also be described . The signal conditioning and instrumentation part of this electrogoniometer will be described in the following chapter.

3.1 Design considerations

Principally, the mechanical assembly of the electrogoniometer will consist of two light weight aluminium bars attached to proximal and distal to the joint. A potentiometer mounted at the joint of the two bars, acts as a sensor and gives electrical signal output proportional to the angular movement.

The accuracy of the electrogoniometer developed depends on the accuracy of the mechanical assembly designed. Therefore attention has to be given to the design and fabrication of mechanical assembly which should be simple, sufficiently firm, and repeatable. Further, attachment of the assembly to the experimental subject should be simple and fast. In addition to these, the following factors have been considered in the design.

1) Proper attachment and self adjustments of the mechanical assembly.
2) Allowance for translational movements.
3) Detachment of electronic instrumentation.
4) Mechanical pointer

3.1.1 Proper attachment and self adjustments

The electrogoniometer is an exoskeleton instrument hence attachments have to be made at bony portion rather than fleshy areas. The number of attachments should be as low as possible since each of them disturbs the motion. In this design, two Velcro straps have been rivetted in each shaft (tibial and femoral) for proper attachment to the experimental subject..

The electrogoniometer is attached externally to measure the flexion-extension of the joint. Hence the proper fixing at the joint is of prime importance. The angle measuring axis of goniometer must be placed co-linearly with the axis of the knee joint. The axial rotation axes should be kept in parallel with the long axis of the distal segments of the joint. Due to inter subject variation of anatomical curvatures of the knee joint, self adjustment mechanism should be incorporated in the design. In this design, slanting of the tibial shaft vertically in lateral and medial direction as well as adjustment in height is possible to attach instrument properly depending upon the anatomical curvatures of the lower leg of the subject.

3.1.2 Allowance for translational movements

According to the biomechanics of knee joint, variation of knee joint centre of rotation takes place at different phases of gait cycle. During gait cycle the contraction and expansion of the longitudinal muscle may pull the electrogoniometer attached resulting error in measurement. In order to eliminate the helical translational movement in the flexion-extension (sagittal) direction, sliding mechanism in the vertical direction has been incorporated in the design.

3.1.3 Detachment of electronic instrumentation

In this design, a potentiometer mounted on the mechanical assembly will be connected with the electronic system away from subject under study through a long flexible cable. Therefore, the provision will be incorporated to detach electronic system from the mechanical assembly. For the same purpose, a small, light weight styrene box with connector has been fixed in the femoral shaft to connect or disconnect the electronic system.

3.1.4 Mechanical pointer

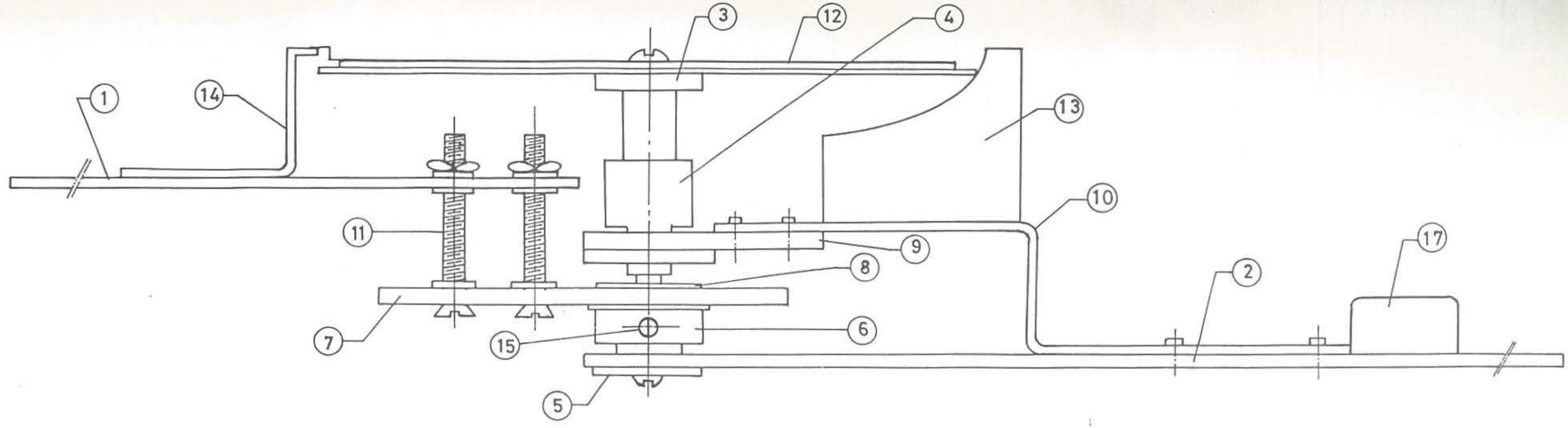
A 360^0 protractor will be mounted concentric with the potentiometer shaft which permits comparison of angle reading with electrical output of the potentiometer. The same scale can be used for the purpose of reading angular movement as well as to calibrate the instrument. The pointer fixed to the femoral shaft and tibial shaft corresponds to 0^0 and 360^0 at zero degree angular movement, i. e., when two shafts are at the same straight line. The movement of tibial shaft pointer with respect to the fixed femoral shaft pointer gives angular movement of the joint.

3.2 Detailed description of the components

An electrogoniometer assembly had been earlier developed by Rina Maiti [4]. Taking that as a base design, and including various design features and considerations as outlined in the previous section, a new assembly was developed. The detailed schematic diagram of the whole assembly of the electrogoniometer and its sectional view is shown in Fig. 3.1 and 3.2. The drawing details of each component is shown in Appendix A. The dimensions of each component of the assembly have been decided based on the anthropometric data collected by Rina Maiti [4] by using photogrammetric technique. This section describes each components of the mechanical assembly in brief.

3.2.1 A description of the system

Basically, the mechanical assembly of the electrogoniometric system is consisted of two rotating aluminium shafts mounted on the potentiometer axis enveloped by the rotating shaft envelope. The potentiometer axis is fixed to the hole in the rotating shaft envelope such that the rotation of the rotating shaft envelope also rotates the potentiometer axis resulting angular excursion. Other components such as sliding bar, fixed ring, and femoral shaft are also mounted on the same rotating shaft envelope. The slot provided on the sliding bar gives freedom for translational movements. Hence, the self adjustment of the length of the tibial shaft is possible during gait analysis. The mechanical pointer fixed at the tibial shaft and femoral shaft gives



(1) Tibial shaft
(2) Femoval shaft
(3) Protector stand
(4) Potentiometer
(5) Washer
(6) Fixed ring
(7) Sliding bar
(8) Rotating shaft envelope
(9) Fixed base
(10) Fixed bar
(11) Two wing nut and bolt
(12) 360 protector scale
(13) Fixed pointer
(14) Movable pointer
(15) Locking screw
(16) Fixing pin
(17) Connector box

Fig. 3·1 Schematic diagram of whole assembly of electrogoniometer

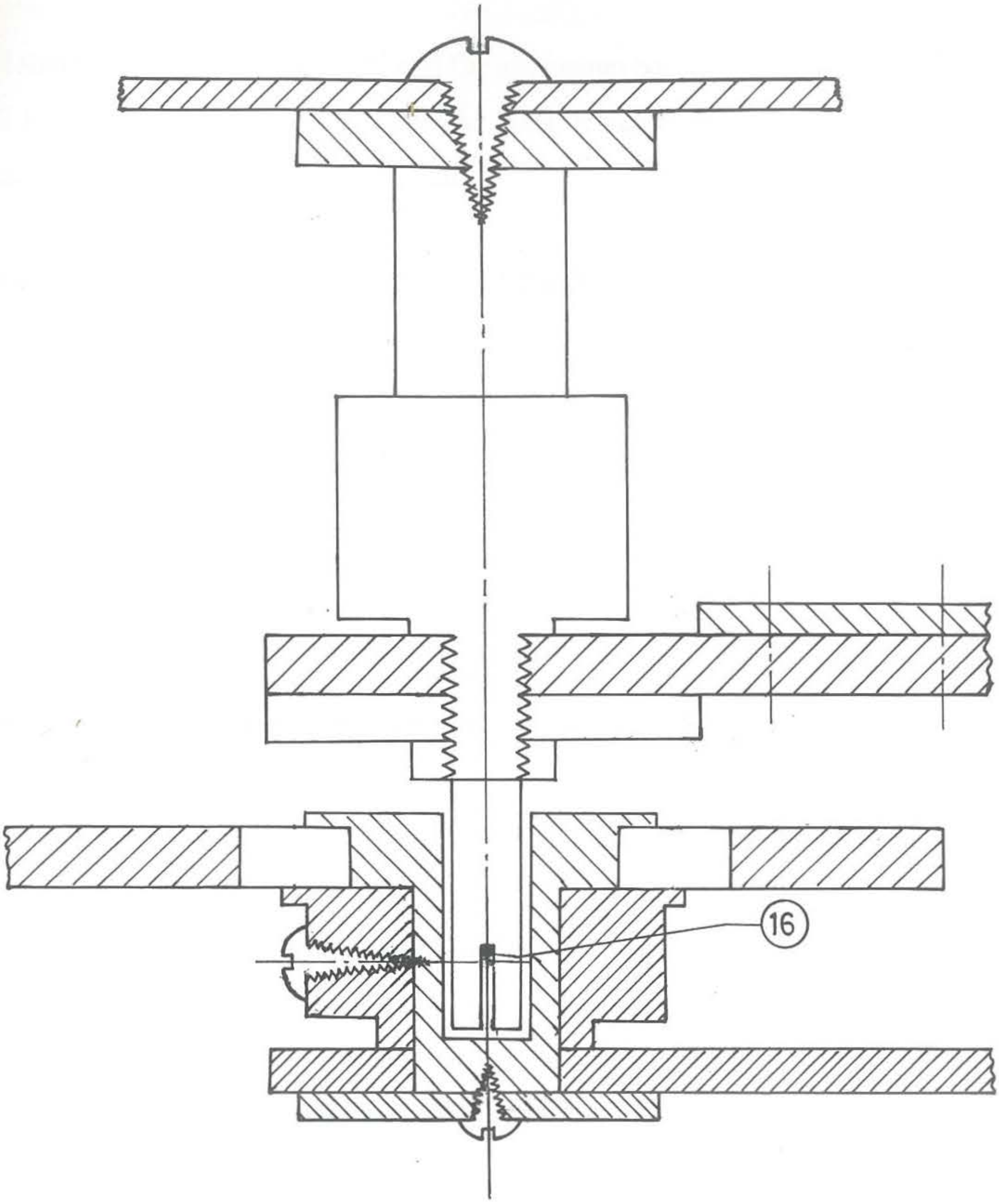


Fig. 3·2 Sectional view of the whole assembly of an electrogoniometer angular readings in degrees corresponding to knee joint movement.

1) **Tibial shaft:** It is a movable, straight, and flat aluminium bar. It is connected with the sliding bar with the help of two two- wing nuts and bolts. It also consists of two Velcro strap for attachment to the lower part of the knee joint.

2) **Femoral shaft:** It is also a long, straight, and flat aluminium shaft but immovable one. It is attached parallel to the femur with the help of two velcro straps rivetted to the shaft.

3) **Protractor stand:** It is a U shaped acrylic structure to support the scale. The lower flat surface is mounted fixed in the potentiometer shaft and the protractor is mounted on the upper flat surface as shown in Appendix B.

4) **Single turn potentiometer:** It is mounted at the intersection of tibial and femoral shaft. It provides signal proportional to the angular displacement.

5) **Washer:** It helps to keep whole assembly in a fixed position and easy rotation

6) **Fixed ring:** It is a three segmented ring fixed to the rotating shaft envelope with the help of the locking screw as shown in Appendix B. The two outer Teflon segment having different diameters bigger one facing tibial shaft and smaller one facing femoral shaft are responsible for guiding two shafts parallel with minimum friction.

7) **Sliding bar:** It is a short styrene bar connected with the tibial shaft with the help of nuts and bolts. It helps to adjust automatically the translational change in sagittal plane.

8) **Rotating shaft envelope:** It is a three segmented PVC extension of the rotating shaft of the potentiometer. It is rigidly fixed to the potentiometer shaft with the help of the fixing pin. The first segment is a round head which helps to guide the sliding bar. The second segment is a rectangular segment in which the sliding bar slides to adjust the translational movement. The third segment is a round segment in which fixed ring and femoral shaft rests forming an axis of the electrogoniometer.

9) Fixed base: It is a styrene base fixed to the base of the potentiometer which helps to hold up the whole assembly. It is connected to the femoral shaft with the help of aluminium bar.

10) Fixed bar: It is used to support the fixed base with the femoral shaft of the goniometer.

11) Two- wing nut and bolt: It connects sliding bar with the tibial shaft. By screwing the wing nut, the sloping of the tibial shaft can be changed.

12) Protractor scale: It is a 360^0 plastic protractor mounted at the protractor stand. This scale can be used to read the angular change of the knee joint and calibration of the instrument.

13) Fixed pointer: It is a styrene pointer fixed to the femoral shaft. It always points zero of the scale for reference.

14) Movable pointer: It is an aluminium pointer attached to the tibial shaft of the instrument. It is a movable pointer which indicates angular displacement on the scale.

15) Locking screw: It locks the fixed ring to the rotating shaft envelope.

16) Fixing pin: It is a C.I. pin which fixes the rotating shaft envelope with the shaft of the potentiometer. Hence the rotation of the shaft also rotates the rotating shaft envelope.

Chapter 4

Instrumentation

In this chapter, the hardware design and implementation of the instrumentation for the electrogoniometric system will be described. The overall set up of the electrogoniometer is shown in Fig. 4.1. In this set up, the single turn potentiometer has been mounted on the mechanical assembly as a sensor which gives output analog voltage proportional to the angular movement. The precision constant current, generated in the signal conditioning circuit, flows through potentiometric resistance across the two core shielded cable (of approx. length 10 m). The voltage developed across the potentiometric resistance is sensed through the same shielded cable. The analog signal obtained is processed in the signal conditioning circuit, and is given to A/D converter for digital display of the angle in degrees. The same analog signal varying as a function of time can be digitized as a sequence with the help of data acquisition card interfaced to a PC, or with the help of a data logger which can be interfaced with computer subsequently for further analysis. Other possibility is to record the analog signal with the help of a strip chart recorder.

4.1 Transducer selection

The potentiometer has been selected as transducer for the measurement of angular motion of the knee joint which when rotated through a known angle, changes resistance by proportional amount. Such type of electrogoniometers have advantages that they provide an analog output which is convenient for analog to digital conversion for display as well as for computerized recording and analysis. The resistive potentiometer has been found suitable on the basis of simplicity, low cost, lightness, and suitability for on-line computer analysis.

Initially locally available potentiometer ("Punkaj" 5 k ohm) was used as a transducer. Later on this transducer has been replaced with high quality square panel single turn potentiometer (RS components model 9511X linearity ± 5%) having maximum resistance of 10 k ohms because of its long rotational life and low torque characteristics. Other technical

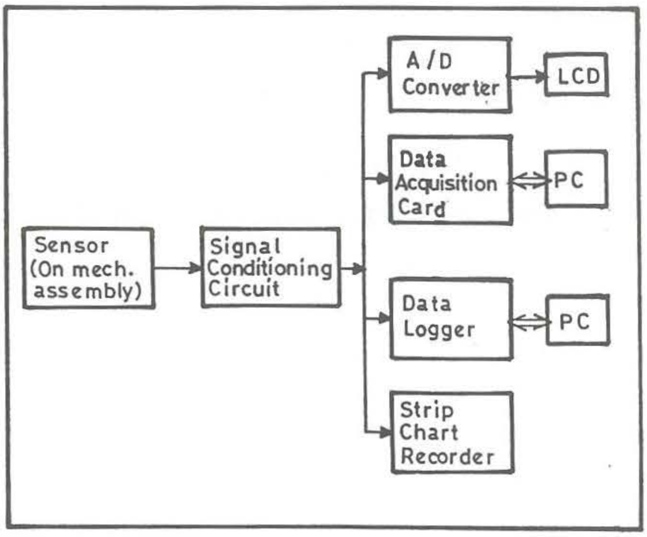


Fig. 4.1 Overall setup of the electrogoniometer

specifications mentioned in RS electronic products catalogue, 1995-96 of the selected potentiometer are as given in Table 4.1

Table 4.1

Technical specifications of sensor potentiometer (RS components, model 9511X)

Power rating	0.5 W at 70^0C
Resistance tol.	± 10% (lin.)
Independent lin.	5% (lin. track only)
Elec. travel	$240^0 \pm 5^0$
Mech. travel	$300^0 \pm 5^0$
Temperature range	-55^0C TO $+125^0$C
Rotational life	$> 10^5$ cycles
Running torque	22 gm cm (max.)

4.2 Calibration of the sensor potentiometer

The single turn, 285^0 rotation, 5 K ohm potentiometer ("Pankaj" locally available) was calibrated. For the calibration, the potentiometer was fixed firmly to the centre of a sufficiently large dial calibrated at an interval of 5^0. The moving pointer was also mounted to the same potentiometer axis. The potentiometer was supplied with a constant regulated d.c. voltage of 12V. The potentiometer pointer was rotated at an interval of 5^0 around the potentiometer axis and the voltage developed was measured with the help of a digital voltmeter. The calibration curve was plotted and shown in Fig.4.2. The curve shows sufficient linearity at the middle range of potentiometer, approximately over 50^0-240^0 hence only this range will be used for our purpose.

The linearity of the locally available potentiometer was unknown. Hence, the calibration of the same was carried out to determine its linearity. Later on, the locally available

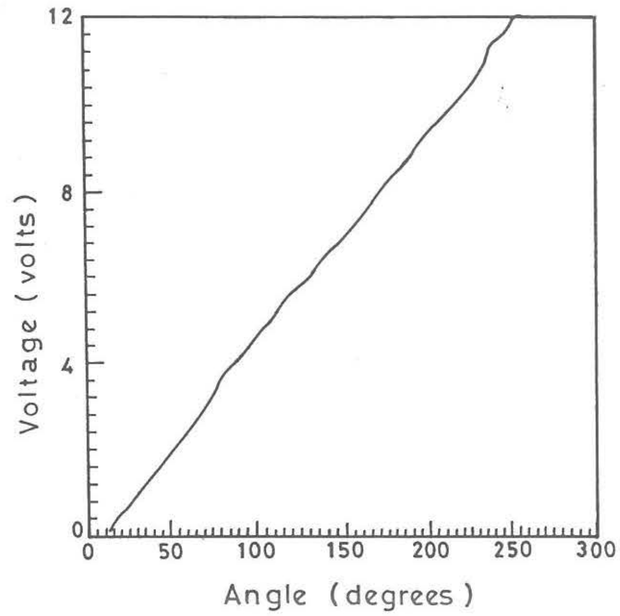


Fig 4·2 Calibration curve of the sensor potentiometer ('Punkaj' 5 k Ω).

potentiometer was replaced with imported one because of its superior features as mentioned above. The newly replaced potentiometer was not calibrated, as the linearity of this potentiometer is already known from its data book.

4.3 Power source for the system

The electrogoniometer has been designed by using a readily available single 9 volt battery as a power source. The 9 volt alkaline battery has 1000 mAh capacity, long shelf life, and a flat discharge curve.

Generally op-amp circuits work with dual ($\pm$ Vcc) supplies. In order to operate the instrument on single 9 volt battery , the concept of split power supply from a single battery has been incorporated in the design. The midpoint "ground" has been chosen in such a way such that the asymmetrical splitted supply of +2.84 volts and -6.16 volts were generated from a single 9 volt battery. All the micropower op-amps in the design were selected accordingly on the basis of asymmetrical dual supply available. This particular splitting of battery voltage has been obtained from the A/D system, which also is powered by the same battery.

4.4 Signal conditioning circuit

First, the design and implementation of a scheme based on constant voltage reference was carried out. However, it was later decided to keep the excitation source away from the sensing potentiometer. This would require a 3 - wire cable of length approx. 10 m. Therefore, it was subsequently decided to use a current source for excitation so that a 2- wire cable will serve our purpose.

The signal conditioning circuit shown in Fig. 4.3 comprises of constant current source, voltage follower, and summing amplifier. The constant current has been generated by using a micropower op-amp LM 308, temperature compensated voltage reference diode LM 385-2.5, and other discrete components. The generated constant current runs along a long flexible two core shielded cable of approximately 10 m length. The same wire has been used for the sensing of voltage across the potentiometer. The voltage sensed across a potentiometric resistance was

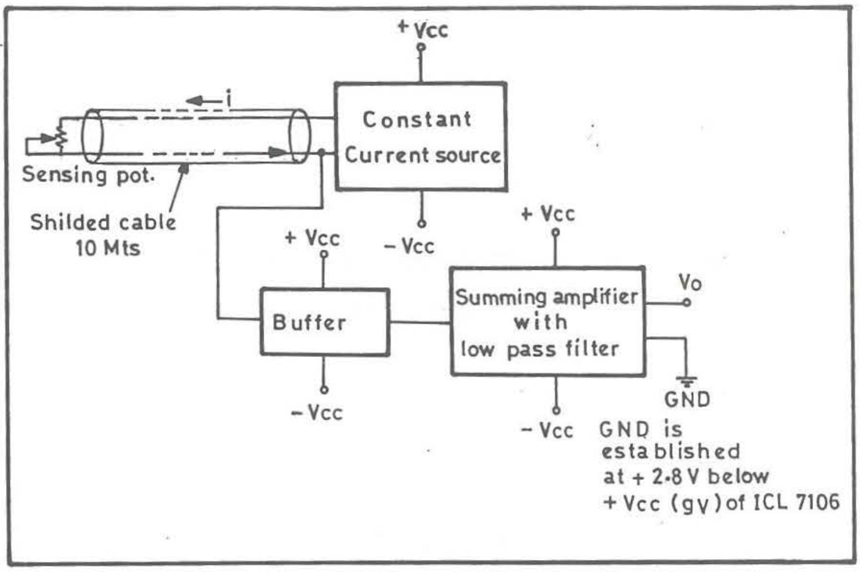


Fig. 4·3 Block diagram of signal conditioning circuit.

buffered and fed to the digital section for A/D conversion and to display the corresponding slowly varying angle proportional to the voltage sensed. The dynamic angular variation can be recorded by using a chart recorder or a data acquisition system.

Various sections of the signal conditioning circuit, such as precision constant current source, summing amplifier, and RC low pass filter will be described in the following subsections.

4.4.1 Precision constant current source

The constant current has been generated using a micropower op-amp LM 308, the temperature compensated voltage reference diode LM 385-2.5, and few discrete components as shown in Fig. 4.4. The LM 385-2.5 is a micropower two terminal voltage regulator diode operating over a 10 uA to 20 mA current range providing long term stability [7]. The extremely low power drain of the LM 385-2.5 makes it useful for micropower circuitry. The current has been established with external resistors. The output current can be changed from 1 uA to 1 mA by changing the value of resistances R_2 and R_3 as shown in Fig. 4.4.

$$I = Vz / (R_2 + R_3)$$

The buffer output voltage will be $Vx = Vcc - I (Rx + Ry)$

Where, Rx = Sensing potentiometer resistance.

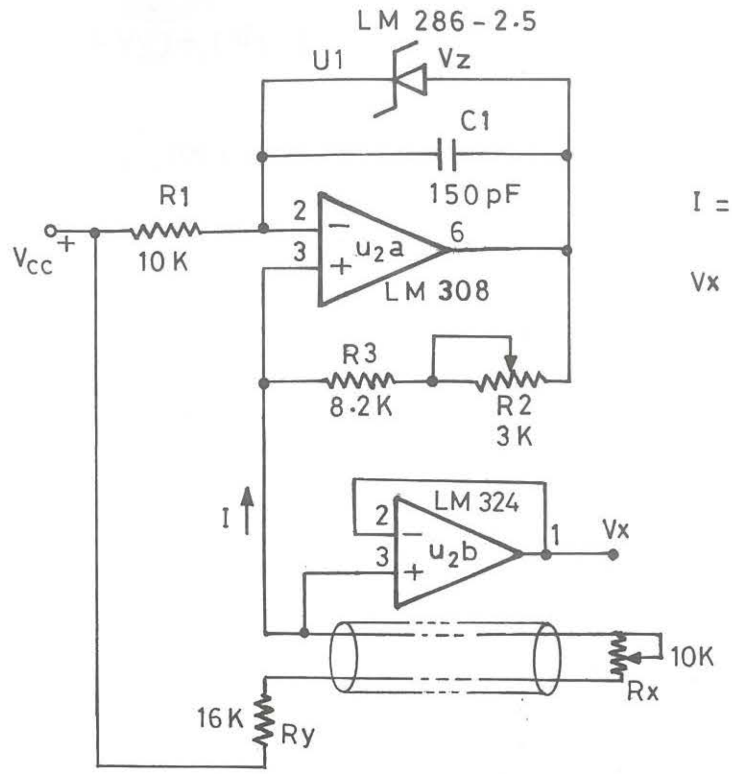
Ry = Fixed resistance.

Vz = Reference voltage of the regulating diode = 2.5 V

and Vcc = Potential diff. between Vcc+ and GND as established by ADC = + 2.84 V

4.4.2 Summing amplifier with low pass filter

The voltage follower is followed by a summing amplifier to make the reading of the display zero corresponding to 0^0 angular displacement. The inverting configuration with two inputs can be used as summing amplifier as shown in the Fig 4.5.



$$I = \frac{Vz}{R2 + R3}$$

$$Vx = 2.8 - (Rx + Ry)i$$

Fig. 4.4 Precision constant current source followed by buffer, Rx is the sensing potentiometer.

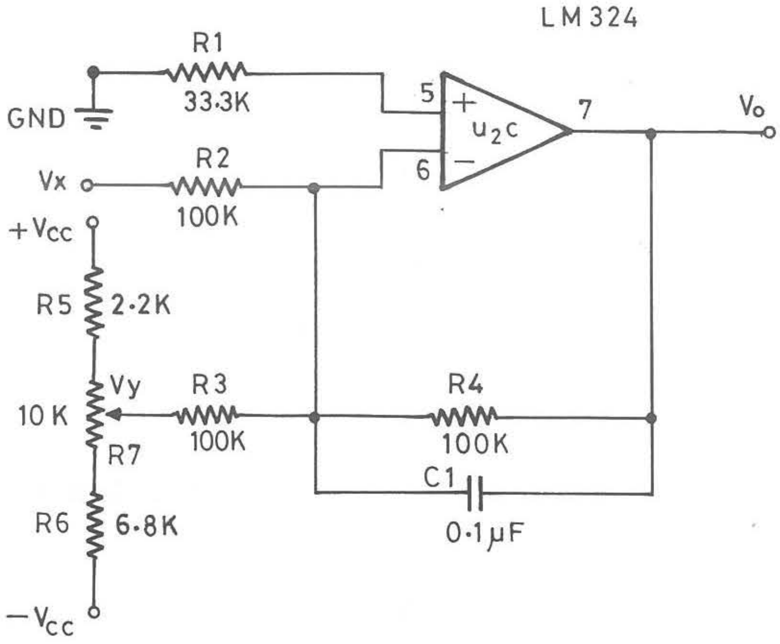


Fig. 4.5 Summing amplifier with low pass filter

$$Vo = -(Vx + Vy) = (Vz(Rx + Ry))/(R_2 + R_3) - Vcc - Vy$$

C_1 of 0.1 uF in parallel with R_4 (100 k ohms) provides with a low pass filtering with a cutoff frequency of 16 Hz.

4.5 Digital section

The Intersil 7106, $3^1/_2$ digit LCD single-chip A/D converter has been used to display angle moved directly into degrees corresponding to input signal level. The ICL 7106 is a low power $3^1/_2$ digit A/D converter containing all the necessary active devices on a single CMOS IC, including seven segment decoders, display drivers, a reference, and a clock [2]. The other feature of this IC is that the analogue common pin sets the common mode voltage where the input signals are floating with respect to the power supply. The "common" pin sets a voltage 2.84 V below the positive supply. The same pin has been exploited as a ground in signal conditioning circuit in order to obtain split power supply operation. The external component values for 7106 were chosen for 2 volt full scale division which gives maximum counts of 1999 corresponding to 2 volt. The circuit diagram of the digital section is shown in Fig. 4.6.

The middle point of the potentiometer has been adjusted corresponding to 0^0 such that maximum of 120^0 of angle can be measured in both the directions including total angular range of 240^0 . The whole mechanical range of the potentiometer i. e. 300^0 could not be utilised due to the non-linearity of the potentiometer at the extreme ends. The offset adjustment has been also provided in the circuitry for calibration purpose which shifts centre point left or right for zero reading of the display.

4.6 Provision for two channel recording

The provision has been incorporated in the design to record signal from two knee joints simultaneously on the same time axis. For this purpose, two similar PCBs were designed for signal conditioning circuit. The analog signal obtained from both the channels were given to the common digital display. As the same display is shared by both the channels, switching provision has been incorporated for selecting the particular channel and subsequent display of angular movement.

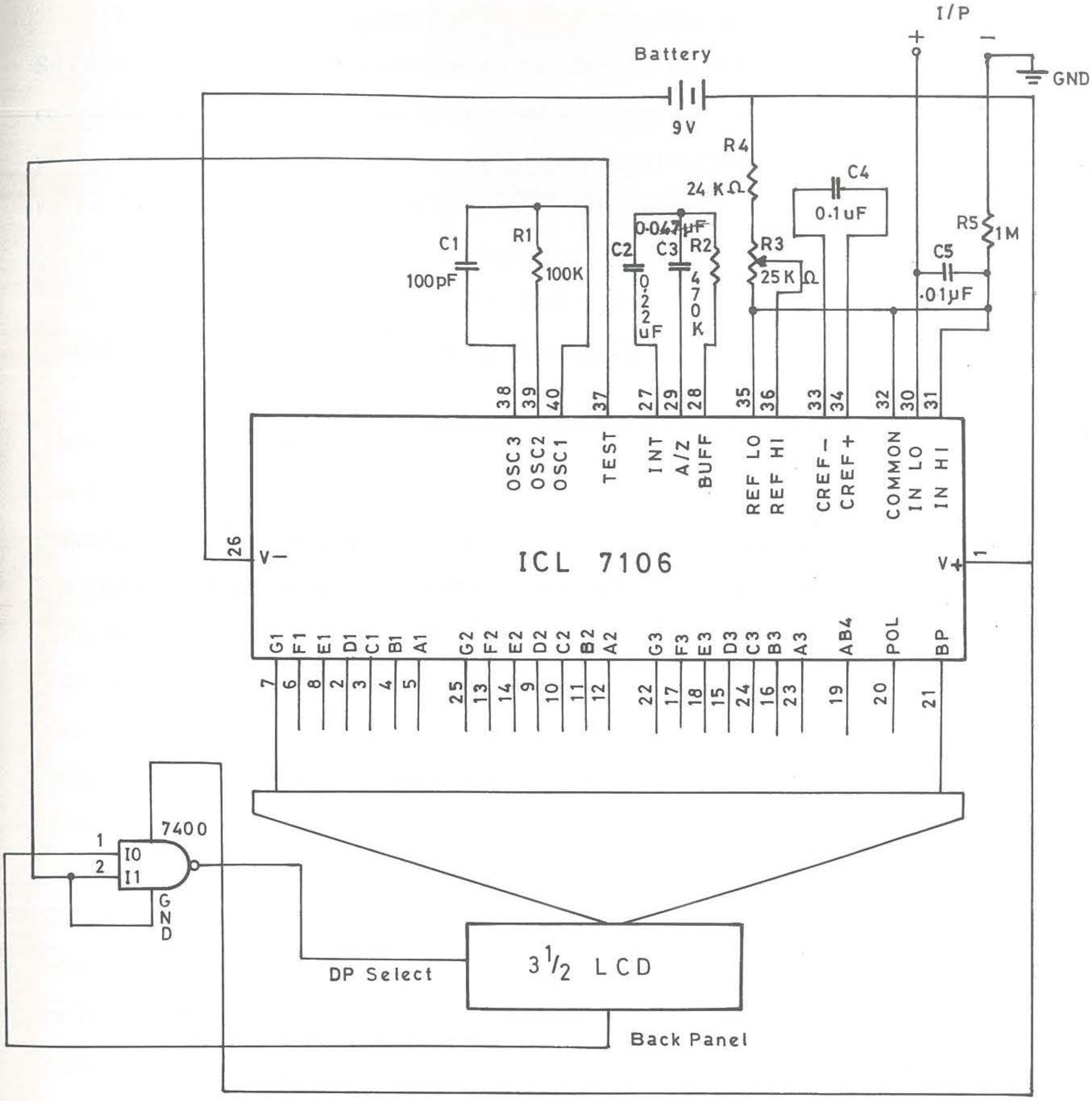


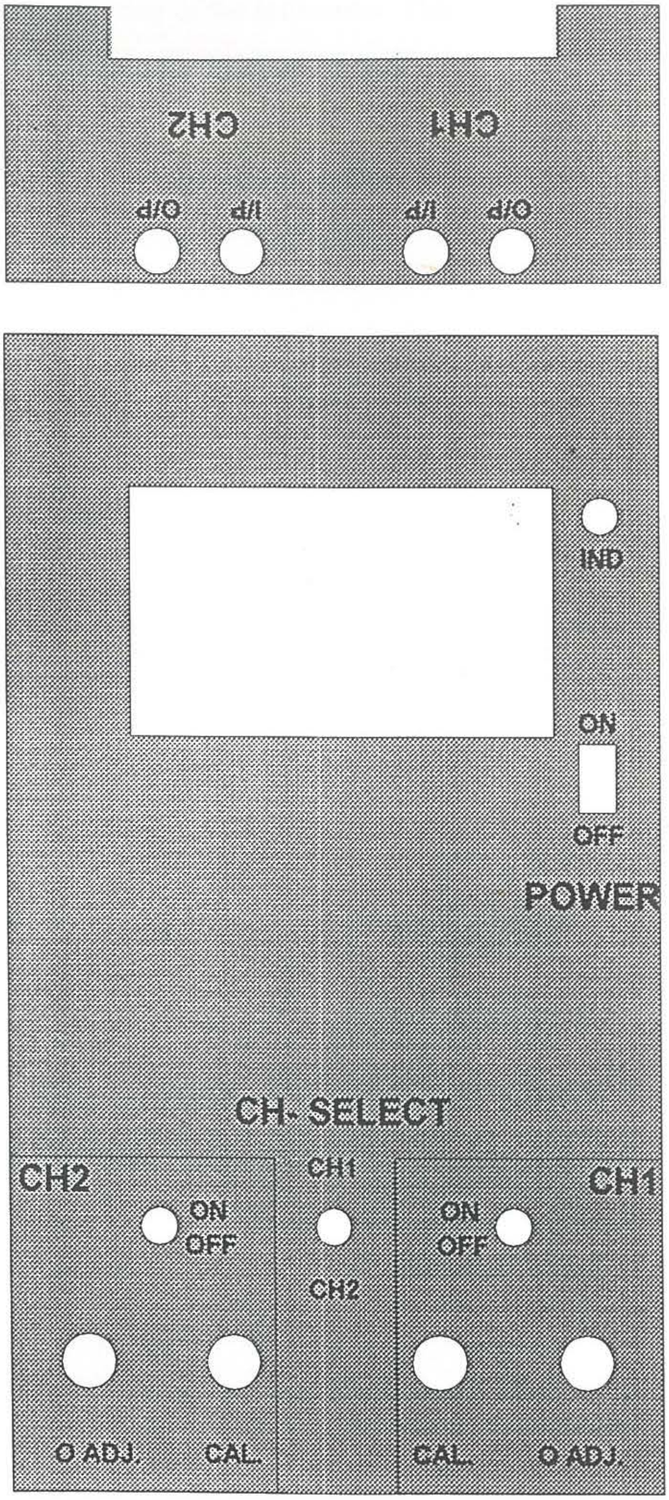
Fig. 4·6 Circuit diagram of digital section of electrogoniometer.

4.7 Control panel organisation

The signal conditioning and digital circuits were implemented on the designed PCB's. Subsequently it was decided to package all the fabricated circuits into a single unit to give a completed prototype. Attempt was made to make an ergonomic and user interactive hand held product. Control panel organisation (CPO) for the hand held instrument was first carried out in a card board. After appropriate modifications , the CPO design was implemented on the styrene sheet of thickness 3 mm. The material was chosen on the basis of lightness, low cost, and ease in working. The box was fabricated using heat treatment for bending , cutting, and gluing. The control panel organisation (in real scale) is shown in Fig. 4.7.

The dimensions of the box have been determined to accommodate all the circuits in a minimum space. The fabricated box has a length of 16 cm., breadth 9 cm. , and height 4 cm. It was decided to put all the switches and knobs in a front panel of the instrument. Hence toggle switches, and small knobs have been used to save space in a front panel, and for easy operation. The $3^1/_2$ digit LCD display was also positioned at the top of the front panel for better readability of the angular movement. The power on/off switch position was also determined at the front panel in order to minimise the time required for searching the switch. In this CPO design, it has been assumed that the subject under study, mounted with sensor in its mechanical assembly always walks in front of the operator during gait analysis. Hence, it is always better to fix the position of the connector facing the subject under study in order to avoid the unnecessary interference, and twisting of the wire. Therefore, the positions of the connectors for inputting shielded wire from the remote sensor to the electronic system, and for outputting the analog signal have been determined at the front elevation of the panel. For this purpose, four connectors have been used for both the channels. The grooves provided at the side of the box is another feature of the ergonomic product. This has been provided for good grip for hand held instrument. An autolock battery compartment has been also incorporated in the design at the back panel to accommodate a single 9 V battery required for its operation. The colour of the product has been chosen light grey in colour scale with mat finishing. All the lettering was done with black transfer letters' in light grey background for better visual effect.

The designed and fabricated control panel needs certain modifications. In any electronic product design, the size of the product should be determined before PCB design to accommodate all the circuits in the limited space. In this project, as the panel was designed and fabricated after the development of the instrumentation, the housing box could not be reduced to a size small



Front elevation view

Top view

Fig. 4.7 Control panel organization of the instrument in real scale.

enough for comfortable hand held operation by most users. Another problem in this design is related with the mounting of control knobs and switches. All the control knobs and switches are mounted on the control panel itself which has increased the length of the internal wiring, and may cause inconvenience during servicing of the instrument. This problem can be solved by mounting the control knobs and switches on the PCB board itself.

Chapter 5

Testing and Recording

This chapter concerns with the calibration and testing of the instrument. The instrument developed was calibrated to measure the exact movement of the joint in degrees. Then the calibrated electrogoniometer was attached to a normal subject , and recording was obtained while the subject walked, sat and rose on the chair, cycled (on an exercise bicycle), and lightly jogged. The signal was recorded by using a plotter, and a battery operated portable data logger unit. Finally, the spectrographic studies of the recordings were carried out.

5.1 Calibration of the instrument

The developed electrogoniometer was calibrated before recording using the zero adjustment and calibration knob mounted on the front panel of the instrument. The calibration knob is fixed to its position once set for the same set of experiments. The zero adjustment knob can be rotated in the left or the right direction for the adjustment of the angle corresponding to $0°$ angular displacement.

For calibration, first the tibial shaft and femoral shafts are aligned in the same straight line by rotating its arm to $360°$ and $0°$ of the protractor scale respectively. Keeping femoral shaft fixed to 0^0 position, rotate the tibial shaft to right of the $360°$ scale. Let the new position of the tibial shaft indicated by the pointer be A^0, and C^0 be the corresponding reading on the display. Bring back the tibial shaft to its original position, and again rotate the tibial shaft to opposite direction, i. e., left of the $360°$ scale still keeping the femoral shaft in its fixed position. Let the new position of the tibial shaft indicated by the pointer be $B°$, and D^0 be the corresponding reading on the display at this position . Adjust the current level by rotating the calibration knob in the control panel such that the difference A^0 - B^0, and C^0 - D^0 becomes equal. The difference of the two readings, i. e., $A°$- $B°$ gives the range of the angular movement. Then bring back the tibial shaft to its original position, i. e., the pointer indicating 360° on the protractor scale. Adjust the reading of the display to 0° corresponding to zero degree angular movement. The maximum value of A° and B° that can be attended is in the range of +120° to -120° corresponding to central position of the tibial shaft.

After calibration, the tibial shaft was rotated in both the directions corresponding to central 360^0 position and the angular readings on the dial indicated by the pointer and LCD display was measured at an interval of 10^0. The analog voltage at the output port of the instrument was also measured using digital multimeter corresponding to each angular reading. Table 5.1 shows observed readings. The plot of dial angular readings Vs the angular readings indicated by the LCD on the control panel showed linearity within a range of $+120^0$ to -120^0 as shown in Fig. 5.1. The readings indicated by the LCD display and the analog voltage available at the outport port matched perfectly and showed perfect linearity.

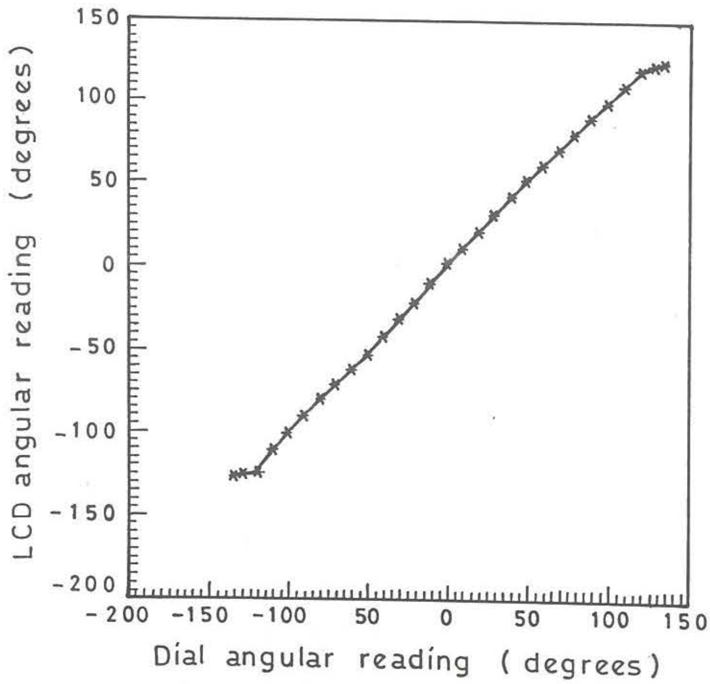


Fig. 5·1 Calibration curve of the electrogoniometer.

Table 5.1

Table showing Dial and LCD angular readings in degrees, and analog signal level in volts at different angular positions.

Dial angular reading (degrees)	Digital multimeter reading (volts)	LCD angular reading (degrees)
0	.009	00.9
10	.094	9.6
20	.193	19.3
30	.301	30.3
40	.406	40.7
50	.503	50.3
60	.597	59.8
70	.690	69
80	.789	79
90	.889	89
100	.983	98.3
110	1.078	107.5
120	1.178	118
130	1.219	121.9
135	1.221	122.1

Contd..

Dial angular reading (degrees)	Digital multimeter reading (volts)	LCD angular reading (degrees)
0	.009	00.9
-10	.106	-10.6
-20	.218	-21.9
-30	.318	-31.8
-40	.421	-42.2
-50	.538	-53.8
-60	.638	-63.8
-70	.724	-72.5
-80	.812	-81.2
-90	.916	-91.6
-100	1.011	-101.2
-110	1.11	-111.2
-120	1.256	-125.6
-130	1.266	-1261.69
-135	1.269	-126.91

5.2 Recording of the signal by using a plotter

The electrogoniometer has been tested by recording the waveforms of the normal knee that are descriptive of each knee motion in the sagittal plane and compared with the type of activities such as walking, sitting and standing, etc., based on known patterns of motion for those activities [6]. The recording has been done using a plotter to determine the type and the frequencies of activities. The print out of the finite segment of the waveform displayed on the oscilloscope was taken with the help of the a plotter interfaced to the digital storage oscilloscope. Different patterns have been observed for different kind of activities as shown in Fig. 5.2, 5.3, and 5.4. The frequencies observed for different activities were approximately 0.58 Hz, 0.25 Hz

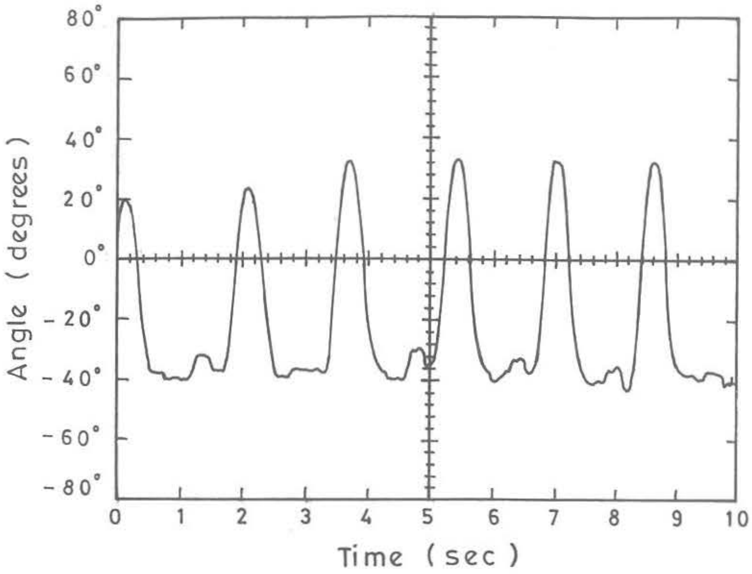


Fig. 5·2 Flexion waveforms for walking for the normal knee, recorded using a DSO and plotter.

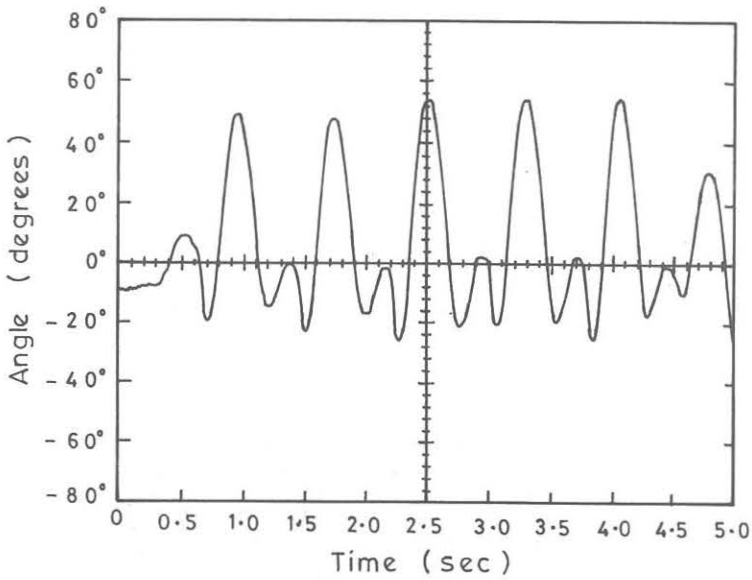


Fig. 5·3 Flexion waveforms for jogging for the normal knee, recorded using a DSO and plotter.

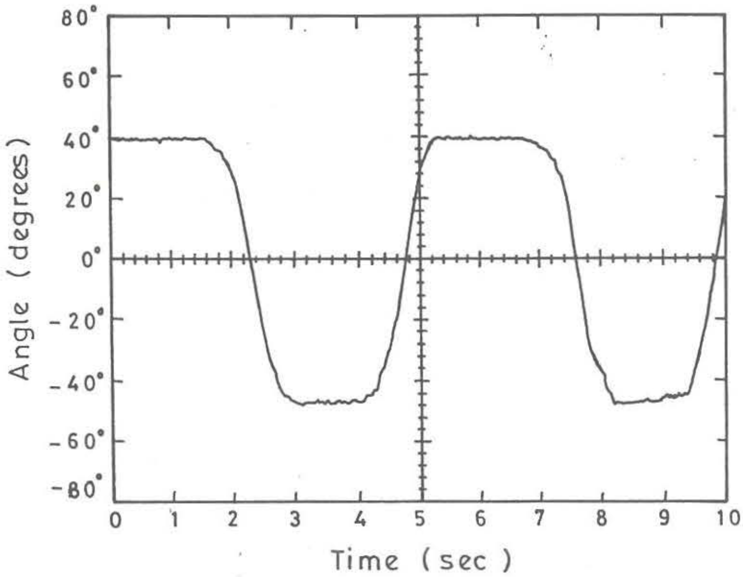


Fig. 5-4 Flexion waveforms for sitting and rising for the normal knee, recorded using a DSO and plotter.

and 1.3 Hz corresponding to walking, sitting and standing on a chair, and jogging. Same type of patterns were observed for walking and jogging except the change in frequency. By observing change in the pattern of the waveforms compared to the normal flexon waveforms at a particular instance of swing or stance phase of the gait cycle, valuable information regarding prognosis and diagnosis of the diseases related with the knee joint can be obtained.

5.3 Recording of the signal using a data logger

The knee joint angle signal was also recorded using a battery operated data logger " Mighty - Micro Site " (from Dynalog Microsite, Bombay). This is a hand held data logger with 8 input analog channels, and can be interfaced to a PC through serial port for data transfer / programming. To record the goniometric signal, a sampling rate of 10 samples / sec was used and 1000-1100 samples were gathered for different activities such as walking, sitting and rising on the chair, jogging, and cycling. After logging the data, the data logger was interfaced with the PC. The stored data were offloded to the computer to plot the results. The plots for different activities are shown in Figs. 5.5, 5.6, 5.7. and 5.8. The plots showed compressed but same pattern of waveforms compared to the recordings obtained by using a plotter.

5.4 Spectrographic analysis

Spectrogram is an important tool for the analysis of signal in frequency domain. Spectrogram gives the visual representation of frequency Vs time. Time and frequency are represented by X-axis and Y- axes respectively, and the magnitude is represented by the intensity of the pixels. The spectrogram software used to analyse the goniometric signal has been written in C programming language. The software has been developed by Prasad and Ashok [8, 9, 10,]. The data retrieved from the data logger for different activities were presented for spectrographic analysis. The spectrograms for walking, jogging, sitting and rising on the chair, and cycling are shown in Fig. 5.9, 5.10, 5.11, and 5.12 respectively. Different spectrographic patterns were observed for different activities. All the frequency components within the range of d. c. to 5 Hz having different magnitude distributions for different activities were visualized on

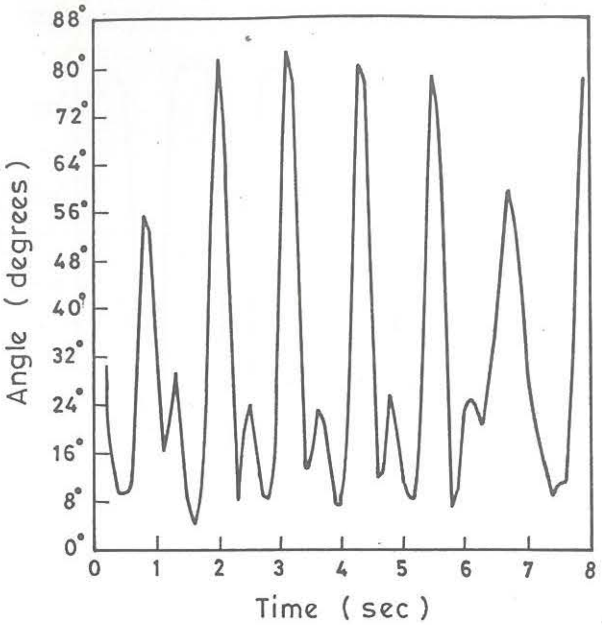


Fig. 5·5 Plot of the data logged by the dynalog microsite data logger for walking for the normal knee.

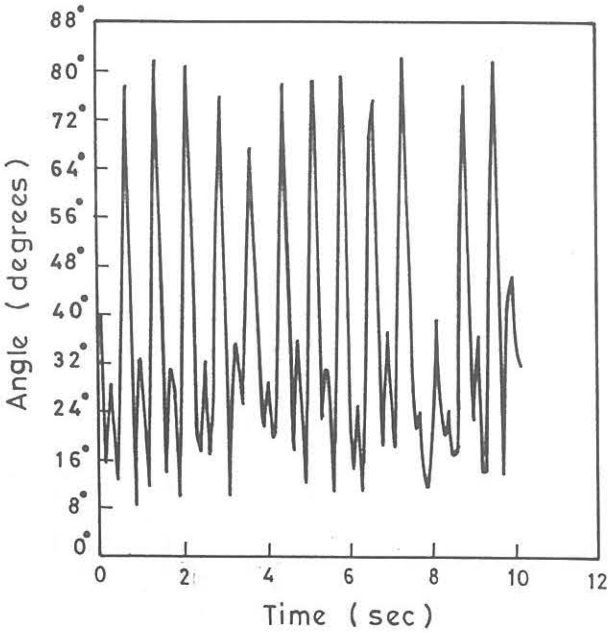


Fig. 5·6 Plot of the data logged by the dynalog microsite data logger for jogging for the normal knee.

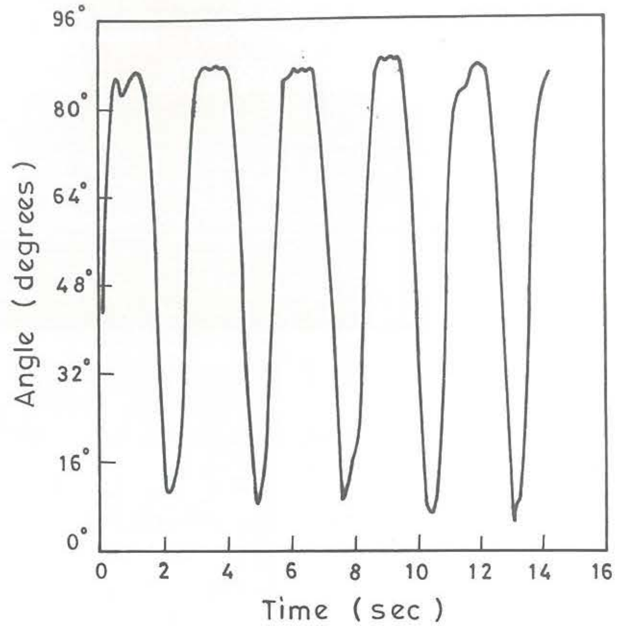


Fig. 5·7 Plot of the data logged by the dynalog microsite data logger for sitting and rising on the chair for the normal knee.

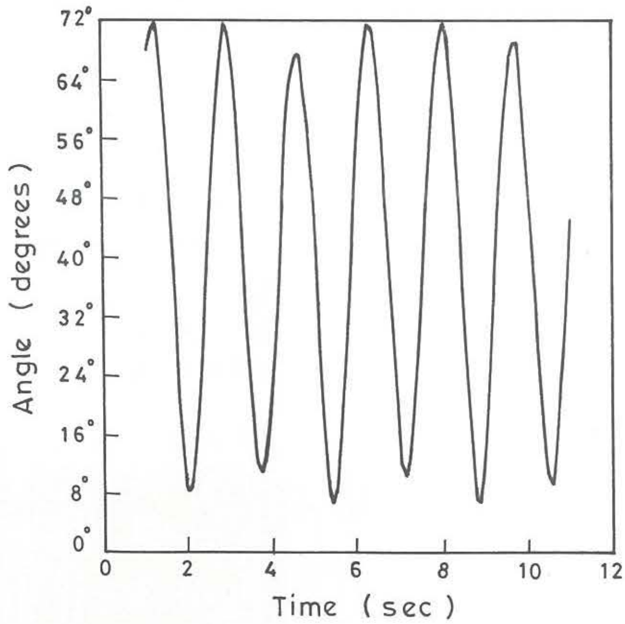


Fig. 5·8 Plot of the data logged by the dynalog microsite data logger for cycling for the normal knee.

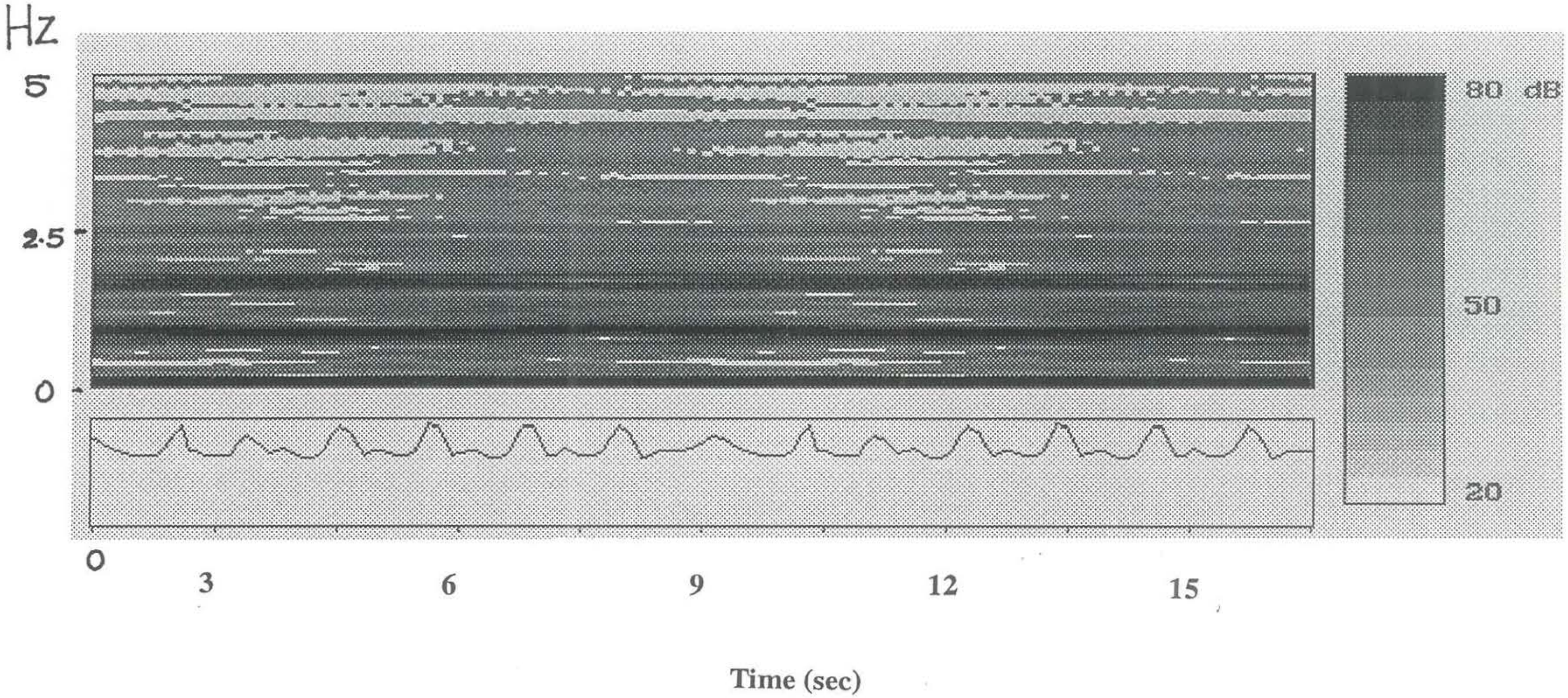


Fig.5.9 Spectrogram of the data logged by the data logger for walking for the normal knee.

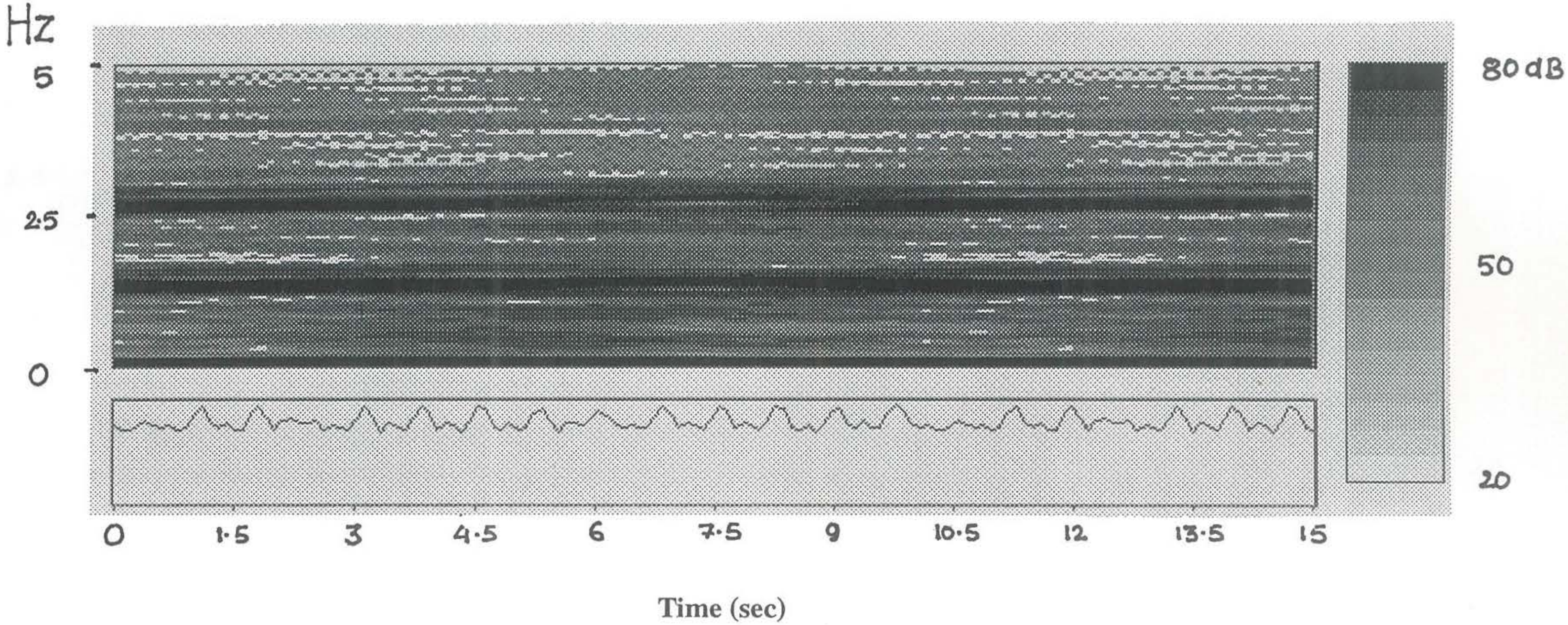


Fig.5.10 Spectrogram of the data logged by the data logger for jogging for the normal knee.

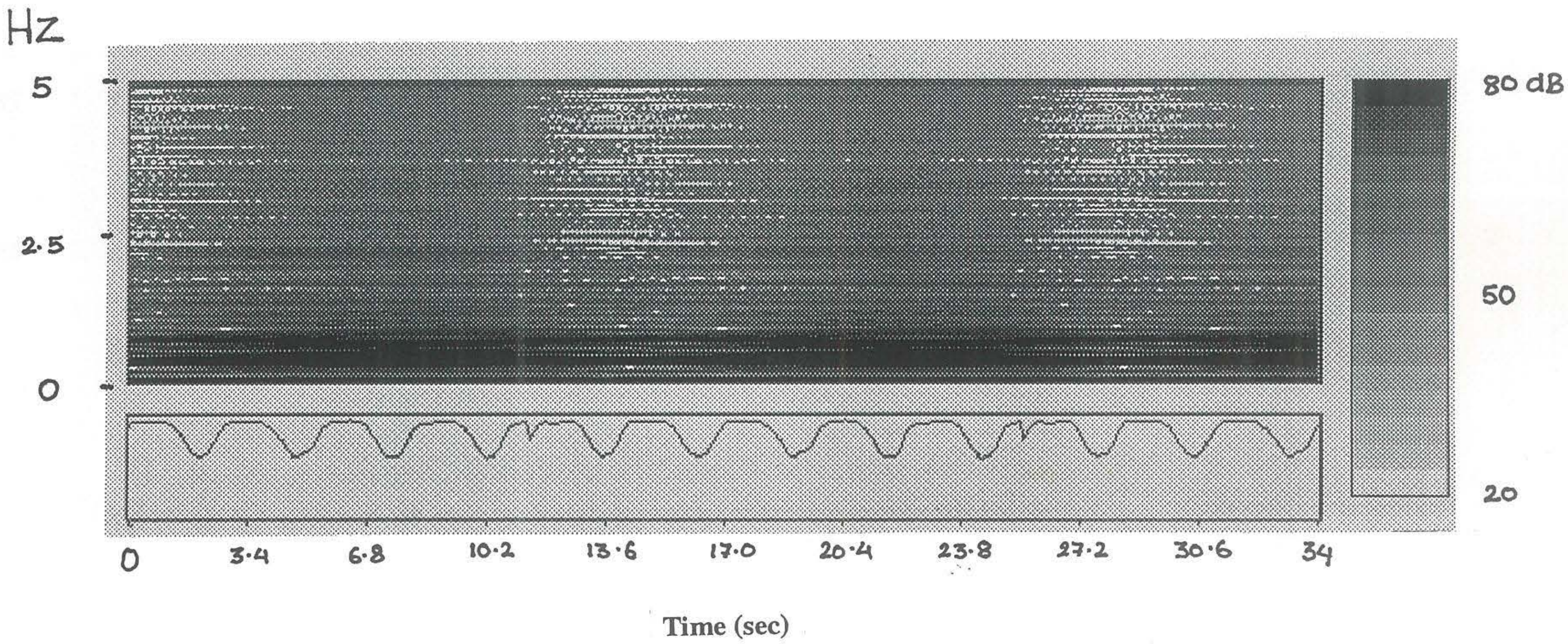


Fig.5.11 Spectrogram of the data logged by the data logger for sitting and rising on the chair for the normal knee.

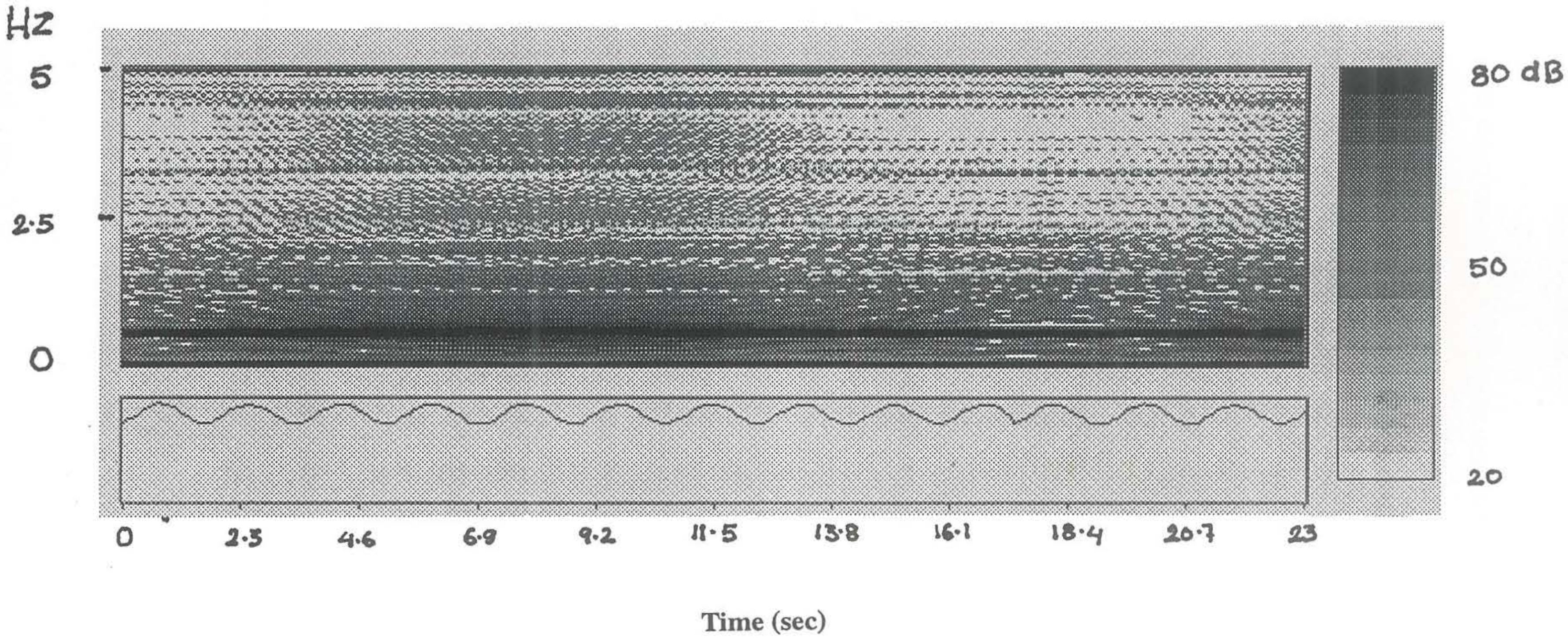


Fig.5.12 Spectrogram of the data logged by the data logger for cycling for the normal knee.

the spectrogram.

The change in the spectrographic patterns compared to the patterns obtained from the normal knee for different clinical conditions may be used as a useful parameter for the evaluation of many diseases related with the knee joint. Another parameter which can be extracted from the spectrographic study is analysis of frequency distributions at a particular point of the spectrogram for different clinical conditions. The different frequency distribution patterns for different clinical conditions may be exploited for the prognosis, and diagnosis of knee diseases.

5.5 Gait analysis of normal and pathological subjects with reference to knee joint angle

In this subsection, an attempt has been made to study the angular variation particularly at the two peak points i. e., peak flexon and extension points during gait cycle. In order to know the angular variation at a particular instance of the gait cycle, the total gait cycle has to be divided into different phases. For the same purpose, atleast four foot switches have to be mounted below the heel, 1 st metatarsal head, 5 th metatarsal head, and large toe region. With the help of the pressure transducer signals obtained from different regions, the total gait cycle can be divided into different events. The goniometric signal , and the pressure transducer signals recorded as a reference signal along the same time axis gives the angular variation at a paticular phase of the gait cycle. In this study, the angular variation is studied only at two peak points of the gait cycle as these points are easily detectable in the recorded waveforms. Hence the mounting of the pressure transducer is not required for this experimental set up. The peak flexon and extension angular variations are considered for the evaluation of normal and pathological subjects. From these two extreme angular values obtained, the total range of motion (ROM) for normal as well as pathological subjects were also calculated.

5.5.1 Experimental protocal

For the present study, Five normal subjects (Male students within the institute campus, mean age 22 yrs., mean height 165 cm, mean weight 62 kg.) without having any knee joint diseases, bone problems, and dyfunctioning of leg muscles were selected for the study. Only one male subject (height 1522.2 cm, weight 55.2 kg, age 48 yrs.) having abnormal gait pattern due to paralytic left leg muscle was selected due to nonavailability of the other subjects having similar problem within the campus.

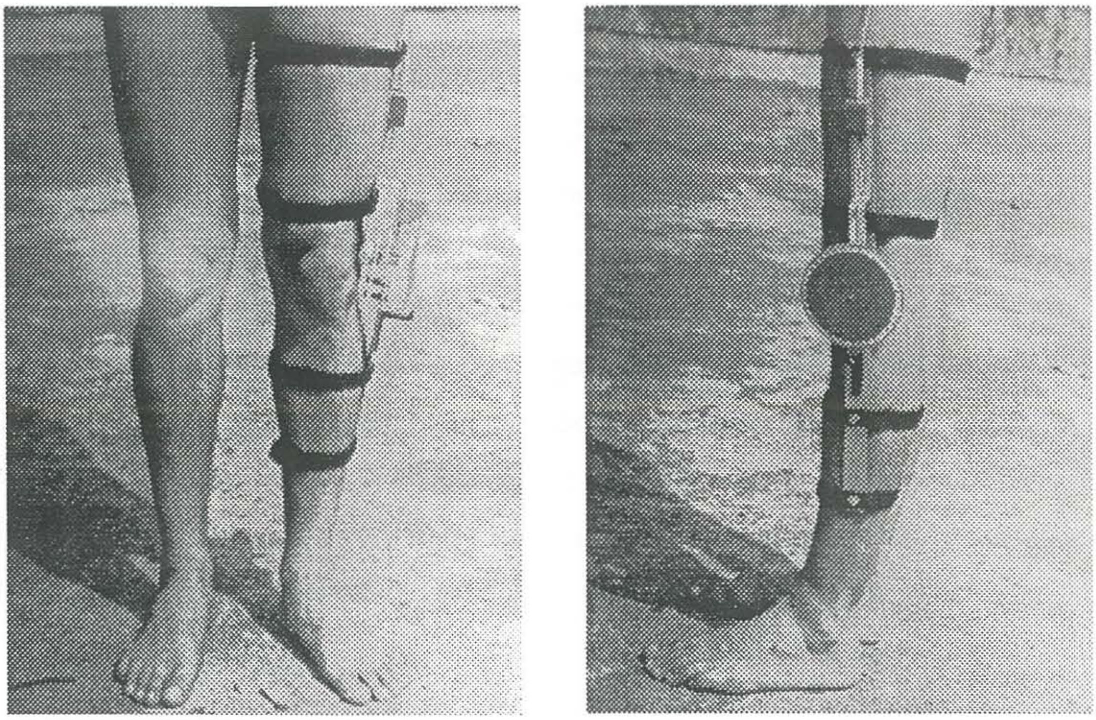


Fig. 5.13 Front and side view of the developed electrogoniometer worn by the subject during gait analysis.

The subjects were trained to walk synchronously with the timing of the Metronome (Timer) and sufficient time was given to adopt with the experimental set up in order to avoid artificiality in walking style. The waveforms were recorded for constant walking speed for each subject maintained by the timing of the metronome. The waveforms were recorded by using a portable data logger (Dynalog Microsite) for 1-2 minuates setting sampling rate to 10 samples/ sec. After gathering data, ten highest and ten lowest data points corresponding to peak flexon and peak extension were detected and their mean and standard deviations were calculated for each subject. The reference point was kept at 16^0 for each subject before starting the experiment except for the right leg of the pathological subject which was fixed at 32^0 . The maximum and minimum angular excursion corresponding to reference point were obtained by subtracting peaak angles from reference angle fixed before data gathering.

5.5.2 Results and discussion

The mean peak flexion and extension angles for ten data points for each subjects are given in Table 5.2 and 5.3. Table 5.4 shows mean range of motion attained by the normal and pathological subjects in degrees. The result showed less intrasubject angular variation for the normal subjects but significant intersubject angular variation was observed at two peak points of the recorded waveforms. The peak knee flexon attained 29.99^0 - 37.91^0 excursion in angular movement for normal subjects. Similarly , the peak extension attained a range of (-0.55^o) - (-7.37^0) in angular movement below reference point for normal knee. The negative sign shows the hyperextension of the leg when the knee joint attains a angular value below reference. The large standard deviations were observed for both the peak mean angular values. The intersubject peak flexon and extension angular variation may be due to change in walking speed of the subject during gait analysis. From the peak flexon and extension obtained in degrees, the total range of motion of the knee joint was also calculated for each subject. The range of motion observed was within a range of 32.04^0 - 40.71^0 with the intersubject variation of 8.67^0 for the normal subjects.

On analyzing the data obtained from pathological subject. The left leg (paralytic leg) showed mean peak extension of $+2.08^0$ from reference point. The result showed that there is no hypertension of the left leg during walking as the angular value attained is above the reference point. The paralytic left leg showed decreased peak extension compared to normal knee by 6.07^0. The peak flexon attained was 24^0 for the same leg. The calculation of mean range of motion (ROM) of the left leg showed decreased freedom of angular movement compared to the mean angular freedom of the normal knee joint by 5.07^0

The angular variation of the right leg of the pathological subject was also studied. The peak flexon attained was found only 8.40^0. The result showed large decrease in peak flexon compared to normal subjects. In contrast, the right leg showed large increase in peak extension i. e., -23.58^0 below reference compared to normal subjects. It was observed that the decreased range of motion during peak flexon was compensated by the increased range of motion during peak extension but the total range of motion remained almost same as compared to the normal knee. It was also observed that deformaties present on the left leg also caused abnormal gait pattern of the right leg.

Table 5.2. Mean peak flexon of normal and pathological knee expressed in degrees calculated from ten highest data stored by a data logger.

No. of subjects	Mean peak knee flexon No. of data points taken (n = 10)	Mean ± SD
1 Normal	33.94 ± 0.22	
2 Normal	37.91 ±0.21	
3 Normal	28.28 ± 0.59	32.98 ± 2.57
4 Normal	29.99 ± 0.22	
5 Normal	34.80 ± 0.19	
6 Pathological (left leg)	24.00 ± 0.46	24.00 ± 0.46
Pathological (right leg)	8.40 ± 0.25	8.40 ± 0.25

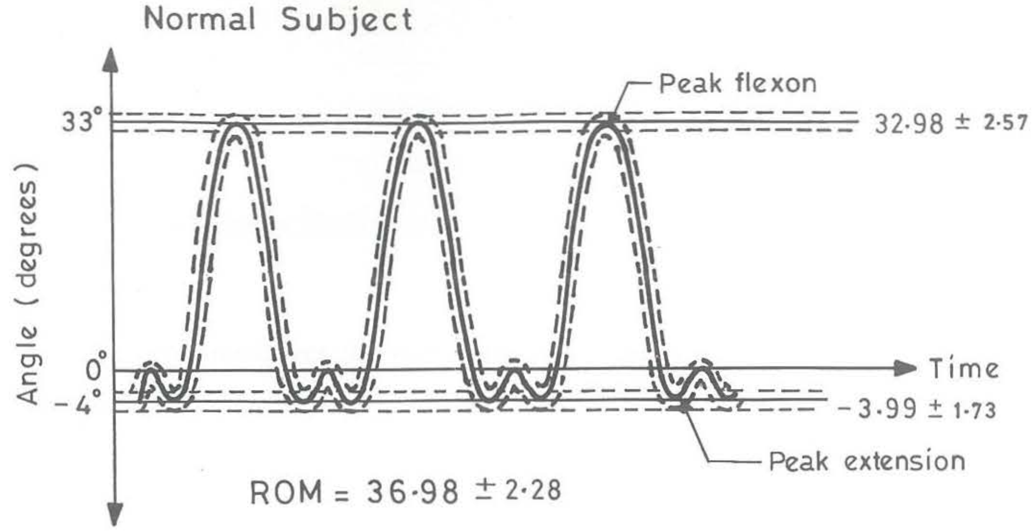
Table 5.3. Mean peak extension of normal and pathological knee in degrees calculated from ten lowest data stored by a data logger

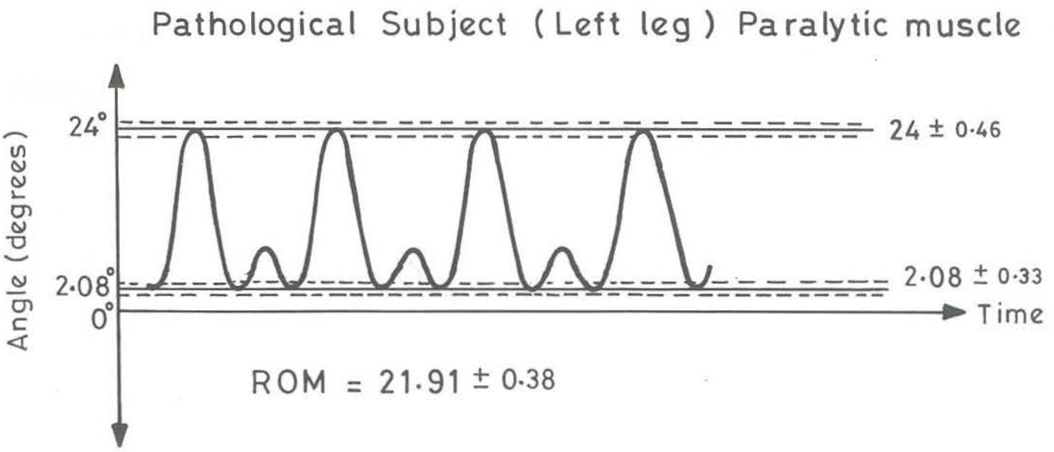
No. of subjects	Mean peak knee extension No of data points taken (n = 10)	Mean ± SD
1 Normal	- 5.51 ± 0.34	
2 Normal	- 2.80 ± 0.16	
3 Normal	- 3.75 ± 0.44	- 3.99 ± 1.73
4 Normal	- 7.37 ± 0.13	
5 Normal	- 0.55 ± 0.43	
6 Pathological (left leg)	+ 2.08 ± 0.30	+ 2.08 ± 0.30
Pathological (right leg)	-23.58 ± 0.45	-23.58 ± 0.45

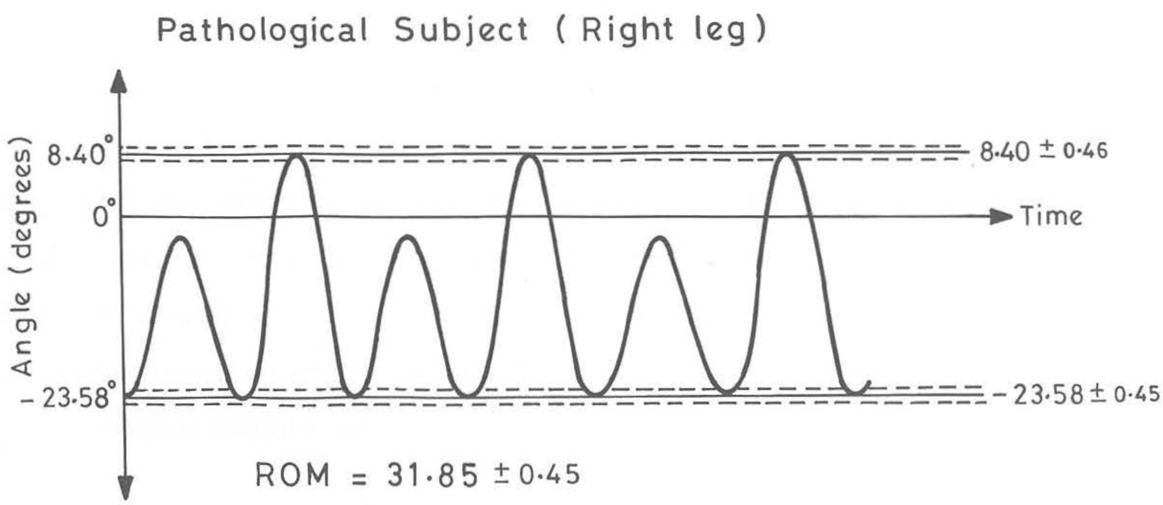
Table 5.4. Mean range of motion (ROM) expressed in degrees of the normal and pathological knee calculated from mean peak flexon and extension.

No. of subjects	Mean range of motion (ROM) in degrees.	Mean ± SD
1 Normal	39.45 ± 0.26	
2 Normal	40.71 ± 0.23	
3 Normal	32.04 ± 0.80	36.98 ± 2.28
4 Normal	37.37 ± 0.22	
5 Normal	35.36 ± 0.53	
6 Pathological (left leg)	21.91 ± 0.38	21.91 ± 0.38
Pathological (right leg)	31.85 ± 0.45	31.85 ± 0.45

RESULTS


Normal Subject
Peak flexon
33°
32·98 ± 2·57
Angle (degrees)
0°
-4°
Time
-3·99 ± 1·73
Peak extension
ROM = 36·98 ± 2·28


Pathological Subject (Left leg) Paralytic muscle
24°
24 ± 0·46
Angle (degrees)
2·08°
0°
2·08 ± 0·33
Time
ROM = 21·91 ± 0·38


Pathological Subject (Right leg)
8·40°
8·40 ± 0·46
0°
Time
Angle (degrees)
- 23·58°
- 23·58 ± 0·45
ROM = 31·85 ± 0·45

Chapter 6

Summary and conclusions

This chapter summarizes the work done, problems faced, and suggestions for further improvements in brief.

The detailed design and fabrication of electrogoniometer has been carried out. Less repeatability response of the mechanical assembly, attachment problem, lack of selfadjustment,translational motion compensation, etc. have been observed in the electrogoniometer developed in the initial stage of this project. Hence the possible modifications in the mechanical assembly developed by Rina Maiti [4] has been carried out and the product was redesigned and fabricated. Now, the fabricated electrogoniometer has mechanical error of approx. 4^{0}. This error can be minimised by refabricating the electrogoniometer taking minute details into consideration.

The electronic design of electrogoniometric system has been carried out. The designed electronic circuitry was first tested on the bread board and required modification were carried out. The tested circuit was subsequently assembled on general purpose PCB. Finally, PCB was designed for digital as well as for signal conditioning circuit and the components were soldered on it. In order to record signal from both the knees along the same time axis, two channel system was made sharing the common display for both the channels.

Attempt has been made to make an ergonomic and user friendly hand held prototype. Control panel organisation (CPO) for the hand held instrument was first carried out in card board. After appropriate modifications in card board, the CPO design was implemented on styrene sheet. The circuitry assembled on the PCB was packed in the box with the appropriate control knobs, and switches.

The developed prototype was calibrated and tested. The instrument was used for recording the signal obtained for different activities such as walking, sitting and standing on a chair, and jogging for normal subject using a plotter. The instrument was interfaced with a battery operated portable data logger unit (Dynalog " micro Site ") and finally the spectrographic studies of the recordings for various activities were carried out.

In the design of control panel, all the control knobs are mounted on the control panel itself which has resulted in increased internal wiring length for permitting the opening and closing of the control panel. This problem can be solved by mounting the control knobs and switches in the PCB board itself. The control panel can be grooved to fit exactly all the knobs and switches appropriately so that it can be closed or opened without any interfere. In this design, the potentiometer is connected with the electronic system with the help of a long flexible shielded cable. The long cable provides interference and friction during gait analysis. This problem can be solved either by integrating the electrogoniometer circuit with the battery operated data logger, which can be worn by the subject during gait analysis or by developing telemetric system for transmitting and receiving goniometric signal.

The planar electrogoniometer is useful for the assessment of joint angle in only one plane. Since knee joint motion involves complex three dimensional motion on three different planes, the application of mono - planar electrogoniometer is limited. Hence the modification can be made in the existing electrogoniometer to measure joint motion in three different axes. The tri-axial electrogoniometer gives more information regarding joint function and deformity in pathological condition. Hence, the instrumentation portion can be modified for tri-axial measurement of joint angle.

References

[1] E. Y. S. Chao, "Justification of triaxial goniometer for the measurement of joint rotation", *J. Biomechanics,* vol. 13, pp. 989-1006, 1980.

[2] Intersil, Component Data Catalog, 1987.

[3] J. Isacon, L. Gransberg and E, Knutsson , "Three dimensional electrogoniometric gait recording", *J. Biomechanics,* vol. 19, pp. 627-635, 1986.

[4] R. Maiti, *Gait Analysis : Development of Electrogoniometer and Determination of EMG Activity with Special Reference to Knee Angle*, M. Tech. dissertation, School of Biomedical Engineering, IIT Bombay, 1994.

[5] P. R. E. Malcolm, G. R. Fulford, and A. O. Quanbery, "An electrogoniometer for the measurement of single plane movement", *J. Biomechanics,* vol. 9, pp. 423-424, 1976.

[6] P. C. Mcleod, D. B. Kettelkemp, V. Srinivasan, and O. L. Henderson, "Measurement of repetitive activities of the knees joint", *J. Biomechanics,* vol. 8, pp. 369-373, 1975.

[7] National Semiconductor Corporation, Linear Data Book, 1988.

[8] V.V.S.R. Prasad, *Speech Processing for Single Channel Sensory Aid*, M. Tech. dissertation, Dept. of Electrical Engg., IIT, Bombay, 1996

[9] T. G. Thomas et al, "A PC based spectrograph for speech and biomedical signals," *Proc. Intl. Conf. Recent Advances in Biomedical Engineering"*, Osmania Univ., Hydrabad, pp. 6-8, 1994.

[10] B. N. Ashok, *A Speech Training Aid for the Deaf*, M. Tech. proj. report, Electrical Engg. Dept., I. I. T., Bombay, 1996.

[11] J. A. Tata, A. O. Quanbury, T. G. Steinke, and R. E. Graheme, "A variable axis goniometer for the measurement of single plane movement", *J. Biomechanics.,* vol. 11, pp. 421-425, 1978.

[12] A. Trankoczy, and T. Bazd, "A simple electrogoniometric system and its testing", *IEEE Trans. on Biomedical Engineering, vol. 22, pp. 257 - 259, 1975.*

[13] J. G, Webster, *Encyclopedia of Medical Devices and Instrumentation,* vol. 3. pp. 1353-1365, and Vol. 4., pp. 2524-2529, New York, Willey interscience, 1988.

Appendix A

Diagram of Mechanical Assembly Components

The schematic diagram of whole assembly of the electrogoniometer including its cross sectional view details has been already mentioned in chapter three. In this appendix, the drawing details of each components will be included.

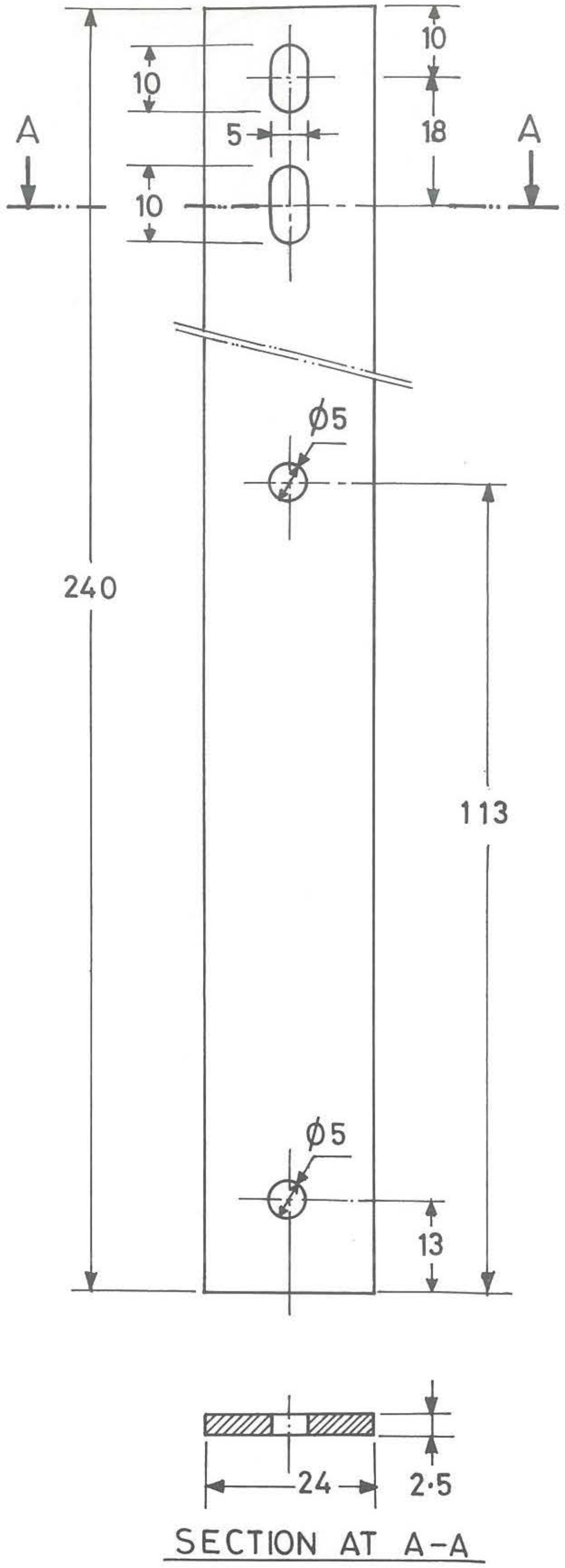


Fig. A.1 Tibial shaft

ELECTROGONIOMETER

Component :- Tibial shaft (1)

Scale	Material	All dimensions in mm
1 : 1	Aluminium	

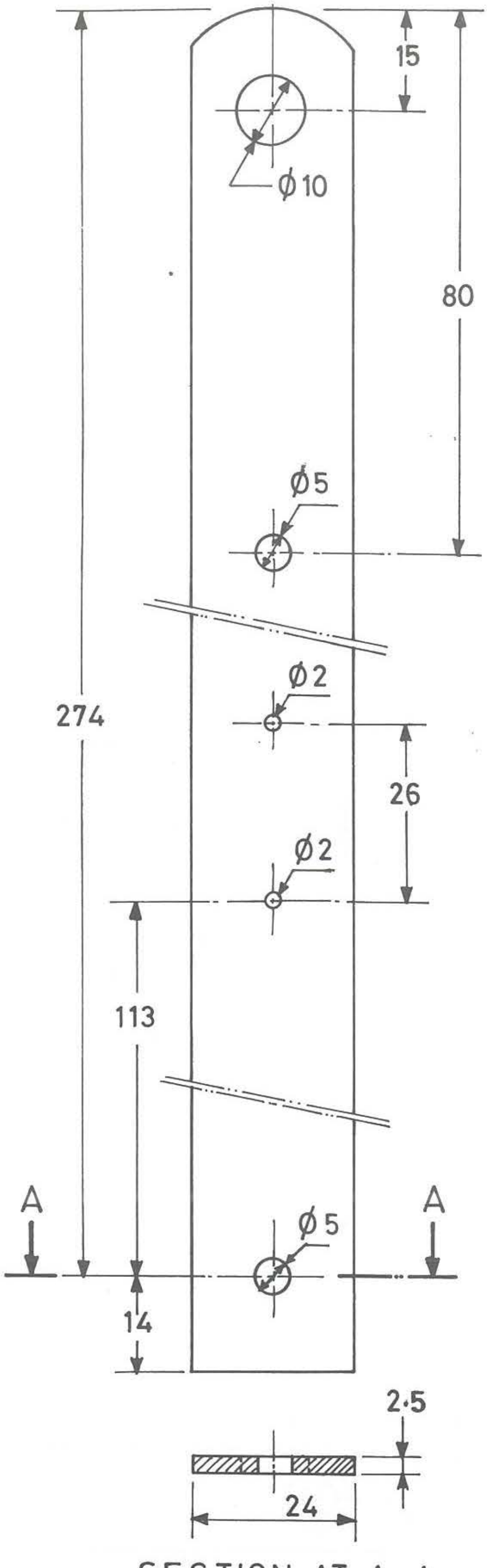
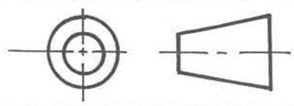
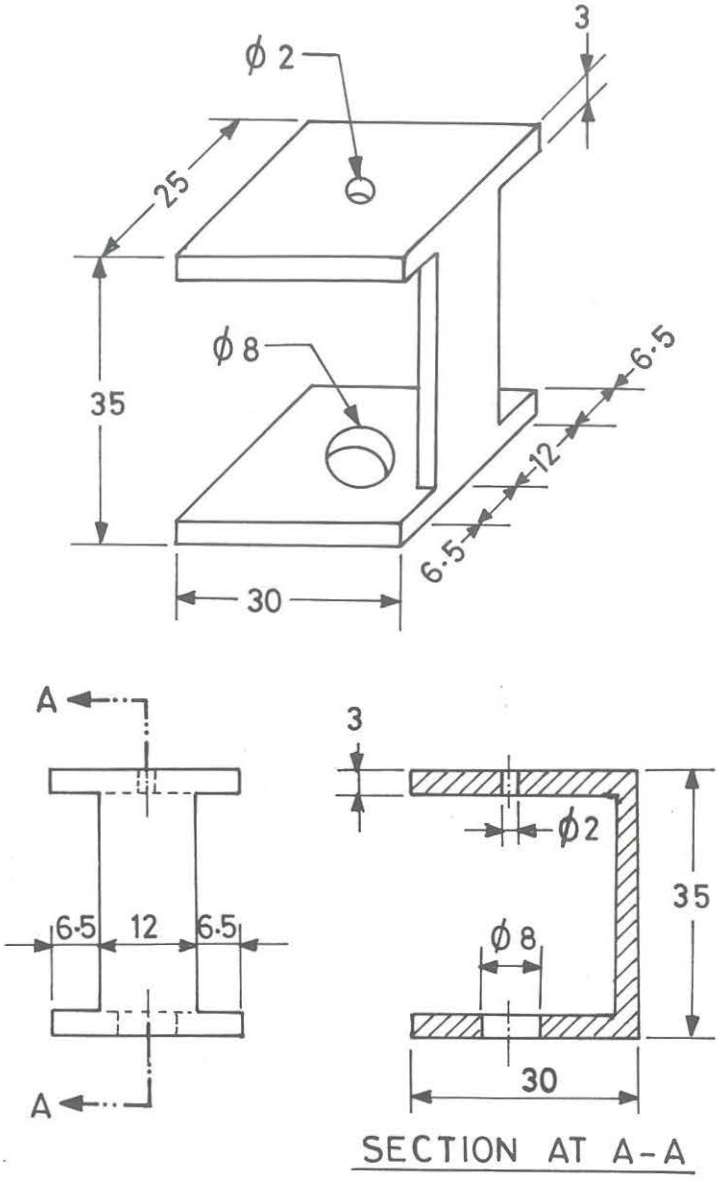


Fig. A.2 Femoral shaft

ELECTROGONIOMETER Component :- Femoral shaft (2)		
		
Scale	Material	All dimensions in mm
1 : 1	Aluminium	



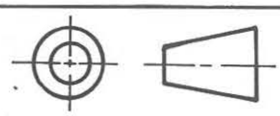
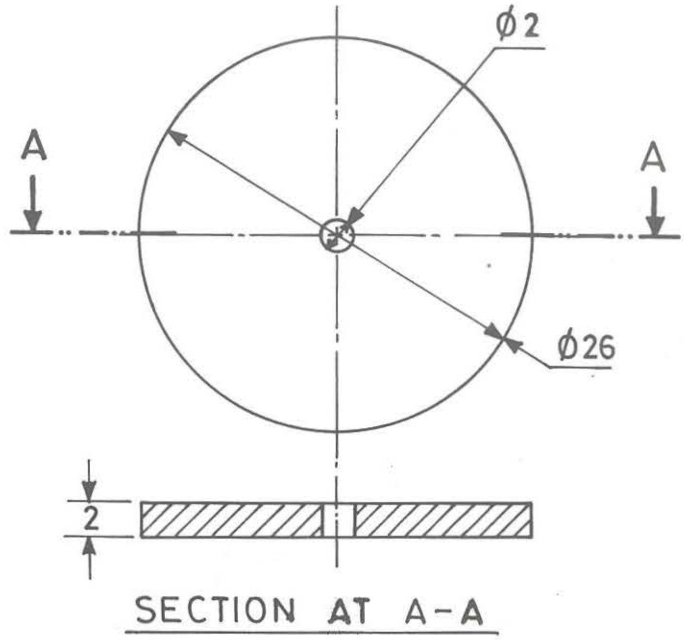
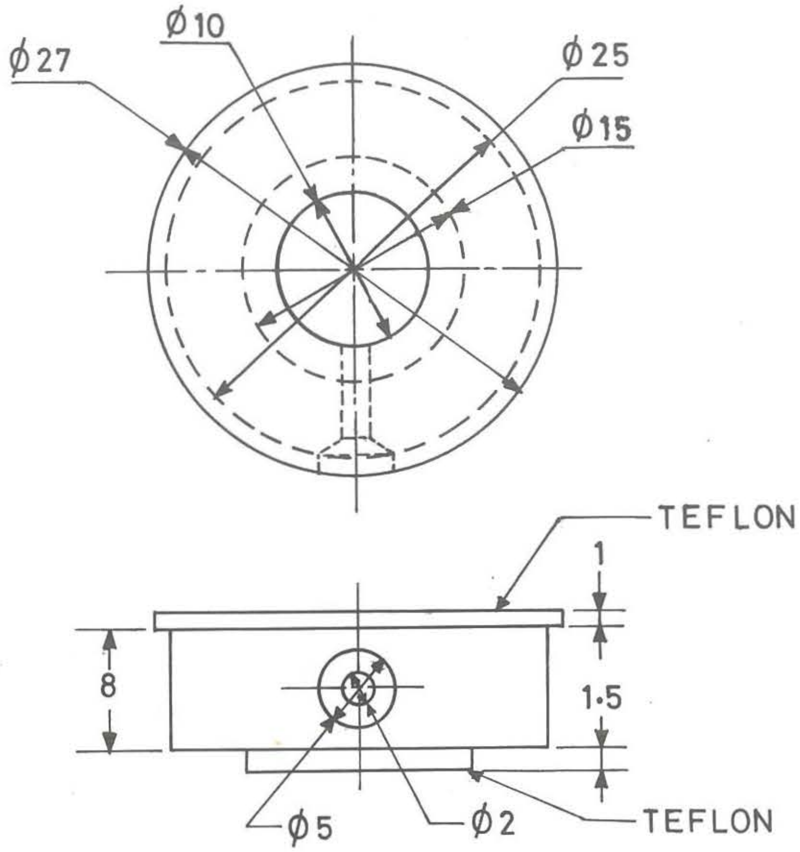
ELECTROGONIOMETER Component :- Protector stand (3)		
		
Scale	Material	All dimensions in mm
1 : 1	Acrylic	

Fig. A.3 Protractor stand



ELECTROGONIOMETER		
Component :- Washer (5)		
Scale	Material	All dimensions in mm
2 : 1	Styrine	

Fig. A.5 Washer



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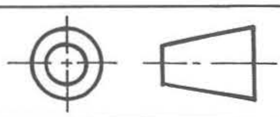
<tr><td colspan="3">ELECTROGONIOMETER
Component :- Fixed Ring (6)</td></tr>
<tr><td colspan="3"></td></tr>
<tr><td>Scale</td><td>Material</td><td rowspan="2">All dimensions in mm</td></tr>
<tr><td>2 : 1</td><td>Styrine</td></tr>
</table>

Fig. A.6 Fixed ring

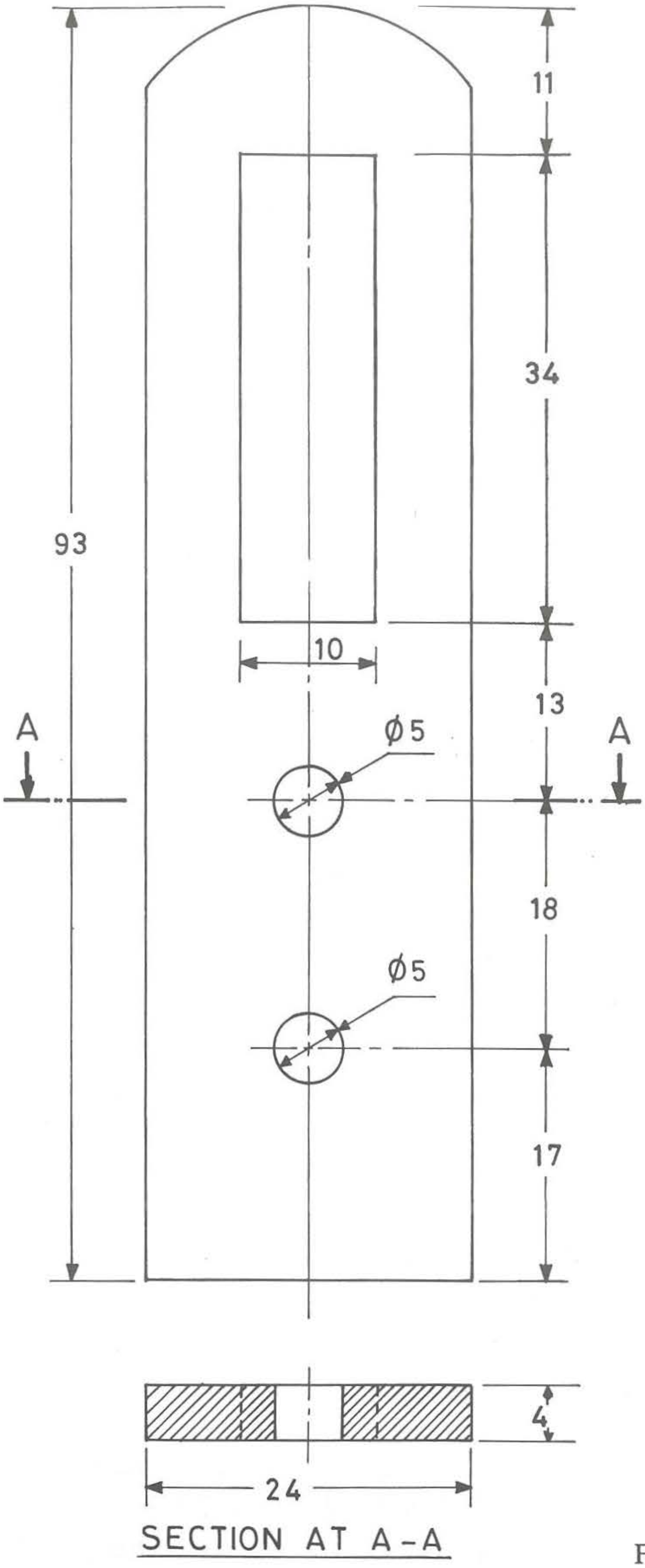
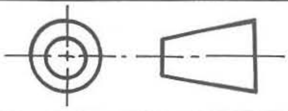
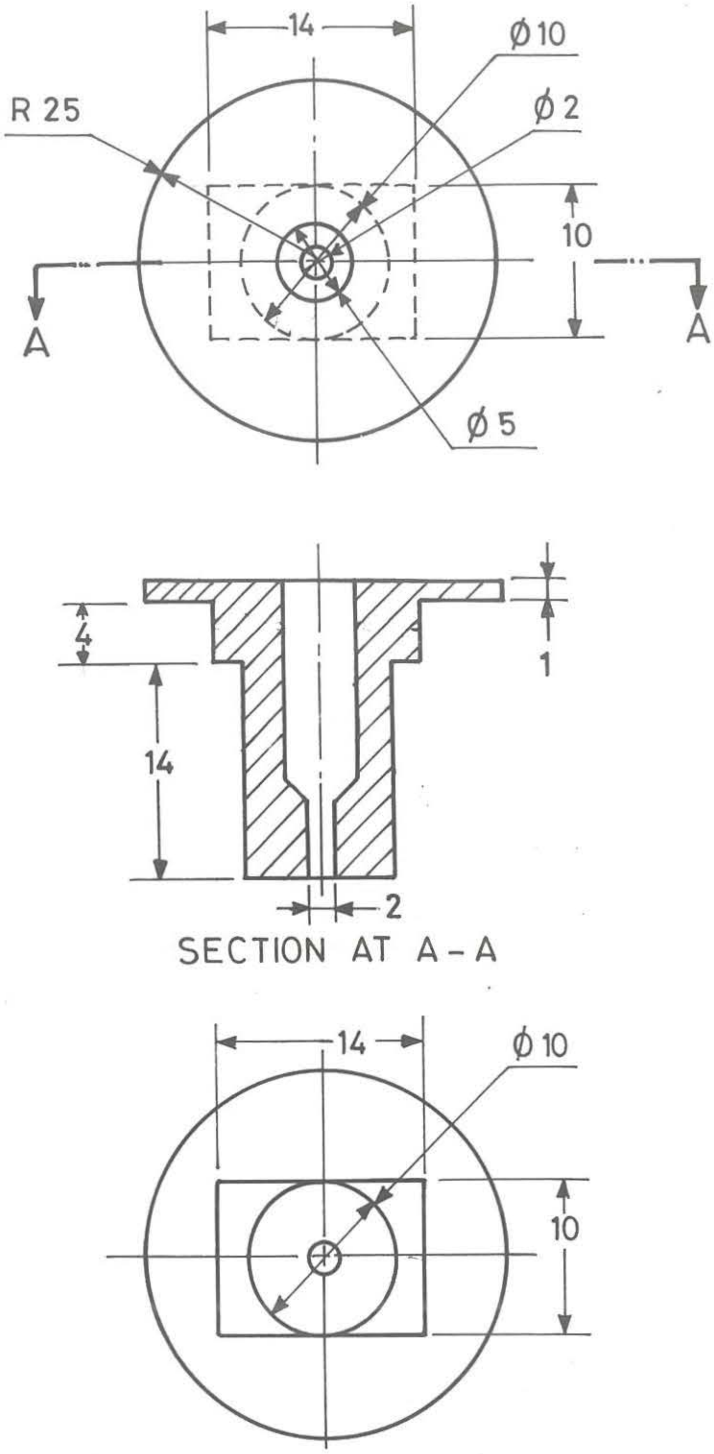


Fig. A.7 Sliding bar

ELECTROGONIOMETER Component :- Sliding bar (7)		
		
Scale	Material	All dimensions in mm
2 : 1	Styrine	

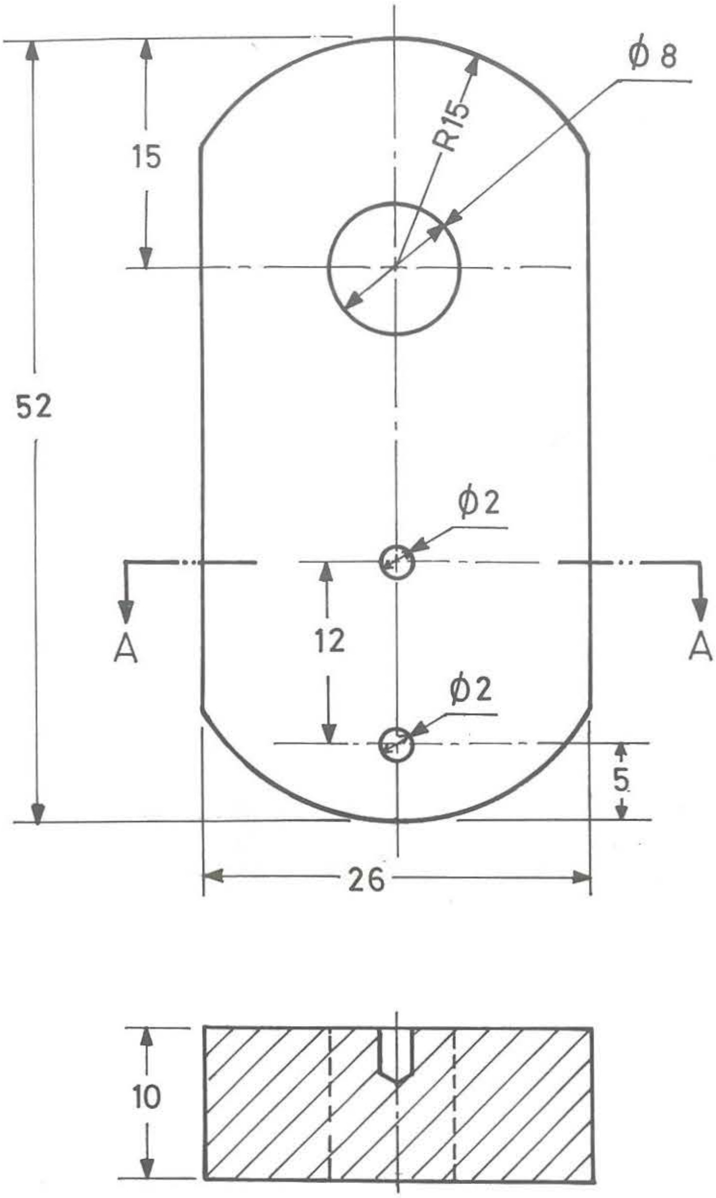


ELECTROGONIOMETER

Component :- Rotating Shaft Envelope (8)

Scale	Material	All dimensions in mm
2 : 1	P V C	

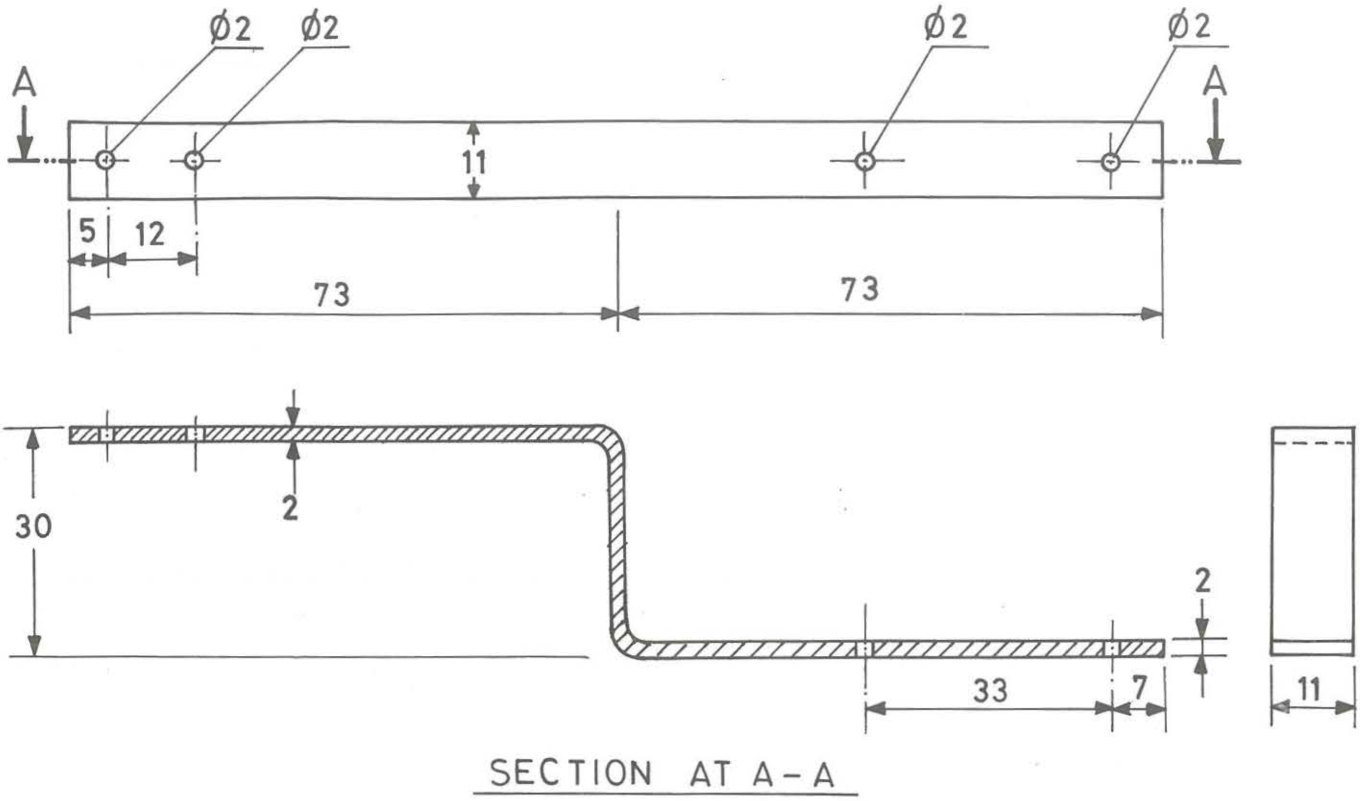
Fig. A.8 Rotating shaft envelope



SECTION AT A – A

ELECTROGONIOMETER Component :– Fixed Base (9)		
Scale	Material	All dimensions in mm
2 : 1	Styrine	

Fig. A.9 Fixed base



ELECTROGONIOMETER Component :- Fixed bar (10)		
Scale	Material	All dimensions in mm
1 : 1	Aluminium	

Fig. A.10 Fixed bar

Appendix B

PCB Layouts

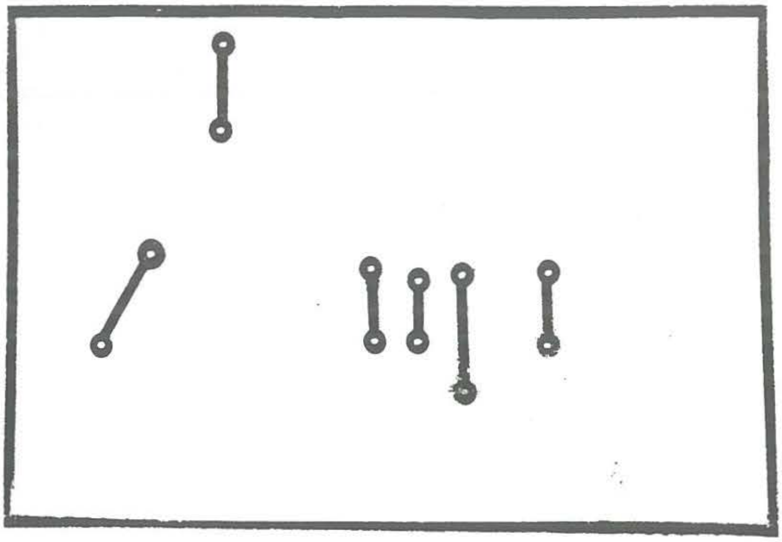


Fig. B.1 Component side of the signal conditioning circuit.

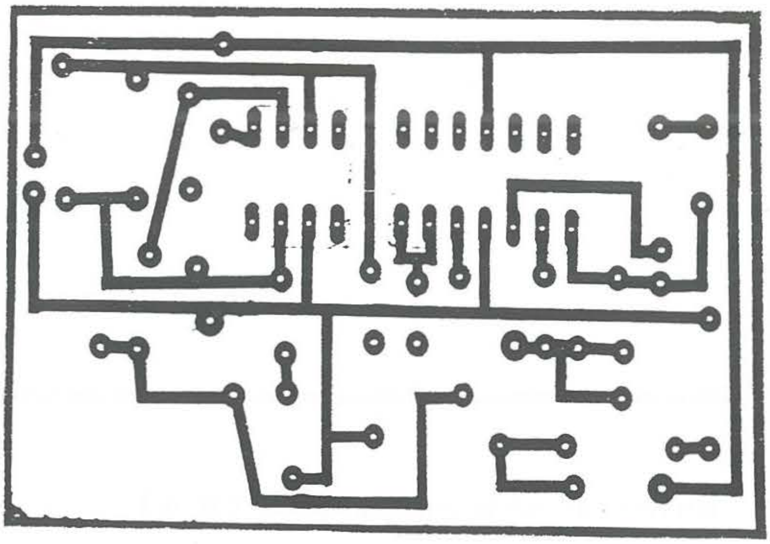


Fig. B.2 Soldering side of the signal conditioning circuit.

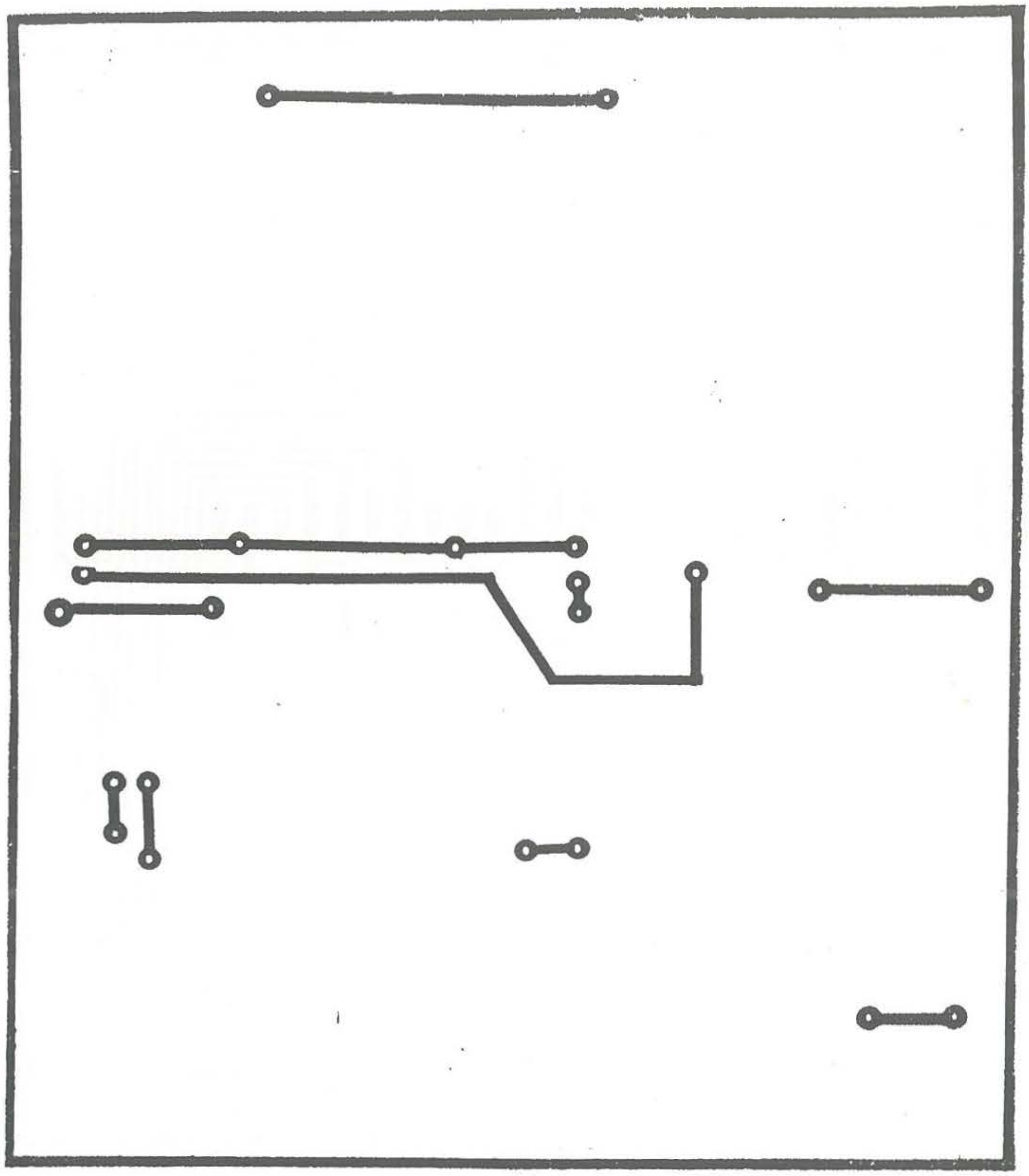


Fig. B.3 Component side of the digital section.

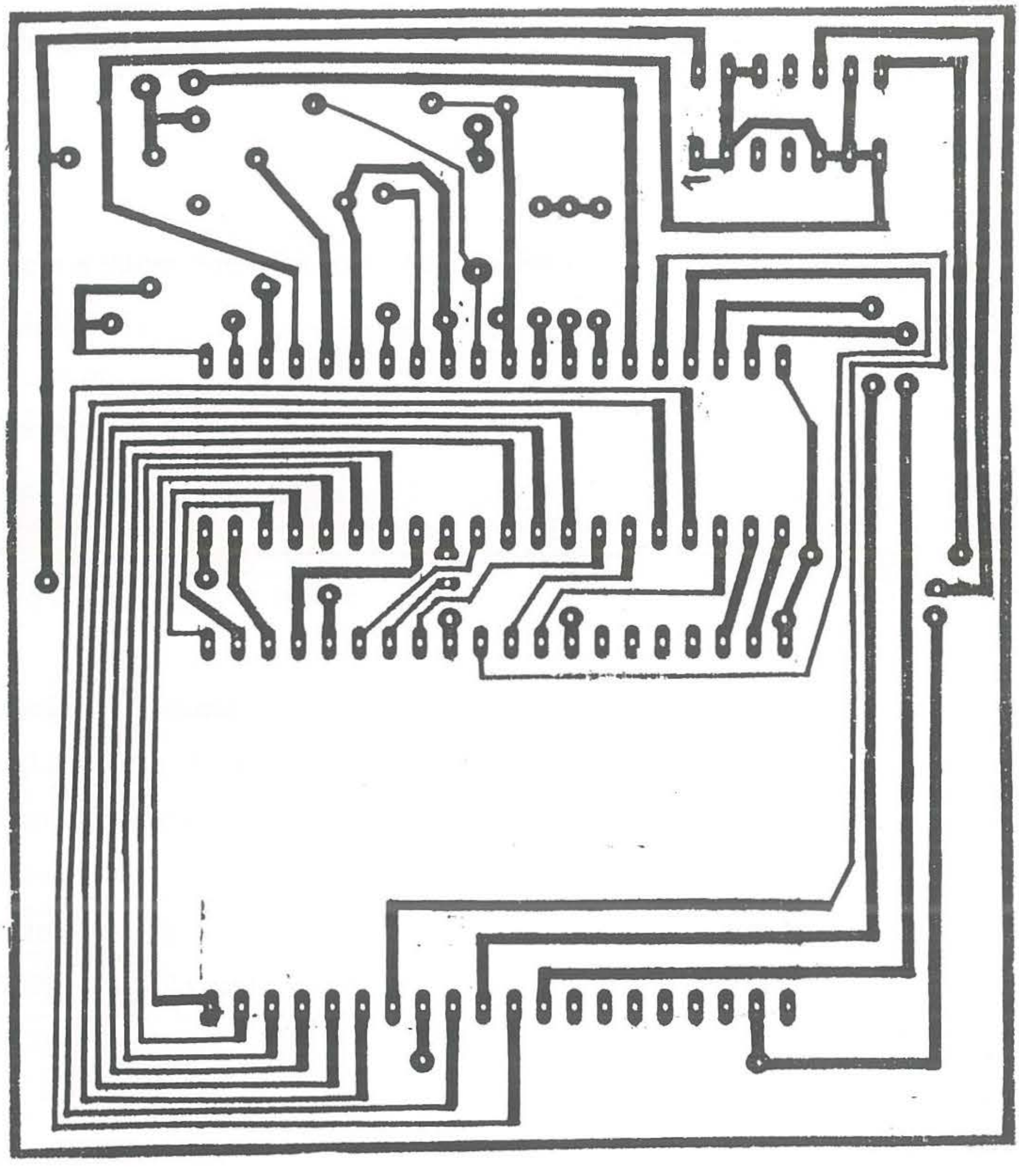


Fig. B.4 Soldering side of the digital section.

Appendix C

Cost analysis

Material	Price
Mechanical assembly	
1) Aluminium sheet	Rs. 50
(8 x 4 feet, 3 mm thickness, Rate Rs. 450)	
2) Styrene sheet	Rs. 20
(90 cm X 90 cm, 3 mm thickness, Rate Rs. 360)	
3) Mechanical pointer	Rs. 10
4) Protractor	Rs. 10
5) Velcro strap	Rs. 30
6) Potentiometer	Rs. 298
7) Acrylic sheet	Rs. 5
8) Two wing nut, screws, needle	Rs. 20
Electronic components	
1) A/D converter - LCD	Rs. 325
2) Signal condtioning circuit	Rs. 100
3) Battery	Rs. 30
4) Shielded cable	Rs. 20
5) Switches, knobs, and connectors	Rs. 60
6) PCB development	Rs. 200
Box fabrication	
1) Styrene	Rs. 100
2) Sand paper	Rs. 15
3) Paint, thinner	Rs. 40
4) Transfer letter	Rs. 30
	Total Rs. 1,363

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January, 1996

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