Naval Research Laboratory
Washington, DC 20375-5320

NRL/MR/6755--00-8494

A Versatile Vacuum- and Plasma-Compatible 3D Probe Positioning System for Large Scale Vacuum Chambers

D.N. Walker
W. Amatucci
R. Lanham

Charged Particle Physics Branch
Plasma Physics Division

G. Gatling
T. McCulloch

Sachs Freeman Associates
Landover, MD

J. Stracka

APTI Inc.
Washington, DC

October 30, 2000

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave Blank*)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	October 30, 2000	Interim

4. TITLE AND SUBTITLE

A Versatile Vacuum- and Plasma-Compatible 3D Probe Positioning System for Large Scale Vacuum Chambers

5. FUNDING NUMBERS

6. AUTHOR(S)

D.N. Walker, W. Amatucci, R. Lanham, G. Gatling,* T. McCulloch,* and J. Stracka,**

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Research Laboratory
Washington, DC 20375-5320

8. PERFORMING ORGANIZATION REPORT NUMBER

NRL/MR/6755--00-8494

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

*Sachs Freeman Associates, Landover, MD
**APTI Inc., Washington, DC

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT (*Maximum 200 words*)

This report describes briefly a three-dimensional probe-diagnostic positioning system designed for use in plasma physics experimentation in the Space Physics Simulation Chamber (SPSC) at the Naval Research Laboratory. The system is computer controlled, fully independent, and uses LABVIEW software. The environment inside the SPSC is variable in neutral pressure from atmosphere to 10^{-6} Torr; the plasma density can vary from 10^4 to 10^{12} cm^{-3}, and there is an external DC magnetic field which is as large as 50 gauss. The purpose of this report is not to provide detailed descriptions of software control or descriptions of the entire engineering effort, although some engineering drawings are included for completeness. An additional, more detailed, treatment, including software and machining details, will follow in a future paper. The intent here is to give the reader interested in developing such a system a view of the advantages of this type of design for large scale vacuum systems where detailed descriptions of the plasma state are desired in three dimensions.

14. SUBJECT TERMS	15. NUMBER OF PAGES
	18
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std 239-18
298-102

TABLE OF CONTENTS

Abstract

This report describes briefly a three-dimensional probe-diagnostic positioning system designed for use in plasma physics experimentation in the Space Physics Simulation Chamber (SPSC) at the Naval Research Laboratory. The system is computer controlled, fully independent and uses LABVIEW(National Instruments, Inc.) software. The environment inside the SPSC is variable in neutral pressure from atmosphere to 10^{-6} Torr; the plasma density can vary from 10^{4} to 10^{12} cm^{-3} and, there is an external DC magnetic field which is as large as 50 gauss. The purpose of this report is not to provide detailed descriptions of software control or descriptions of the entire engineering effort, although some engineering drawings are included for completeness. An additional, more detailed, treatment including software and machining details will follow in a future paper. The intent here is to give the reader interested in developing such a system, a view of the advantages of this type of design for large scale vacuum systems where detailed descriptions of the plasma state are desired in three dimensions.

I. Introduction

We have recently completed the third degree of freedom in a computer controlled probe diagnostics positioning system which is employed in the Space Physics Simulation Chamber (SPSC) at the Naval Research Laboratory. The SPSC, which is pictured in Figure 1, is a stainless steel cylindrical vacuum chamber which is two meters in diameter by 5 meters in length. The chamber is pumped by a combination of a mechanical pump, a turbomechanical pump, and two cryogenic pumps. There are at present three plasma sources, two of which are microwave and the third of which consists of a doubled-ended filament source. The filament sources are constructed of cross-hatched tungsten filaments which can provide densities as high as 10^{12} cm^{-3}. The magnetic field is produced by a set of 5 coils which are arranged in a Helmholtz fashion encircling the vacuum chamber as can be seen in Figure 1. The primary use of the vacuum chamber is experimental plasma physics research. Most often, measurements of electron and ion temperature, plasma potential, and plasma density are required in the experimental scenarios. A desired feature of any plasma diagnostic is to acquire as complete a sampling of relevant parameters in three dimensions as is possible. The system described here can provide these data sets.

Because of chamber vacuum conditions it is necessary to use vacuum compatible stepper motors as drivers for any of the motors that are mounted inside the chamber. In addition, standard lubricants cannot be used because of outgassing and eventual cryopump contamination. Additional constraints must be placed on cabling: it should not interfere with either the motion of the diagnostic platform or the measurements themselves. Also, the length of the cabling should be as short as possible to minimize any electromagnetic pickup. For cable management we are using flexible nylon cable carriers supplied by the Gortrac Corporation.

Design considerations for the probe system had to address the vacuum environment which contains at times hot plasma in a magnetic field. In addition the system is required to be

Manuscript approved October 3, 2000.

as "transparent to the user" as possible in terms of possible interference in the experiment or in the placement of other diagnostic and experimental equipment. In the following sections we address the design of the system consistent with the requirements outlined.

II The Z-X axis system: platform(z) and cart(x)

The basic Z-X axis system is designed around the idea that if a platform, which is the basis of the measurement system, is raised to the top of the chamber and placed on rails it will not interfere with: (1) experimenter access to the bottom and middle portions of the chamber where most of the work is done inside the device, (2) the placement of other experimental equipment, which again mostly involves the lower half of the vacuum chamber, (3) later probe diagnostic penetrations from the side or bottom flanges of the device and, it will (4) allow the cable deployment assembly to be positioned away from the main experimental area: In short, the platform and connections to the platform are "up and out of the way" and not along the chamber bottom.

Since the large dimensions of the chamber are such that a screw drive device penetrating one end of the cylinder would be unwieldy, it is not necessary to use external motor drives if sufficiently vacuum compatible ones can be located. Also the length required outside the chamber, and therefore the limited access around the experimental area for an extended screw drive positioner is not feasible in the laboratory. In order to simplify the chamber penetrations, we decided on an overhead internal motor-driven platform based system. This requires that the motors be able to operate in the hostile environment without overheating, being affected by the external magnetic field or producing an interfering magnetic field themselves. The latter problem is removed however simply by placing the motors well outside the experimental region; the configuration chosen, as shown below, satisfies this requirement. As the magnetic fields in our experiments are on the order of 10's of gauss, we do not have to take special precautions as, for example, in kilogauss fields to insure that motor operation is unaffected by these fields.

The probe Z-X platform and support which are shown in the photograph in Figure 2 consists of five basic components:

(1) the platform itself which moves along the longitudinal, or Z-axis,
(2) rail supports for the platform on either side of the vacuum chamber,
(3) a small cart which rides in the X direction along the platform (the cart itself is obscured by the scissors positioner and motor which is attached to the cart to the far right of Figure 2) and,
(4) Teflon gear trains (seen along the x-axis underneath the platform) driven by rotating aluminum toothed wheels which in turn are driven by,
(5) vacuum compatible stepper motors

The platform and X-axis cart are shown in the actual photographs of Figures 2 and in the engineering drawings of Figure 3 in both the overhead (top) view of Figure 3a and the end-on view of Figure 3b showing chamber walls and support railings. Both Figures 3a and 3b show the central Z-axis motor drive to the right. The Teflon track (item #30 designated as chain) is seen in length extending on the right side of Figure 3b. The motor drive (item #7) is connected to the aluminum toothed wheel, which rotates under motor action, and hence propels the platform along the z-axis as it meshes with the Teflon track during rotation. The Teflon track is fixed in position and the motor travels down the track with the platform (In the actual photographs, the Z-axis drive motor is not shown as it was being repaired at the time the photographs were taken). This basic scheme is also responsible for X-axis motion as is seen next in Figure 4. In this Figure, the view is opposite to the view of Figure 2, i.e., opposite in the sense that the photo is taken from behind the platform as opposed to in front of it. This view clearly shows the motor/toothed wheel/Teflon chain arrangement responsible for propelling the x-axis cart. Almost the entire length of the X-axis chain is visible in this figure. Unlike the Z-axis motion the motor says fixed in position on the platform and the X-axis cart, which is attached to the chain underneath, moves. Note the toothed wheels at extreme far left and right sides of the figure and the attachment points of the chain to the cart which is about halfway between center and the far left end of the picture. An engineering drawing of the X-axis cart (or probe mount) is shown in Figure 5 with the cart centered directly beneath the motor drive.

Also visible in Figure 2 is the flange at the end of the vacuum chamber through which the penetrations for the cables are made. Although cable carriers are not pictured in these views, they will be mounted on rails above the platform rails. The cable carriers are made of nylon, are flexible and can easily be disassembled. At the time of these photographs, the cable as shown is largely "up and out of the way" but the inclusion of the carriers will allow a further concealment of the cabling from view.

III The Y-axis system: scissor-jack assembly

Initially we had considered a telescoping antenna type of design for the 3rd degree of freedom of our system. However in final considerations, the possible weight that might be necessary at this site (10 lbs) precluded any simple designs of this fashion, i.e., the telescoping sections were too large and the supported weight would always be working against the unit gravitationally. On the other hand, a simple screw drive itself would have to be too long (in the stored position) if it were to cover the amount of experimental region desired (about 1 meter along the y direction) Based on these concerns the best choice was still a device that could collapse to a short length (as with the telescoping idea) but could still be extended to the order of a meter or more from its stowed position. Because of this, we chose to use a simple "scissors-jack" type of probe positioner for the 3rd axis of the movable cart platform[1,2]. The basic idea is outlined in Figure 6 below which is a schematic representation of this scheme with lengths labeled corresponding to the calculations and graphs which follow.

III.1 Geometry and length conversion

A schematic of the basic scissor-jack probe assembly is shown in Figure 6. An important point to notice about this assembly is that the nut labeled BN is attached to the support which is mounted on the cart shown below in the figure. This is also true of the motor which drives the Velmex lead screw. Not shown in this view is the fact that the upper arms are displaced by spacers at the joints from the lower assembly (i.e., they would protrude out of the plane of the figure); otherwise the initial, unextended storage position would be limited by the lead screw and assembly. These spacings are seen more clearly in Figures 7 and 8 which show the scissor-jack assembly and motor (Figure 7) in the stowed position and in the partially extended position of Figure 8.

It can be shown from simple trigonometry using the law of cosines that travel along the lead screw, z_1, is related to the angle θ by,

$$z_1(\theta) = r_1\cos(\theta) + r_1((\frac{r_2}{r_1})^2 - \sin^2(\theta))^{1/2} \tag{1}$$

and that the tip position is related to θ by,

$$z_2(\theta) = 2l\cos(\theta) \tag{2}$$

where r_1, r_2, θ, and l are as shown in the Figure. (Note here that z_1 and z_2 as calculated in the equations above do not include the constant offsets seen in the figure. These include, (1) how far the base of the scissor jack assembly is displaced from the lower apex of the lower angle and, (2) how far the probe extends from the upper apex. These values are to some extent variable, particularly the upper value as it is a function of the probe assembly placed into the plasma.)

In addition, θ as a function of z_1 is given by,

$$\theta(z_1) = \cos^{-1}(\frac{z_1^{\,2} + r_1^{\,2} - r_2^{\,2}}{2r_1 z_1}) \tag{3}$$

and tip position, z_2, as a function z_1 is given by,

$$z_2(z_1) = 2l(\frac{z_1^{\,2} + r_1^{\,2} - r_2^{\,2}}{2r_1 z_1}) \tag{4}$$

or the inverse relation,

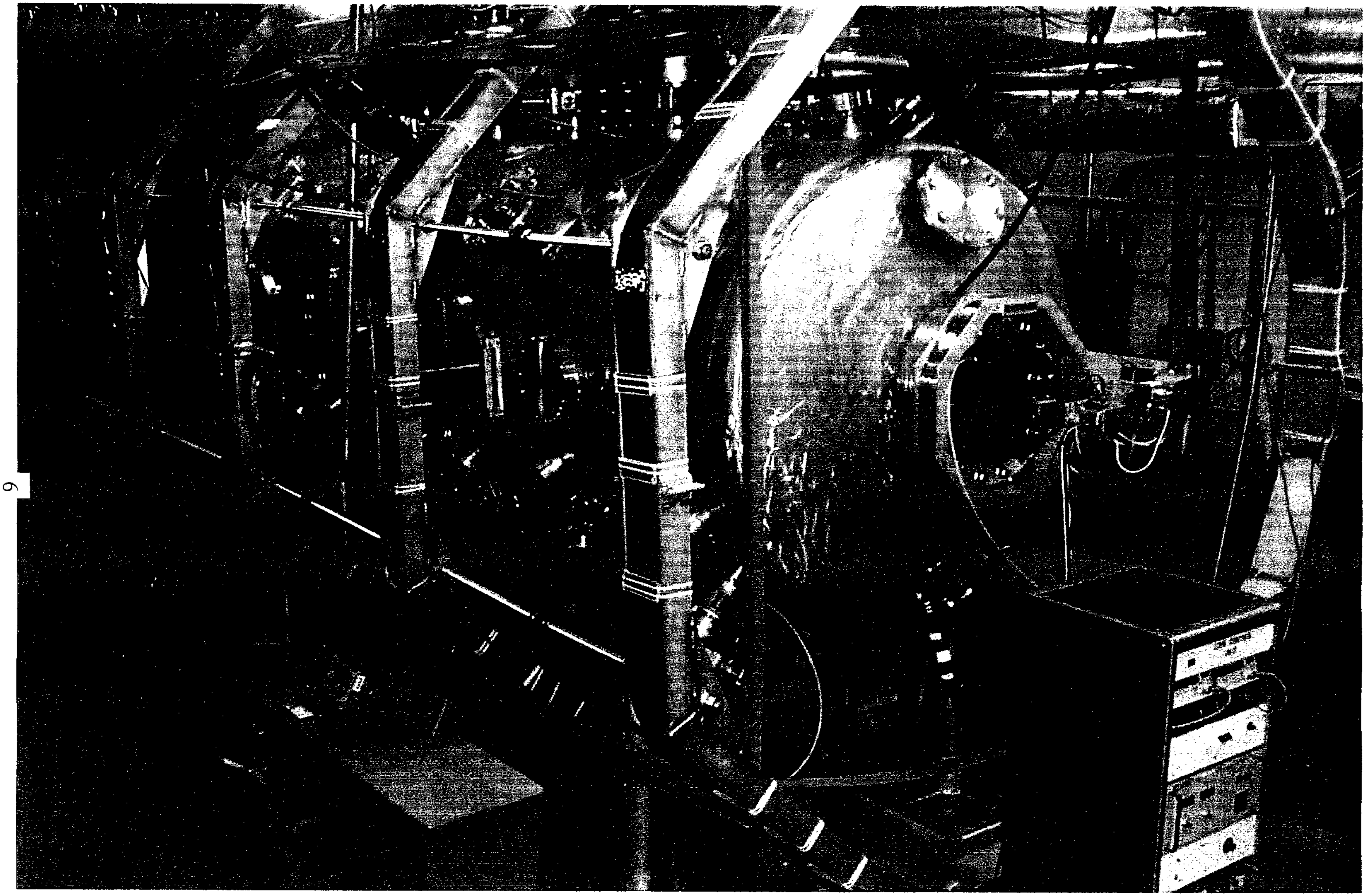
$$z_1(z_2) = \frac{z_2 r_1}{2l} + \frac{1}{2}\sqrt{\left(\frac{z_2 r_1}{l}\right)^2 + 4(r_2^2 - r_1^2)} \qquad \textbf{(5)}$$

The quantities given in Eqs (1) - (4) are plotted in Figures 9. By expressing z_1 in terms of turns/length, the screw pitch can be included in this calculation and therefore θ and z_2 can be directly calibrated.

[1]H. Pfister, W. Gekelman, J. Bamber, D. Leneman, and Z. Lucky, *Rev. Sci. Instrum.*, **62(12)**, 2884, 1991; [2]G. Braught, H. Pfister, and J. Wachtel, *Rev. Sci. Instrum.*, **64(11)**, 3270, 1993

IV. Acknowledgments:

We gratefully acknowledge the support of the Office of Naval Research in this work. We also thank Mr Dwight Duncan who was instrumental in much of the physical placement of various system components for the Z-platform assembly



NRL Space Physics Simulation Chamber

Figure 1

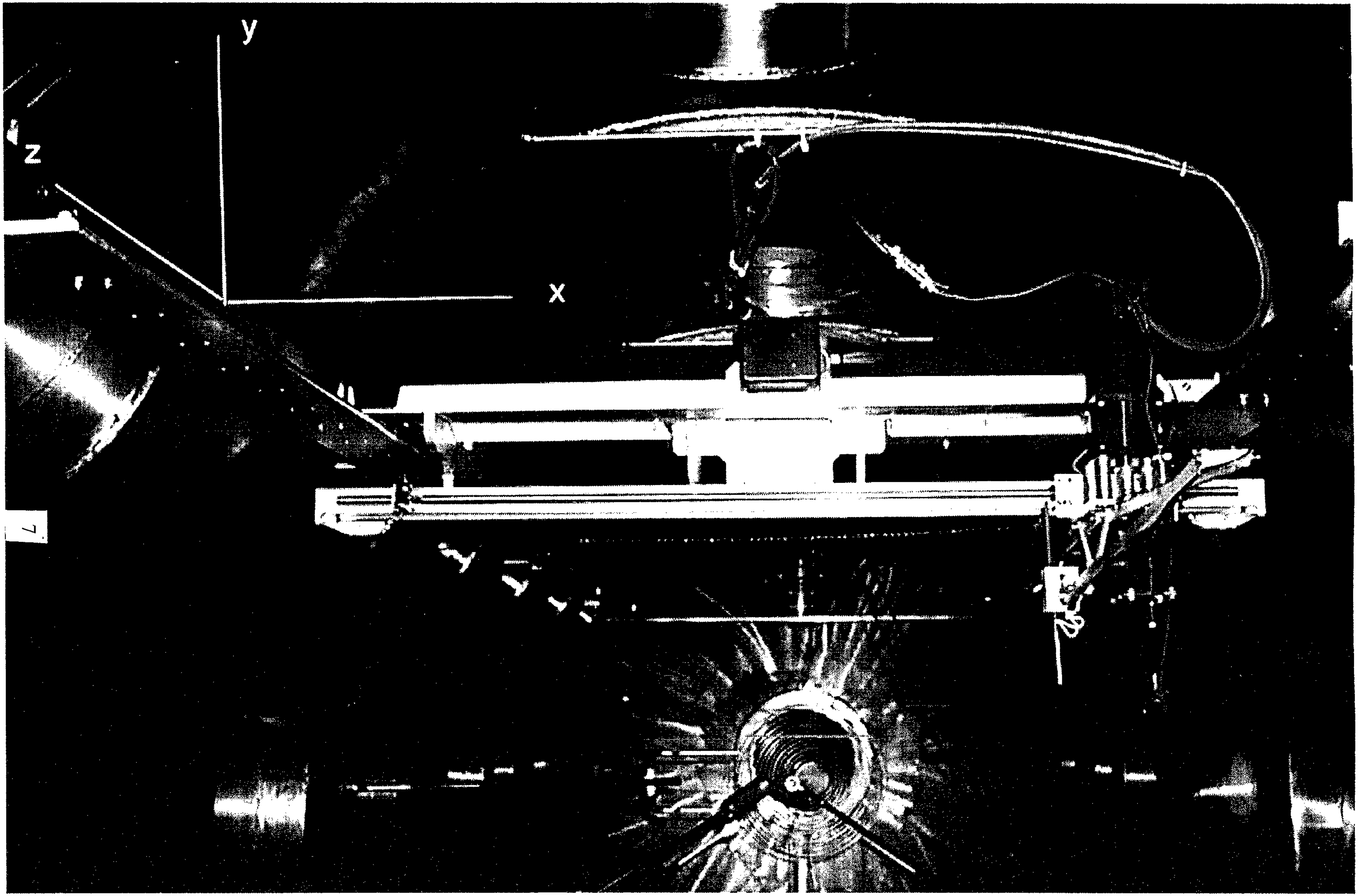
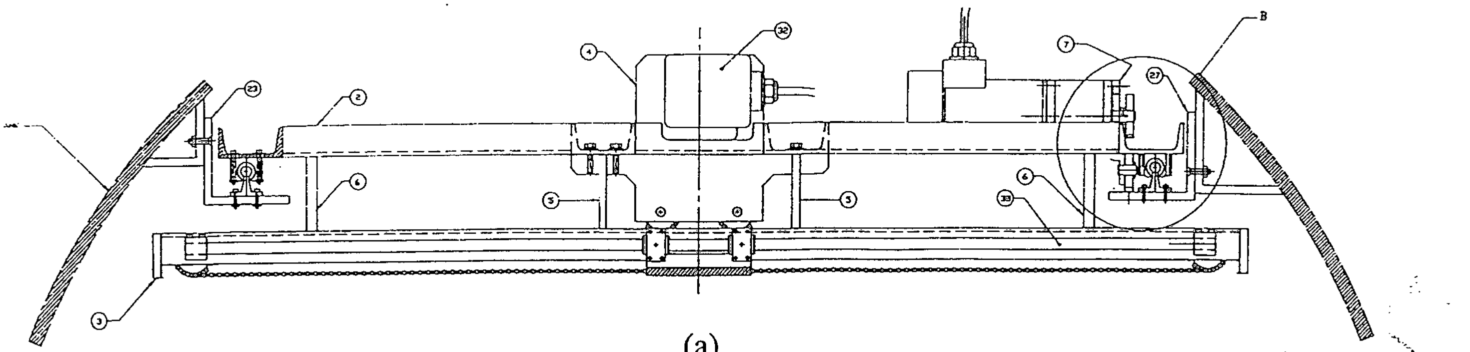


Figure 2



(a)
End-on View

		-31
		-30
		-29
MOUNT (LIMIT SWITCH)		-28
ANGLE 4X4 (RIGHT SIDE)		-27
SPACER #4--PART 5		-26
SPACER #3--PART 4		-25
SPACER #2--PART 3		-24
ANGLE 4X4 (LEFT SIDE) DWG. RAIL-LO PART 2		-23
SPACER (PART 10)		-22
WASHER DELRIN		-21
WASHER DELRIN		-20
SPACER (LINEAR BEAR. HOUSING)		-19
SUPPORT (FOR PARTS 11 & 12)		-18
CHAIN END CLAMP (TOP)		-17
CHAIN END CLAMP (BOT)		-16
PROBE MOUNT PLATE		-15
PROBE MOUNT (CHAIN TENSION		-14
PROBE MOUNT (SIDE)		-13
CHAIN SUPPORT		-12
CHAIN SUPPORT		-11
SPROCKET MOUNT		-10
		-9
		-8
MOTOR MOUNT (SMALL)		-7
SUPPORT (OUTER)		-6
SUPPORT (INNER)		-5
MOTOR MOUNT (LARGE)		-4
CHANNEL		-3
CARRIAGE		-2
ASSEMBLY		-1

3/8 SPLIT LOC WASHER	ST. ST.	-62
3/8 FLAT WASHER		-61
3/8-16 HEX NUT		-60
3/8-16 HEX HD SCREW X 1" LG.		-59
1/4 SPLIT LOC WASHER		-58
1/4 FLAT WASHER		-57
1/4-20 HEX NUT		-56
1/4-20 HEX HD SCREW X 1" LG.		-55
10-32 SOC HD CAP SCREW X 1" LG.		-54
#6 SPLIT LOC WASHER		-53
#6 FLAT WASHER		-52
6-32 HEX NUT		-51
6-32 SOC HD CAP SCREW X		-50
6-32 SOC HD CAP SCREW X 1 1/2 LG.		-49
6-32 SOC HD CAP SCREW X 1" LG.		-48
6-32 SOC HD CAP SCREW X 3/4 LG.		-47
6-32 SOC HD CAP SCREW X 5/8 LG.	ST.ST.	-46
6-32 SOC HD CAP SCREW X 7/8 LG.		-45
		-44
		-43
BEARING NYLINER PLUS #SL10F-642		-42
SNAP RING		-41
SPROCKET #35CP59A-15		-40
SPROCKET #35CF74A-15 (NO-HUB)		-39
CHAIN #35CCF-		-38
SHAFT SUPPORT #PSR-8PD		-37
LINEAR BEARING #PLC-8		-36
OPEN BEARING HOUSING #S5-13		-35
RAIL .50 O.D. X 6ft LONG #A11-8D		-34
RAIL .50 O.D. X 4ft LONG #A11-8D		-33
MOTOR		-32

(b)
Top View

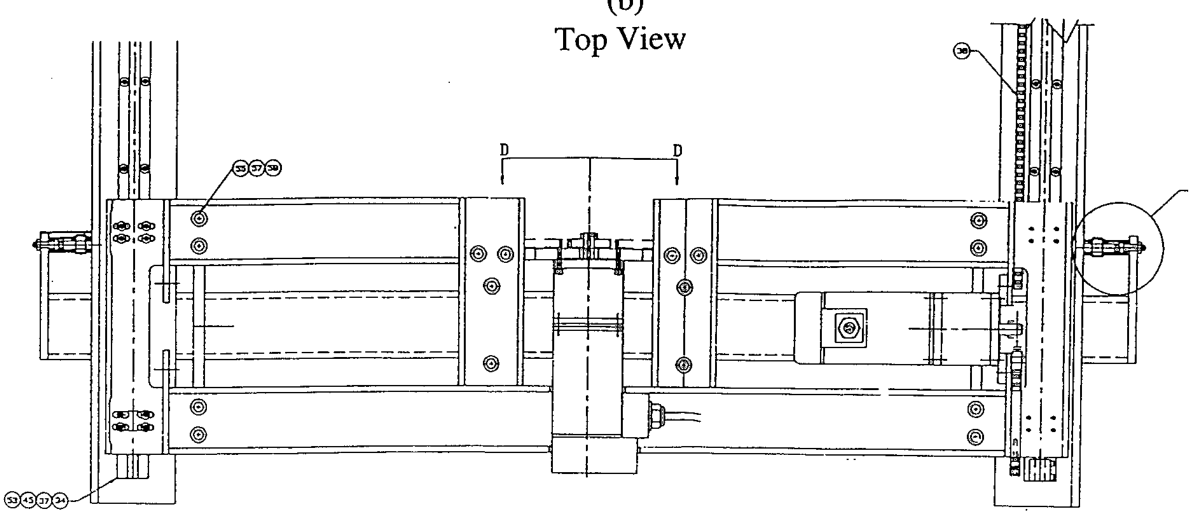


Figure 3

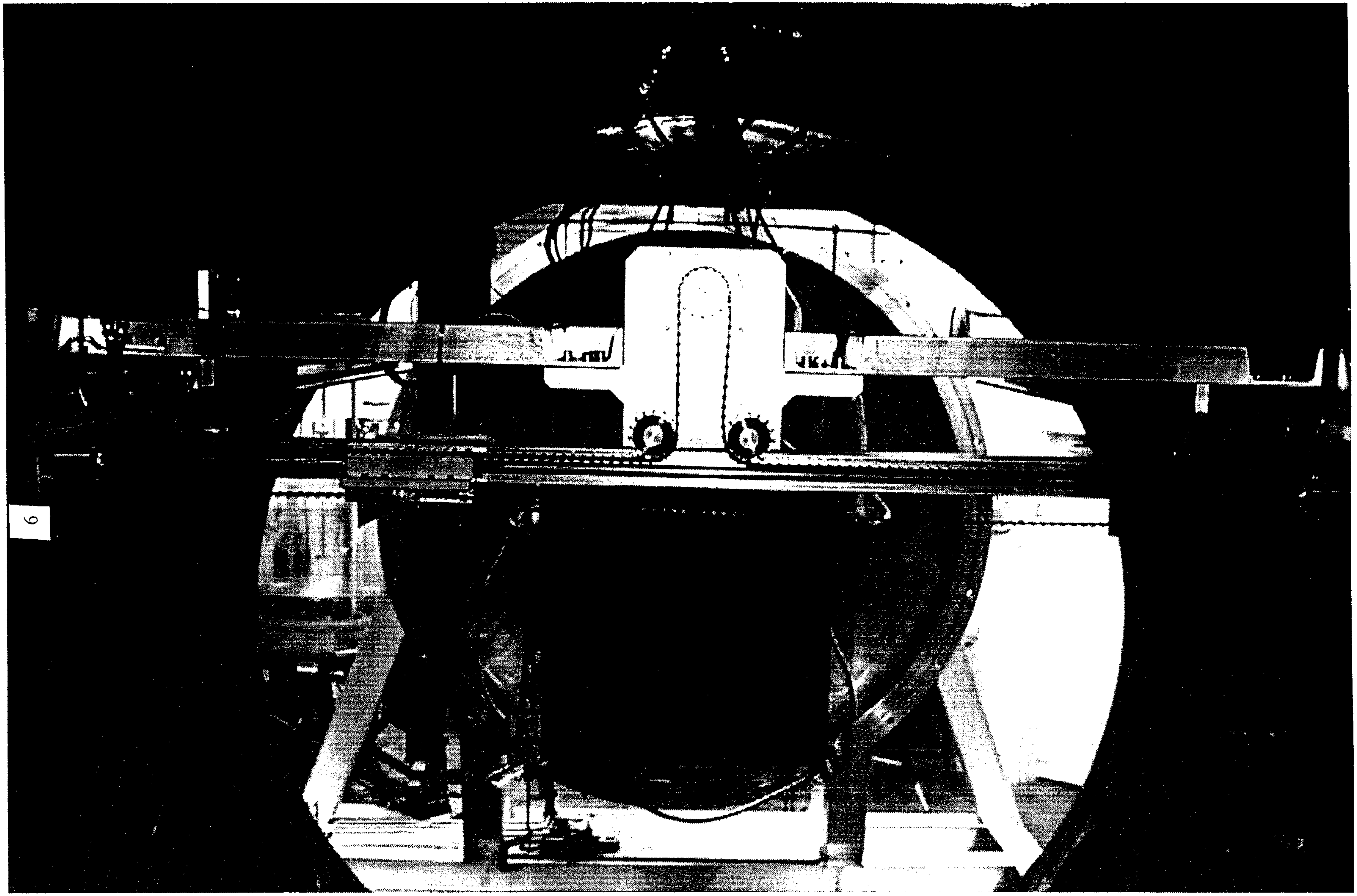


Figure 4

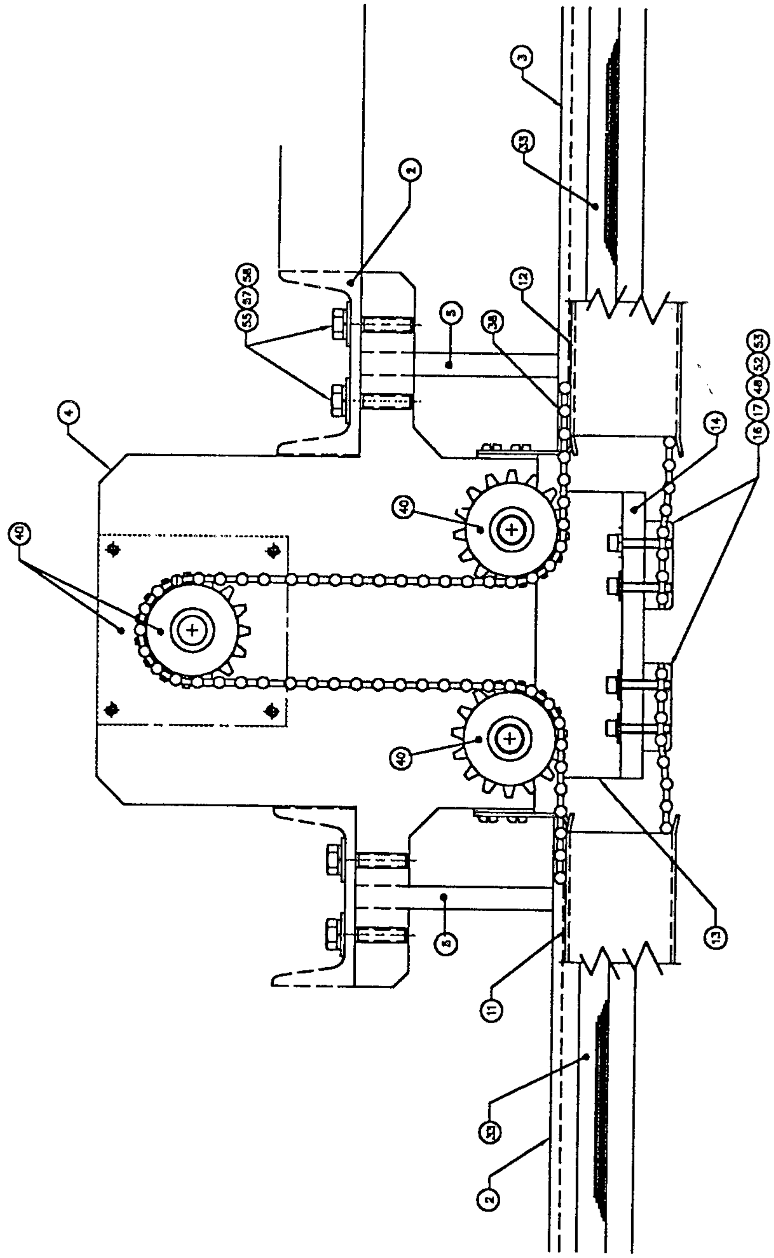


Figure 5

Schematic Scissor-Jack Probe Assembly

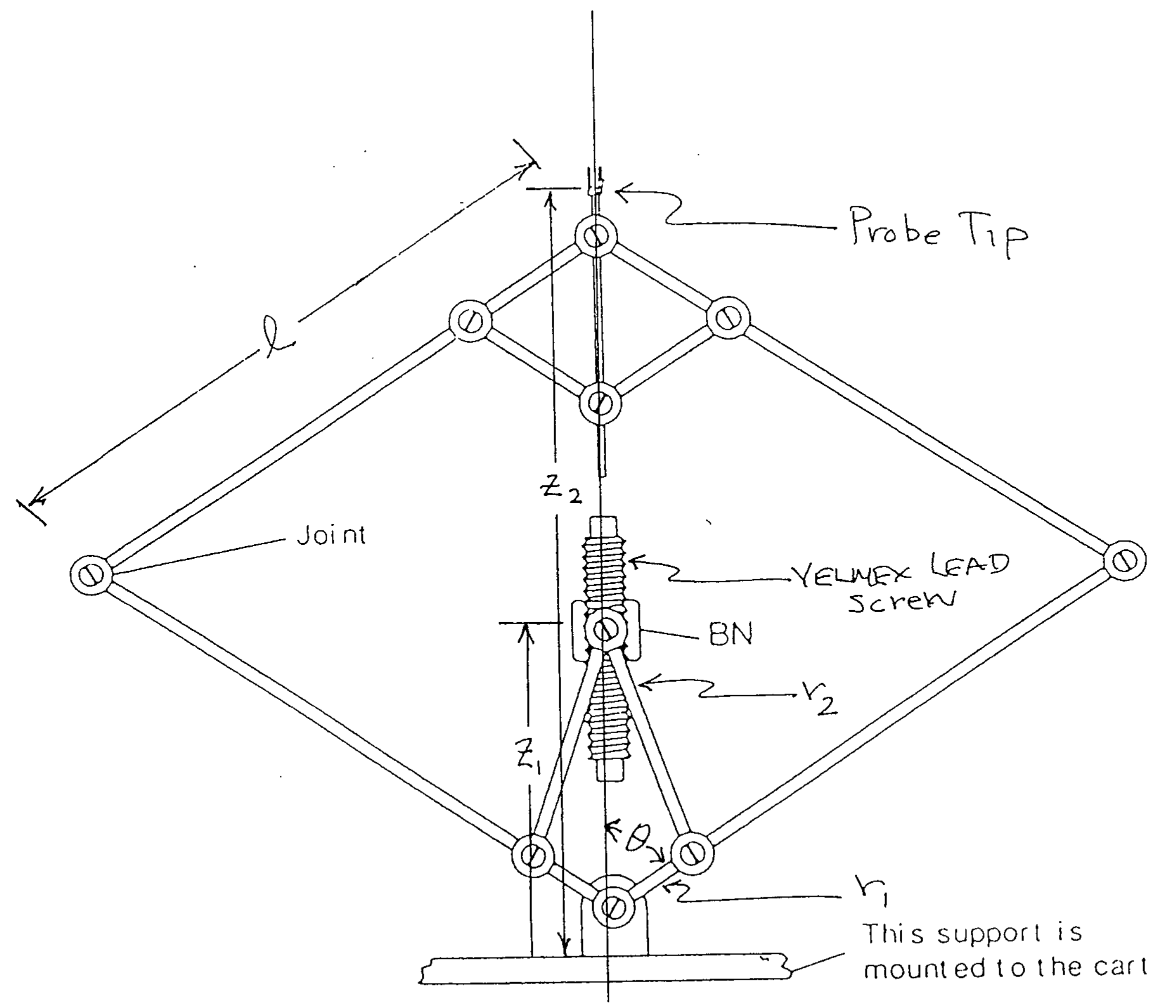


Figure 6

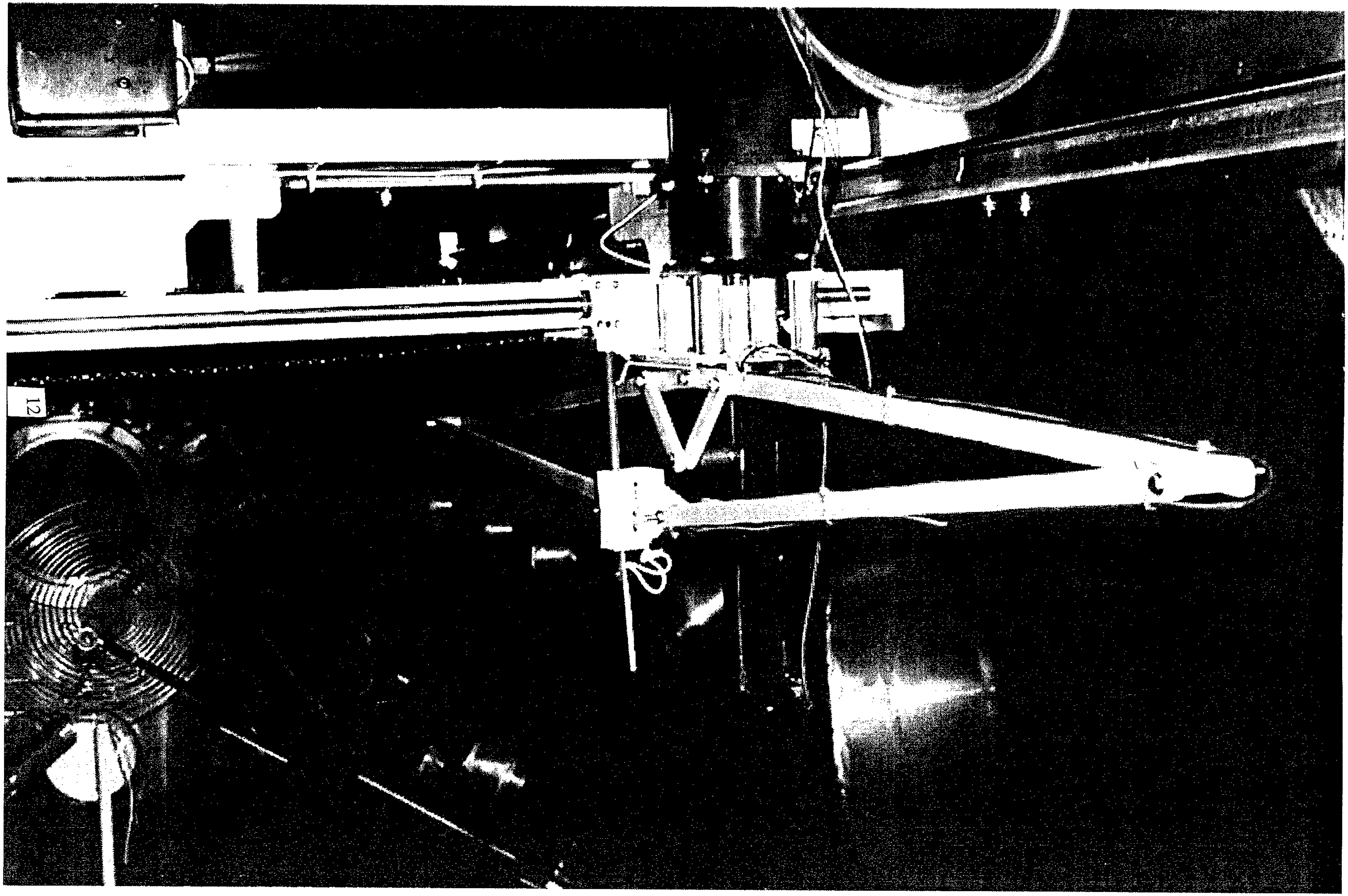


Figure 7

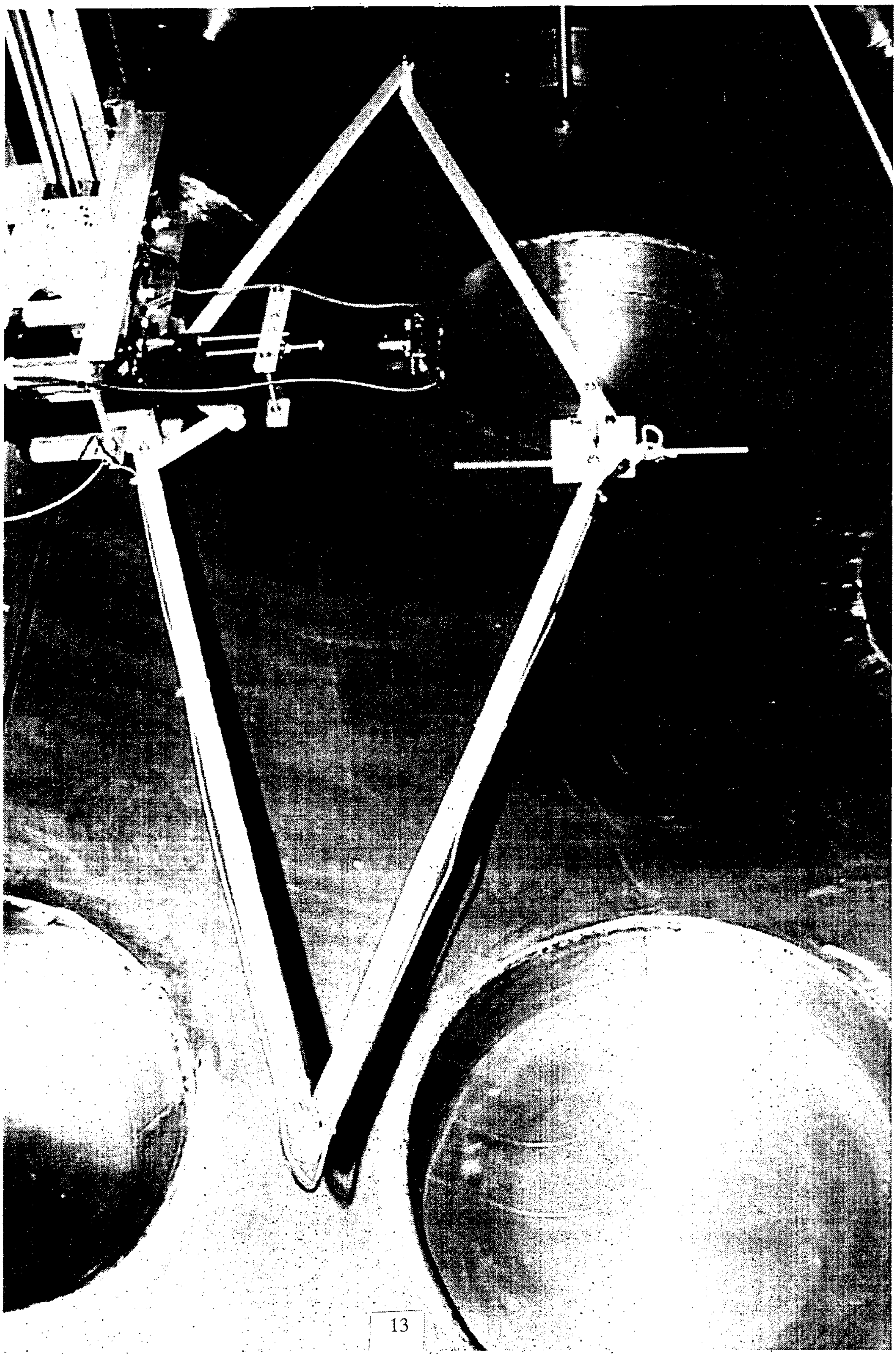
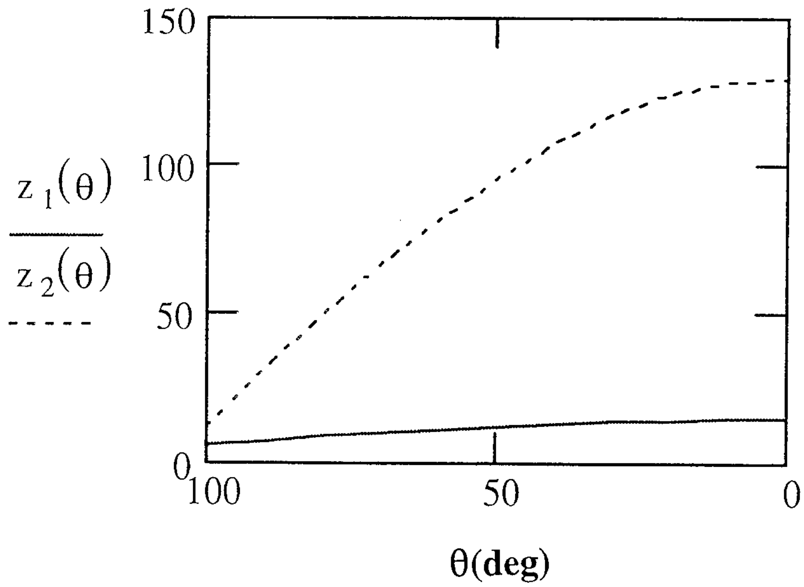


Figure 8


150
100
50
0
100
50
0
$z_1(\theta)$
$z_2(\theta)$
θ(deg)

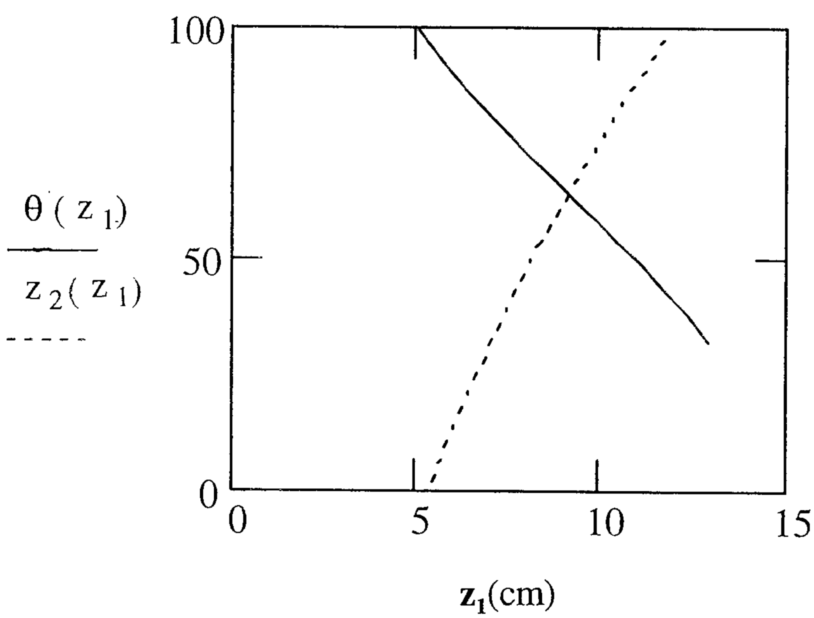

100
50
0
0
5
10
15
$\theta(z_1)$
$z_2(z_1)$
z_1(cm)

Figure 9