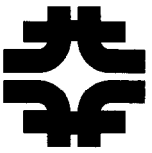

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MAGNETIC AND ELECTRICAL PROPERTIES OF ENERGY SAVER SPOOL PIECES

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Introduction

The following is a compendium of the magnetic and electrical properities of the first 46 correction coil packages (also known as spool pieces) of the Fermilab Energy saver. Due to the large amount of information available, the emphasis will be to provide a global overview of the plots rather than to examine each property in detail. The magnetic properties measured fall into 5 categories:- transfer constants, harmonics, magnetic centers, coil angles and polarities. Of the electrical data available, we will present histograms of DC resistances of coils, number of quenches per coil and high potential breakdown voltages. The polarities of each coil are checked by the measuring system and if incorrect, are corrected immediately and will not be the subject of further discussion here.

The Cyber Data Base.

The magnetic measurements are performed with the aid of a PDP 11/20 computer. The data is transmitted to the Fermilab Cyber 175 by means of magnetic tape. The electrical data are fed into the Cyber from summary sheets at the prompting of a program(called SUMARYS in the procfil SUMARYS) which checks the data for trivial typing errors and organizes it into a neat format. The magnetic and electrical data are then combined and stored in a random access file called SUMSPUL /UN=94420 which is accessible publicly. The procedure called FORMAT in the procfil SUMARYS /un=94420 allows one to print the summary sheet for any set of spools. Another procedure called SHO in the file SUMARYS runs diagnostics on the spools subjecting them to various rejection criteria as well as enabling the production of histograms of any quantity of interest. The histograms are produced using KIOWA whose output can be graphically manipulated and sent to the Calcomp plotter using the program HISTRR. The plots produced are the result of analysis on 46 spool pieces (see attached list for spool names)

Transfer Constants

Figures 1-5 give the histogram of the transfer constants for the various types of coils used in spool piece construction. The sextupole coil in a DSQ package has different dimensions than that in an OSQ package and therefore they are plotted

separately. The quadrupole coils are identical in both packages, hence all quadrupoles are plotted in Figure 2.

The spread in the transfer constants in each plot is a result of two effects. a) the spread in manufacture and b) slight drift in the relative calibration of the two lockin amplifiers used to measure the transfer constants.

One can eliminate the effective of long term drift in the

calibration of the lockin (at the level of 0.5% or so) by fitting the transfer constants of all the coils in any given spool to a set of standard values by multiplying each by an overall calibration factor. Any residual departure from the standard values would clearly be the result of manufacturing errors.

Harmonics

The harmonics measured by the Morgan Coil are with respect to the center of the Morgan Coil probe and are in a co-ordinate system with the x-axis pointing along the horizontal. The harmonic information is used to set the spool piece in the ring with the center of the sextupole on the beam axis. The spools are rotated so that the upstream quadrupole magnetic field is vertical in the horizontal plane passing through the quadrupole center. The harmonics presented here have all been transformed into this co-ordinate system and hence are called ring harmonics. The untransformed harmonics are called Lab harmonics. Figures 6-45 contain plots of various harmonics. The title of each figure is self-explanatory. For instance, Figure 22 is the normal octupole harmonic of the quadrupole coil and hence the title Pole=4, ring harmonics=8, Normal. Since the OSQ and the DSQ sextupoles are similar to each other in angular dimensions, we have not attempted to distinguish them here. Also since we are in the ring co-ordinate system, skew coils will contribute those harmonics to skew plots that normal coils contribute to normal plots. This is particularly evident in plots 44 and 45 which are the normal and skew decupole harmonics of the dipole coil. The dipole coil has a -2% decupole component due to its geometry. Both figures 44 and 45 show a peak at -.02. This is because some of the dipole coils are skew dipoles.

Since we are working in a system where the origin is the magnetic center of the sextupole coil, the quadrupole ring harmonic (normal and skew) of the sextupole coil is

identically zero by definition. (see figures 27,29). This is to be compared with the lab harmonics (figures 26,28) which are broad distributions.

A similar effect is evident in the case of the quadrupole coil (Figures 14-17) and the octupole coil (Figures 38-41) implying that the sextupole center is closer on average to the quadrupole and octupole centers than the Morgan Coil center.

It must be mentioned that in transforming the harmonics to the ring co-ordinate system, we have assumed that all harmonics above octupole are zero for all coils except the dipole coil for which the ten-pole is also considered.

Angles

Figure 46 is the histogram of the angle of the upstream quadrupole coil when the spool piece is set on the measuring table. Figures 47-52 are the histograms of the angles of the various coils with respect to the quadrupole coil. Figures 47 and 49 thus give the relative angles of the coils in the DSQ package. Figure 50 gives the relative alignment of the DSQ package with respect to the OSQ package. Figures 51 and 52 give the relative alignment of coils within the OSQ package. Most of the angles are outside tolerances for the early spools. With the use of the electronic alignment technique, the later spools are known to be much better.

Electrical Data

Figure 53 is the histogram of the cold test run numbers of the spools used in the analysis. Figures 54-59 are the DC resistances of the various coils. The large spread in resistance in some of the plots may be due to calibration errors. Figures 60 and 61 are the plots of the number of quenches it took to get these coils up to their operating current. There is some evidence that the OSQ package quench characteristics are a bit better than those of the DSQ package.

There are a large number of hi-pot tests done per magnet and it is not convenient to histogram each high pot voltage. Figure 62 is the histogram of the high pot test voltage between the dipole and sextupole coil of the upstream package in single phase helium at 22psig. The cut-off limit

is at 2.0kv. There are some coils which do not reach this voltage.

Diagnostics

Figures 63 and 64 give the format of the data summarys sheet for a typical spool TSC050. The program SHO analyzes the numbers and if any quantity is outside the tolerance limits (as specified by Helen Edwards' memo) a message is printed. Figure 65 gives the diagnostic output for spool 50.

Each time a quantity falls outside the tolerance, the program generates a fault number. Figures 66-71 are histograms of the various fault numbers. Figure 66 is the histogram of the "TYPE" fault number which indicates whether a spool advertised as a particular type is indeed that magnetically. So far there have been no TYPE faults. Also a spool has yet to fail the criterion for magnetic centers and the harmonics are well behaved. But the angles and hi-potting more than make up for these instances of good behaviour.

It is a pleasure to thank various members of the Fermilab technical staff, Lou Rolih in particular for carrying out the measurements in question.

LIST OF SPOOLS IN THIS ANALYSIS

SPOOL : TSB013
SPOOL : TSC014
SPOOL : TSC016
SPOOL : TSB017
SPOOL : TSC018
SPOOL : TSD019
SPOOL : TSC020
SPOOL : TSD021
SPOOL : TSA022
SPOOL : TSD023
SPOOL : TSC024
SPOOL : TSD025
SPOOL : TSB029
SPOOL : TSD031
SPOOL : TSC032
SPOOL : TSB033
SPOOL : TSC034
SPOOL : TSC037
SPOOL : TSF038
SPOOL : TSE039
SPOOL : TSB040
SPOOL : TSC041
SPOOL : TSE043
SPOOL : TSB044
SPOOL : TSC045
SPOOL : TSD046
SPOOL : TSD047
SPOOL : TSA048
SPOOL : TSC050
SPOOL : TSD051
SPOOL : TSE052
SPOOL : TSE055
SPOOL : TSB056
SPOOL : TSC057
SPOOL : TSC059
SPOOL : TSB060
SPOOL : TSC065
SPOOL : TSD066
SPOOL : TSC070
SPOOL : TSC073
SPOOL : TSD074
SPOOL : TSA078
SPOOL : TSF079
SPOOL : TSC080
SPOOL : TSD082
SPOOL : TSB083

FIGURE CAPTIONS

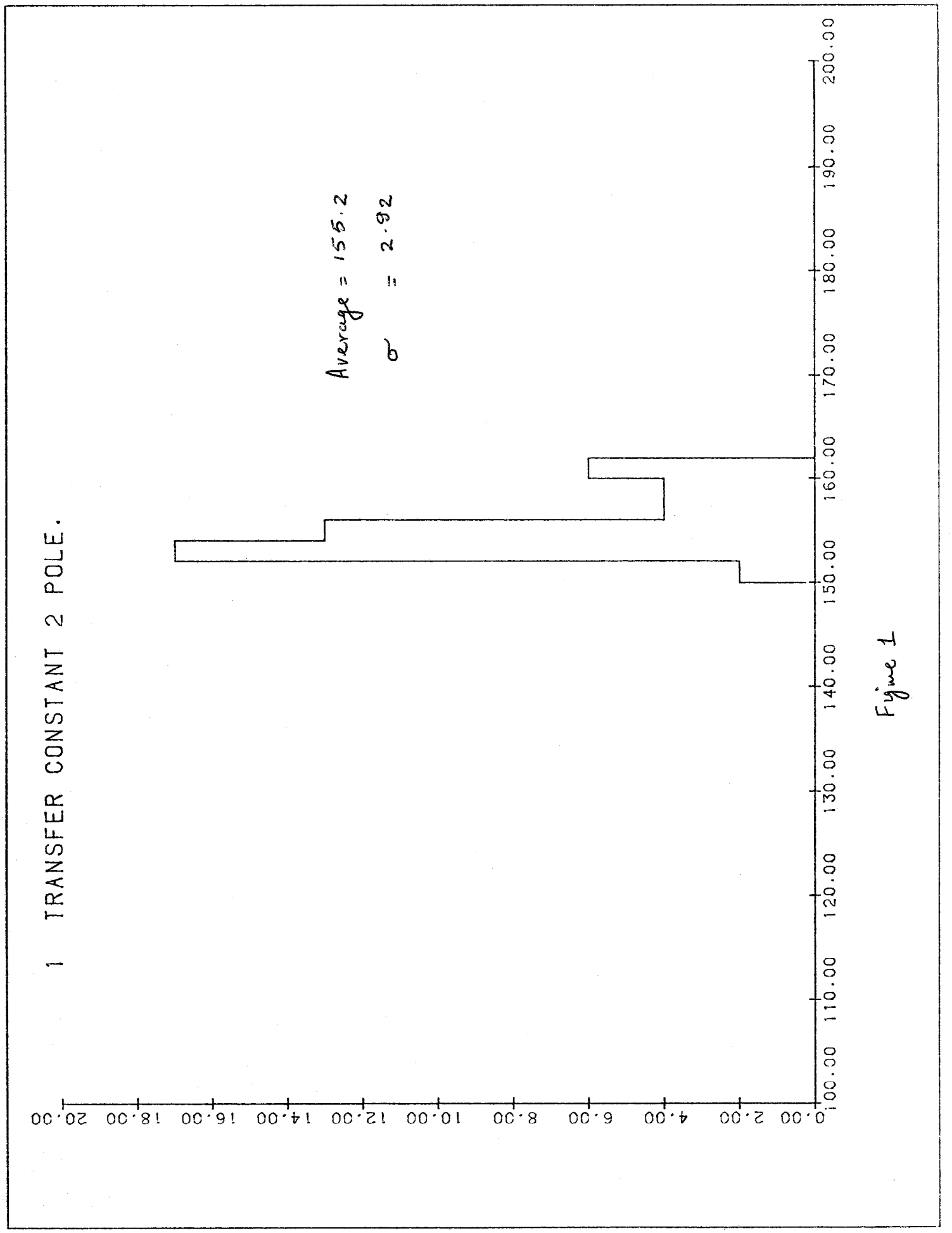
1 TRANSFER CONSTANT 2 POLE.
Average = 155.2
σ = 2.92
100.00
110.00
120.00
130.00
140.00
150.00
160.00
170.00
180.00
190.00
200.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 1

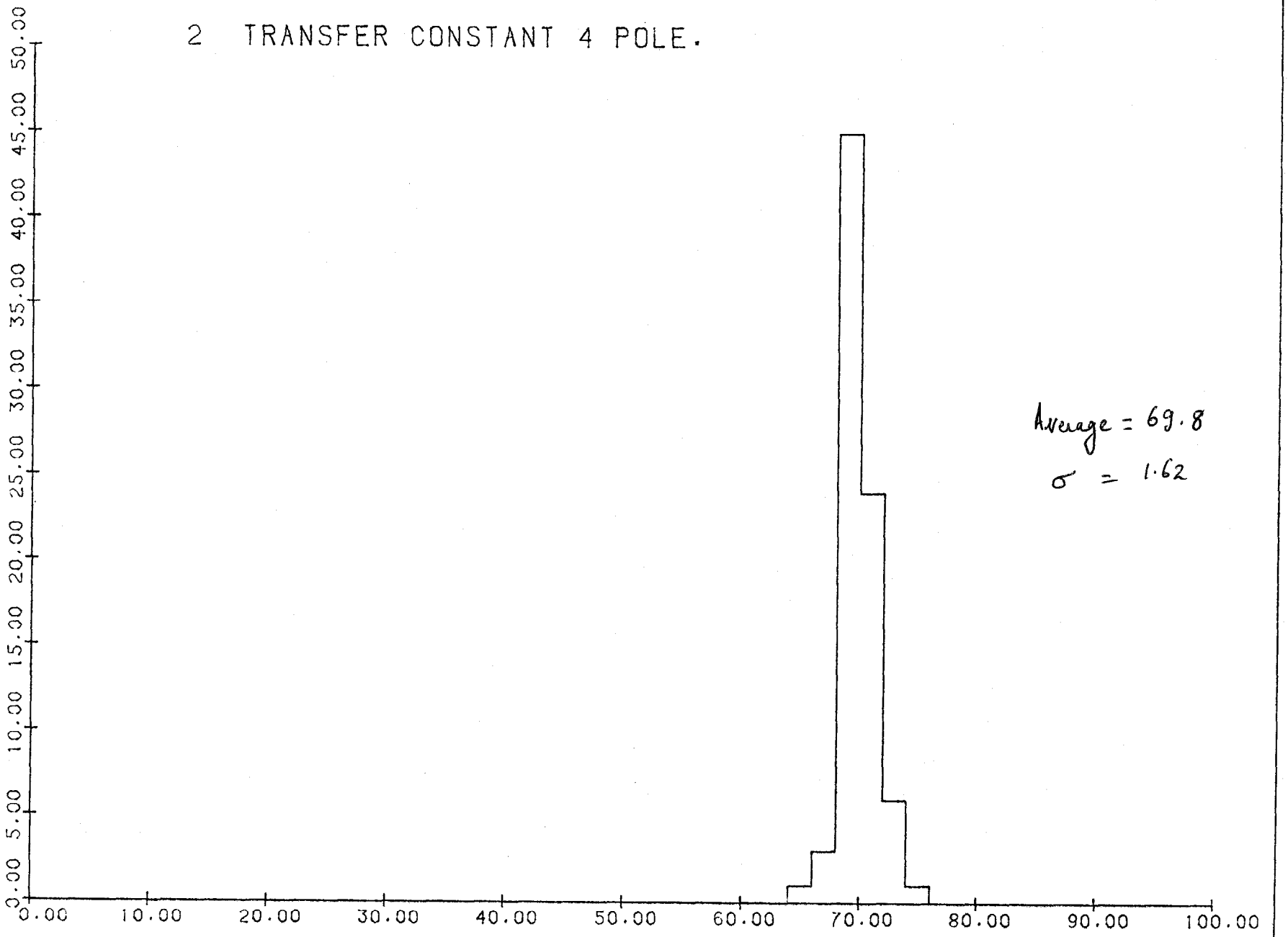
2 TRANSFER CONSTANT 4 POLE.
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Average = 69.8
σ = 1.62

Figure 2

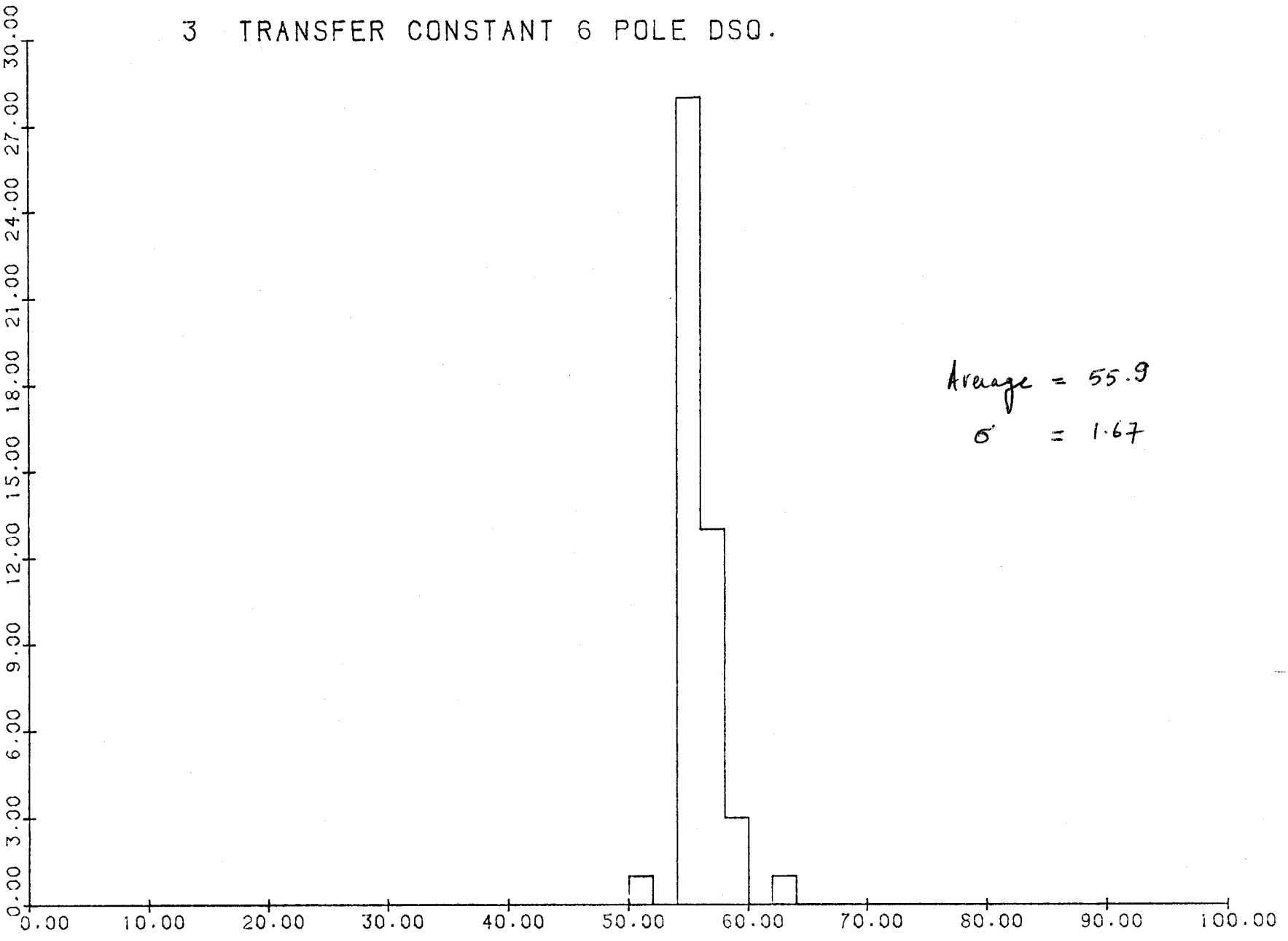
3 TRANSFER CONSTANT 6 POLE DSQ.
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Average = 55.9
σ = 1.67

Figure 3

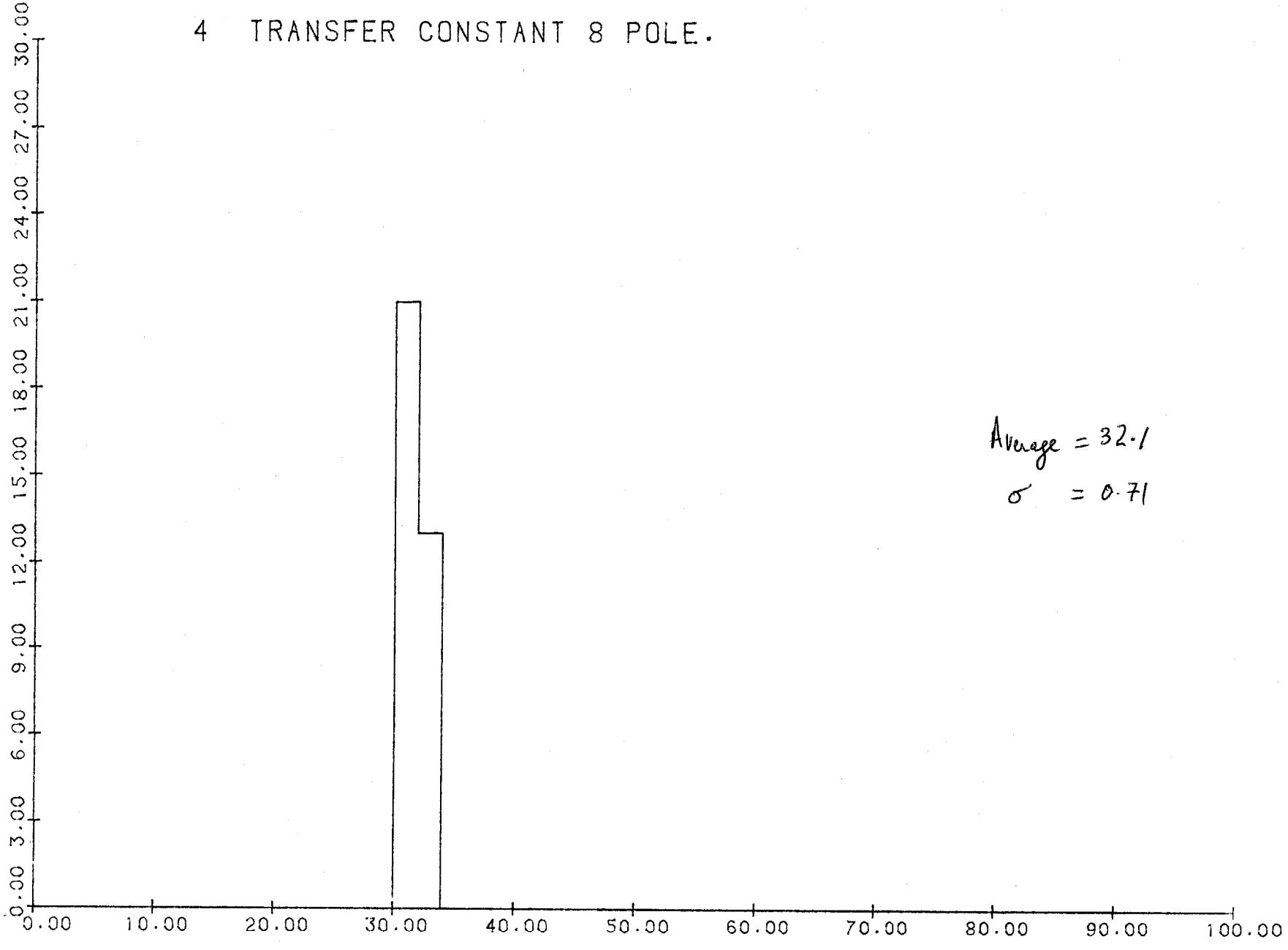
4 TRANSFER CONSTANT 8 POLE.
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Average = 32.1
σ = 0.71

Figure 4

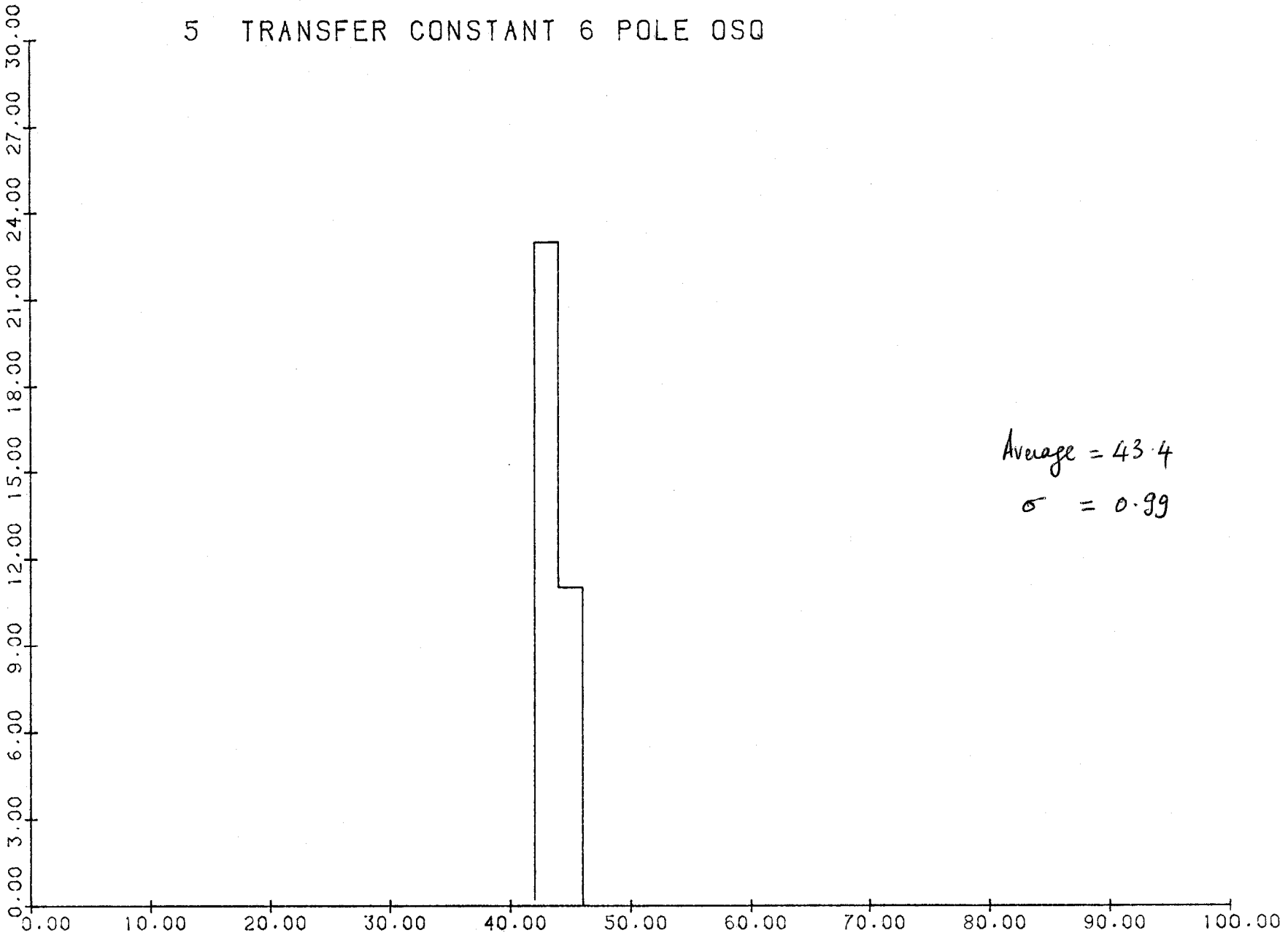
5 TRANSFER CONSTANT 6 POLE OSQ
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
0.00
10.00
20.00
30.00
40.00
50.00
60.00
70.00
80.00
90.00
100.00
Average = 43·4
σ = 0·99

Figure 5

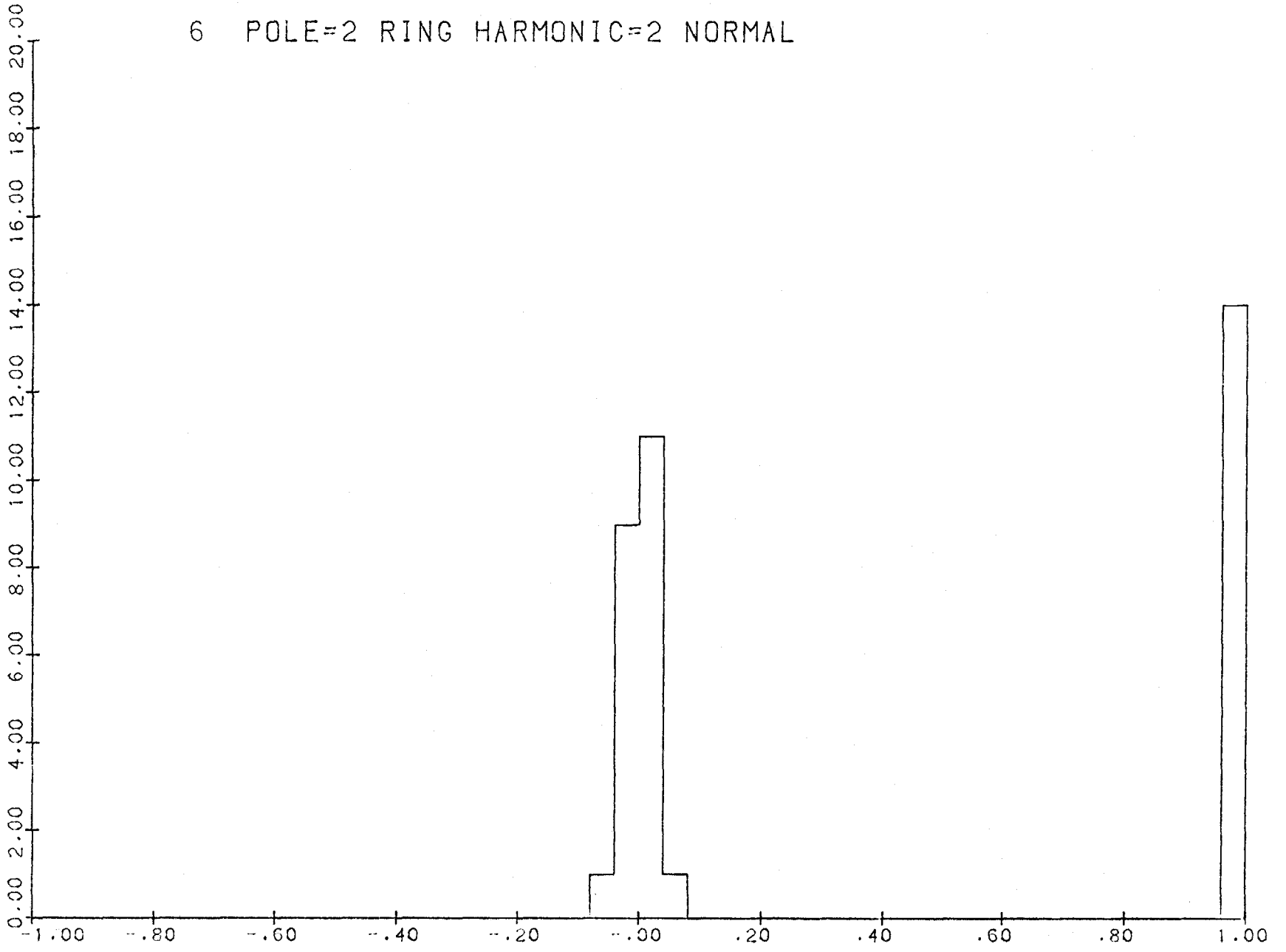
6 POLE=2 RING HARMONIC=2 NORMAL
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00

Figure 6

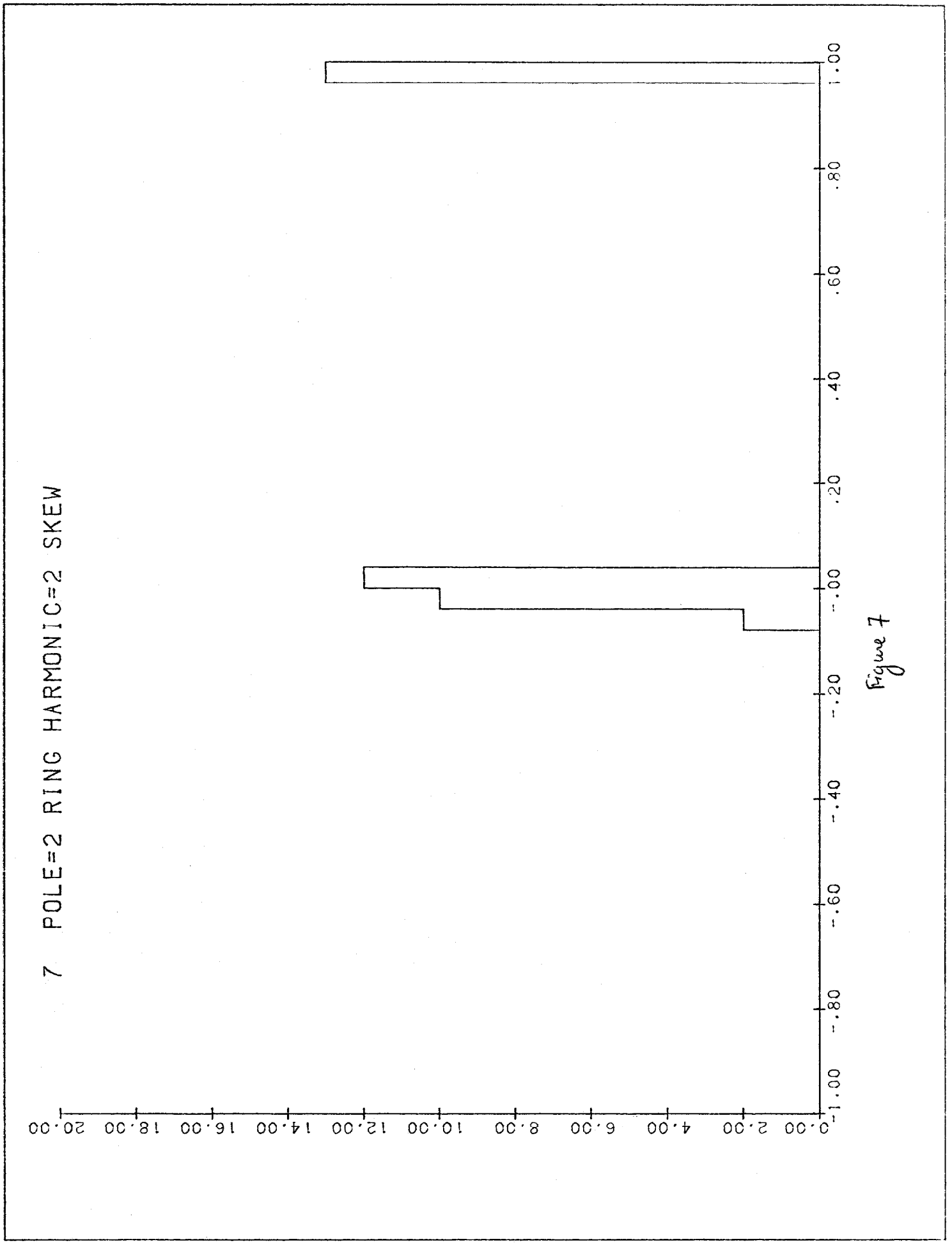
7 POLE=2 RING HARMONIC=2 SKEW
1.00
.80
.60
.40
.20
-.00
-.20
-.40
-.60
-.80
-1.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 7

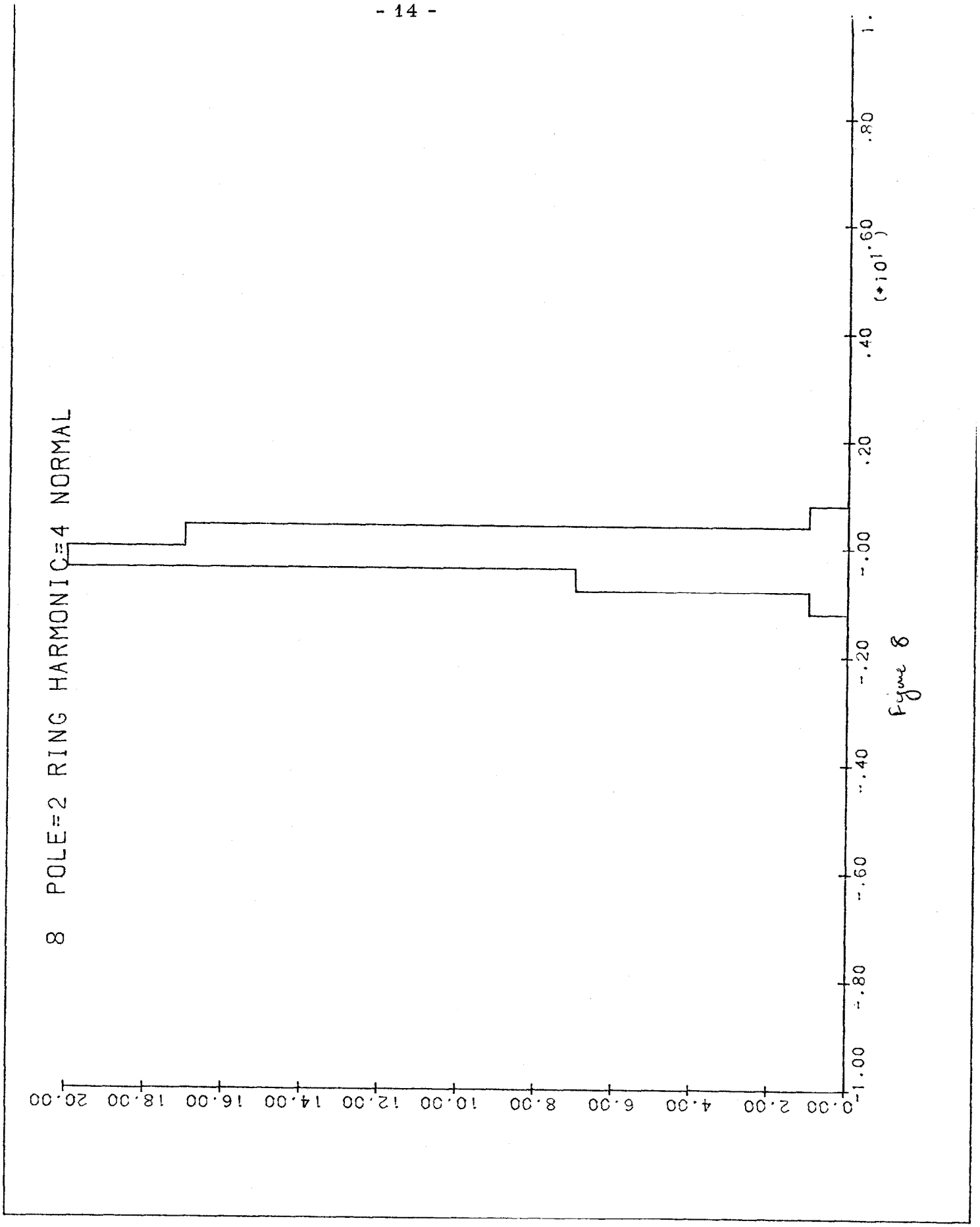
8 POLE=2 RING HARMONIC=4 NORMAL
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.
(*10^-1)

Figure 8

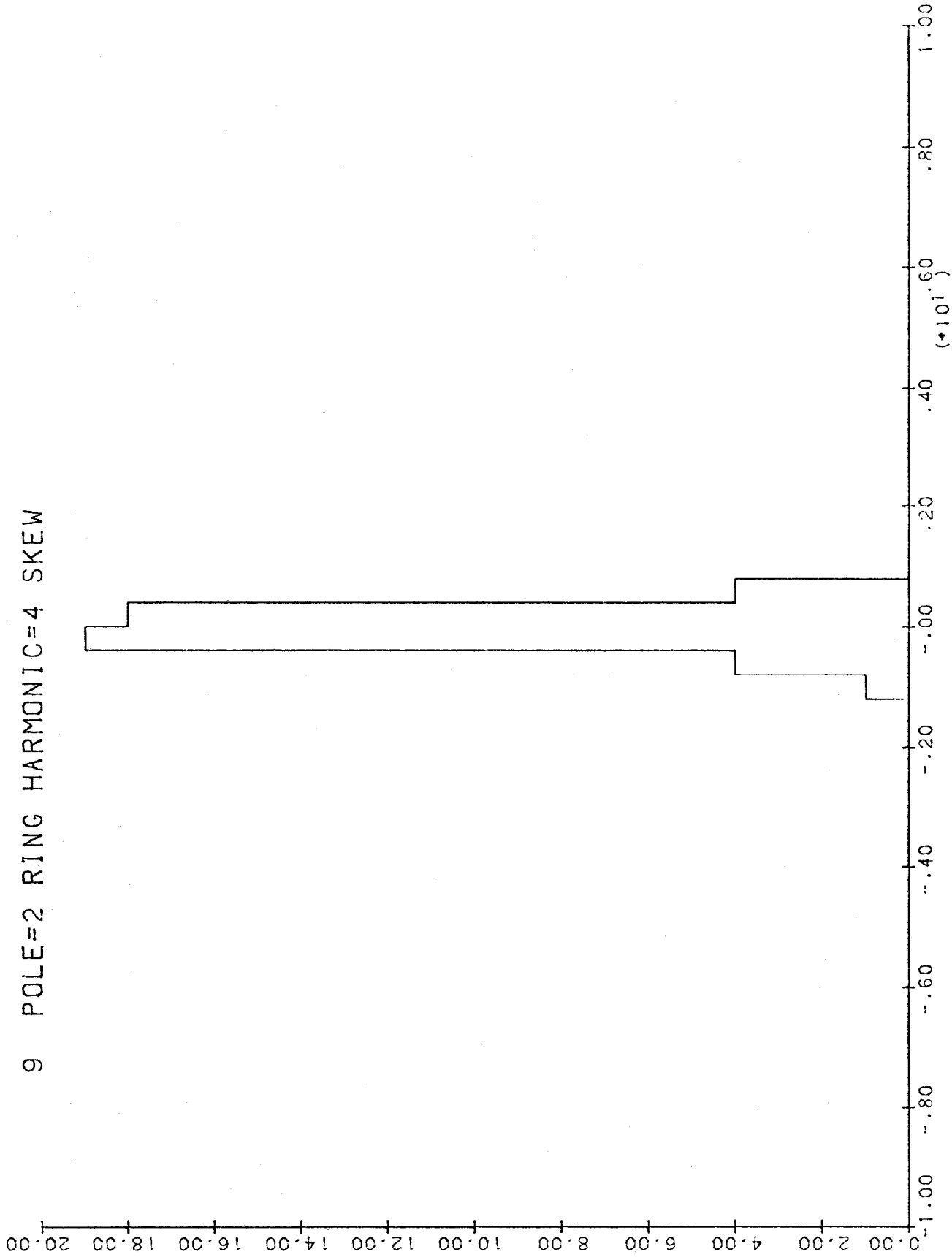
9 POLE=2 RING HARMONIC=4 SKEW
1.00
.80
.60
.40
.20
-.00
-.20
-.40
-.60
-.80
-1.00
(*10^-1)
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 9

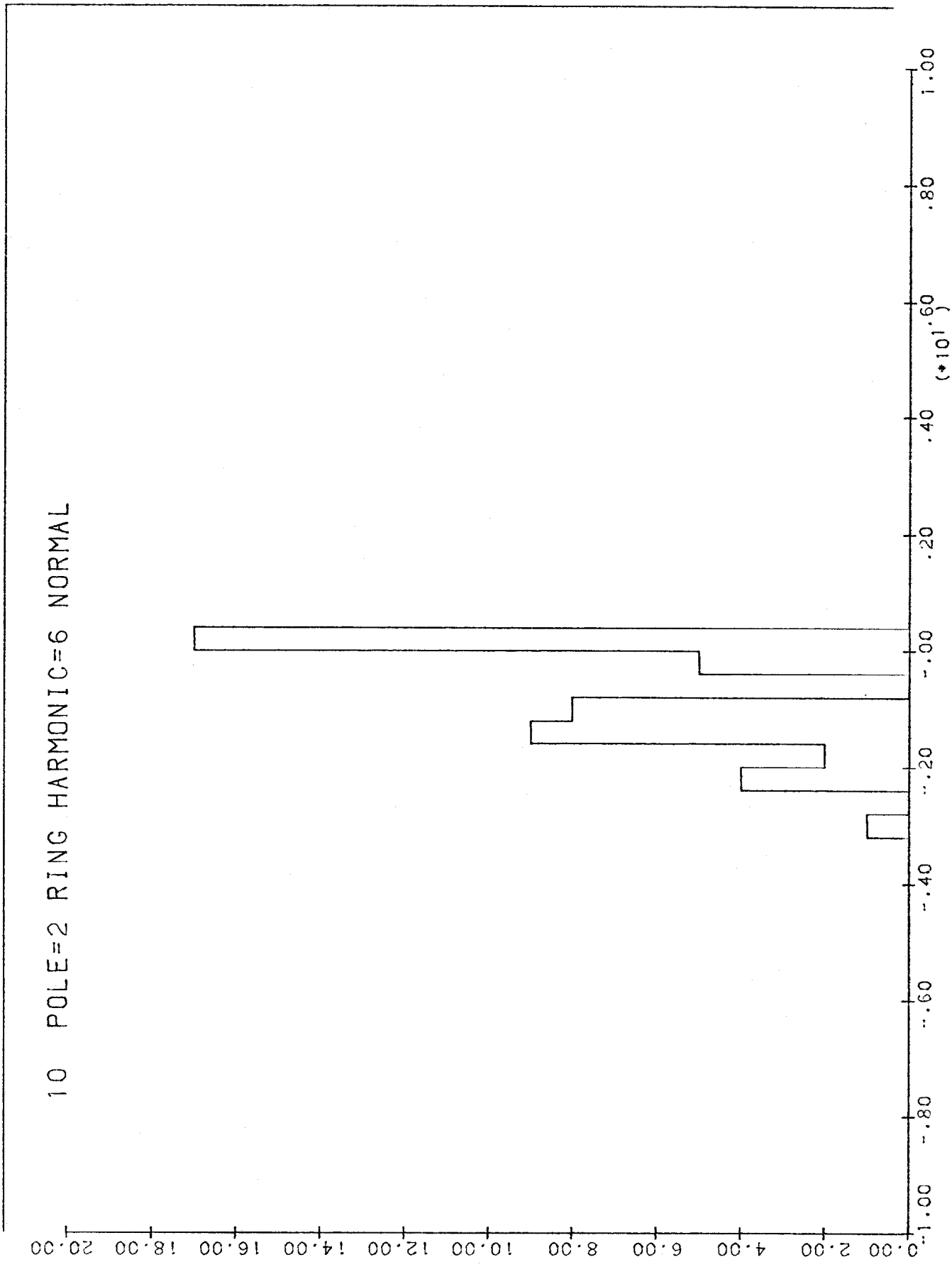
10 POLE=2 RING HARMONIC=6 NORMAL
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1)

Figure 10

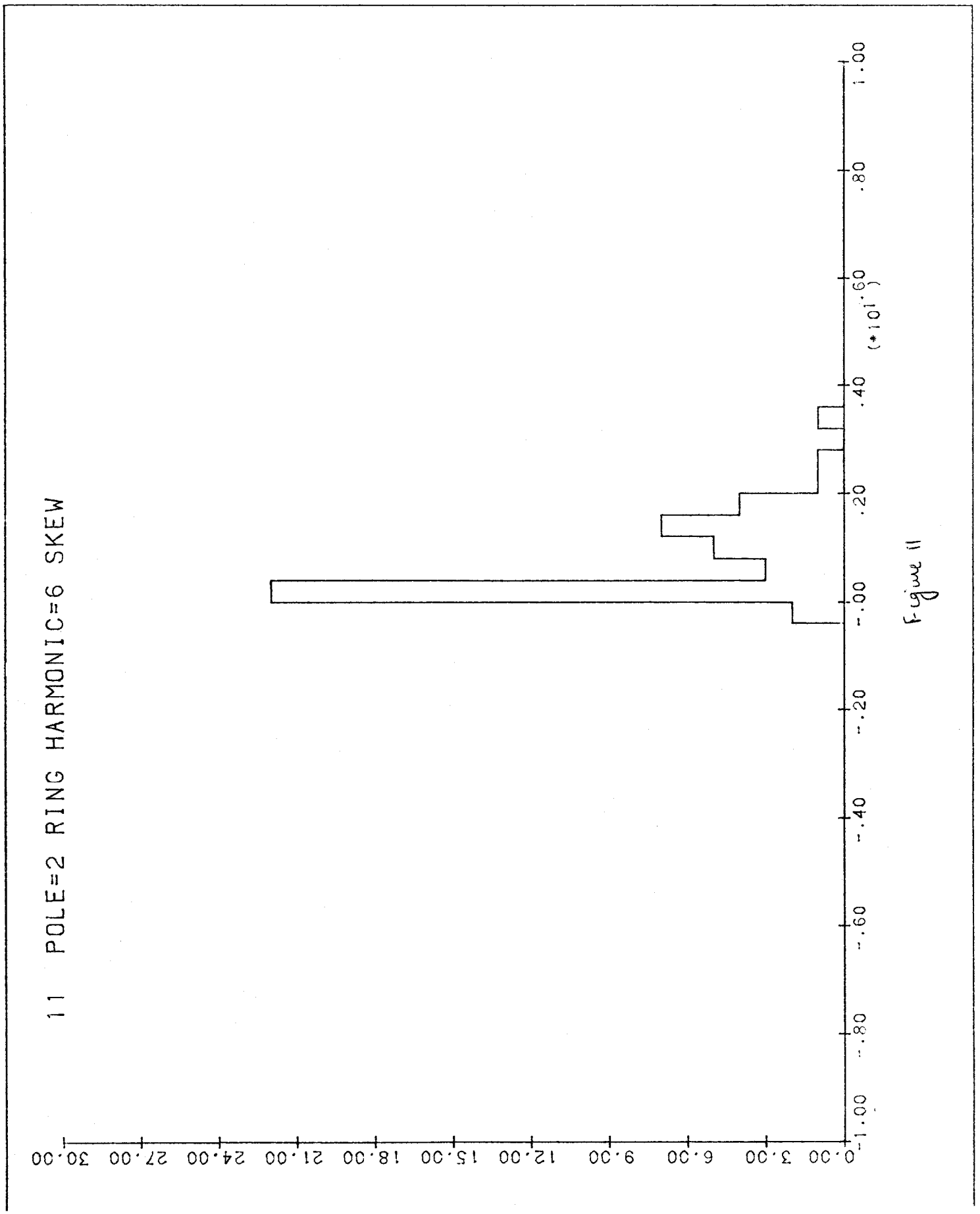
11 POLE=2 RING HARMONIC=6 SKEW
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10**-1)

Figure 11

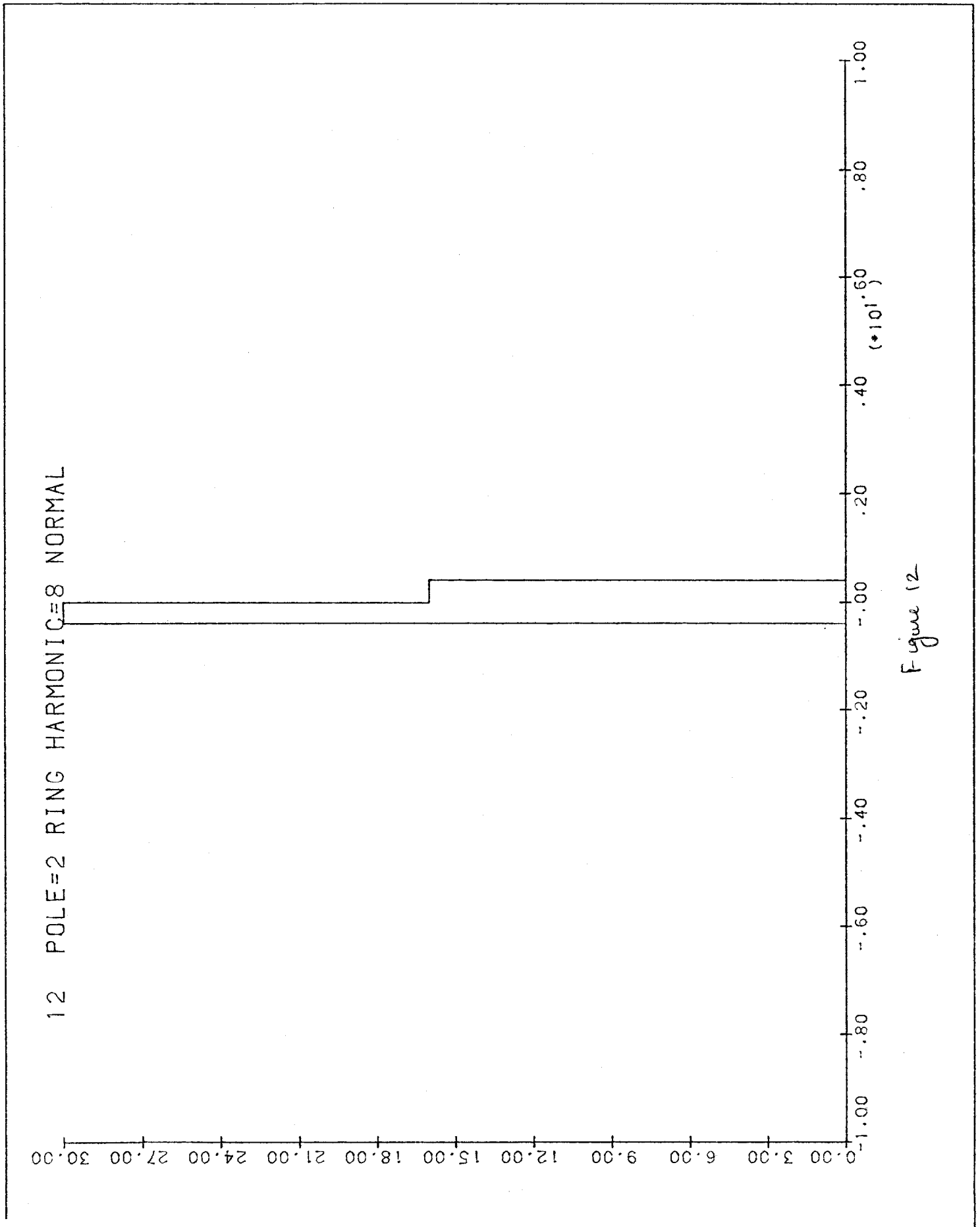
12 POLE=2 RING HARMONIC=8 NORMAL
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10¹)

Figure 12

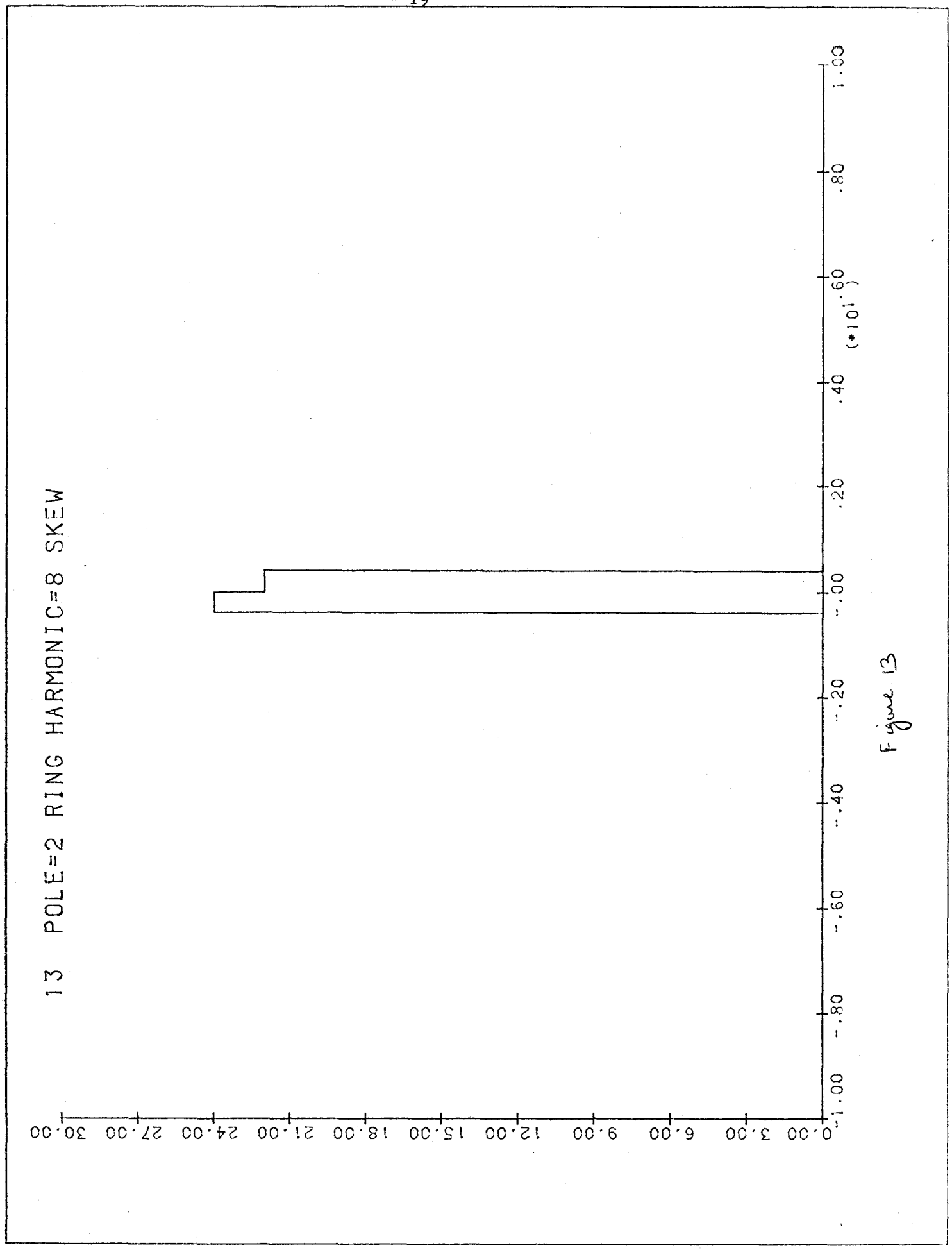
13 POLE=2 RING HARMONIC=8 SKEW
1.00
.80
.60
.40
.20
.00
-.20
-.40
-.60
-.80
-1.00
(*10^-1)
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00

Figure 13

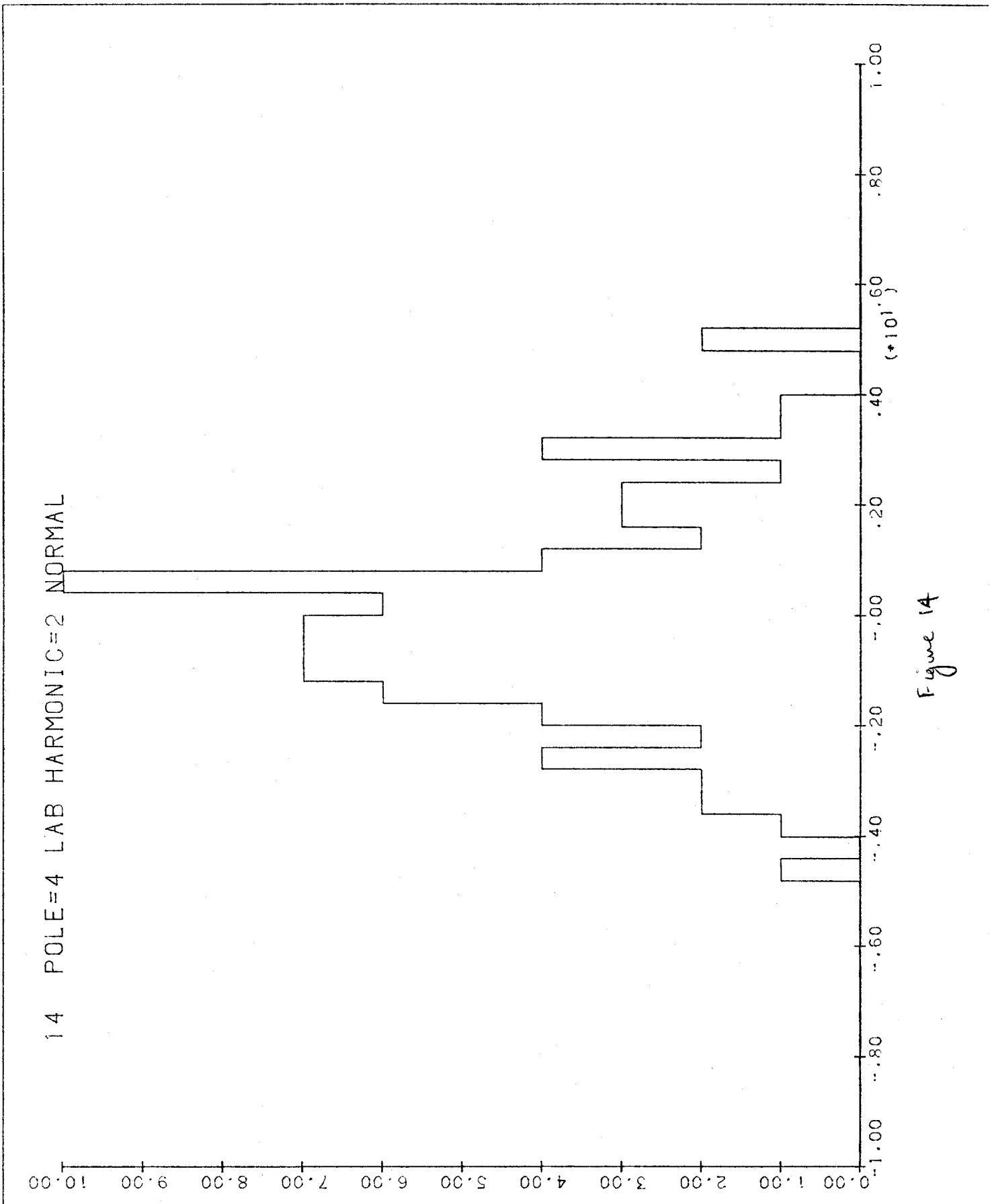
14 POLE=4 LAB HARMONIC=2 NORMAL
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1)
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00

Figure 14

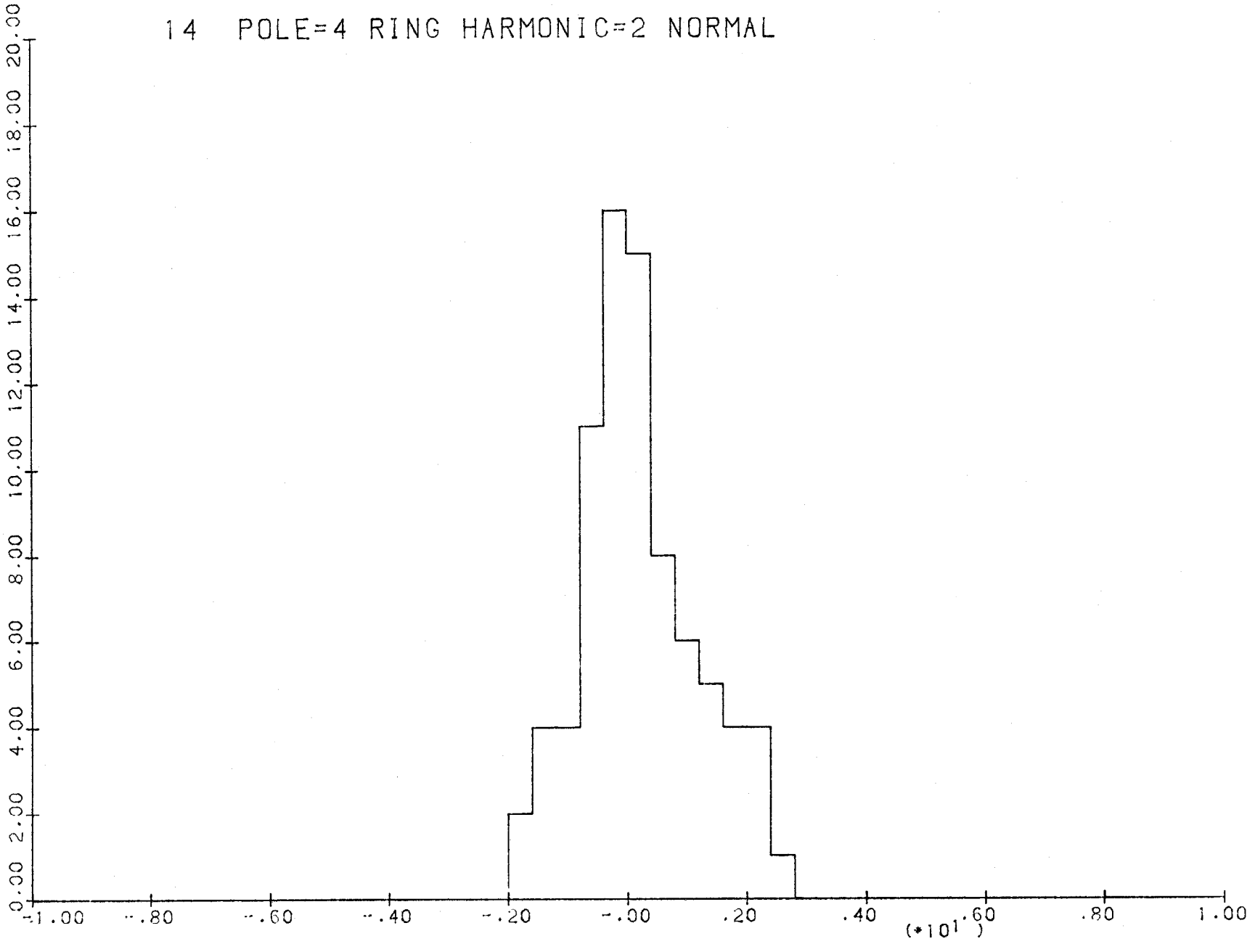
14 POLE=4 RING HARMONIC=2 NORMAL
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10¹)

Figure 15

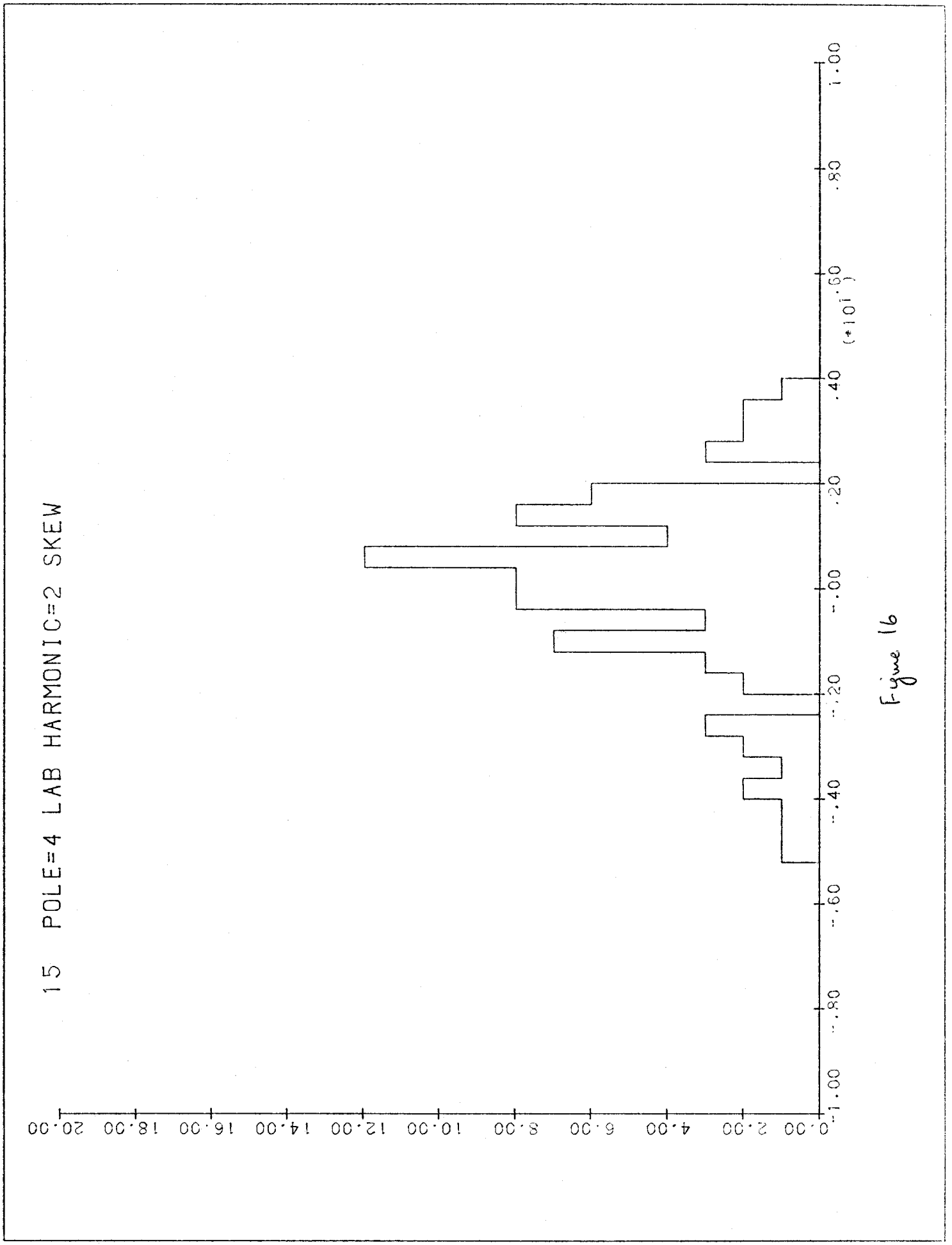
15 POLE=4 LAB HARMONIC=2 SKEW
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1)

Figure 16

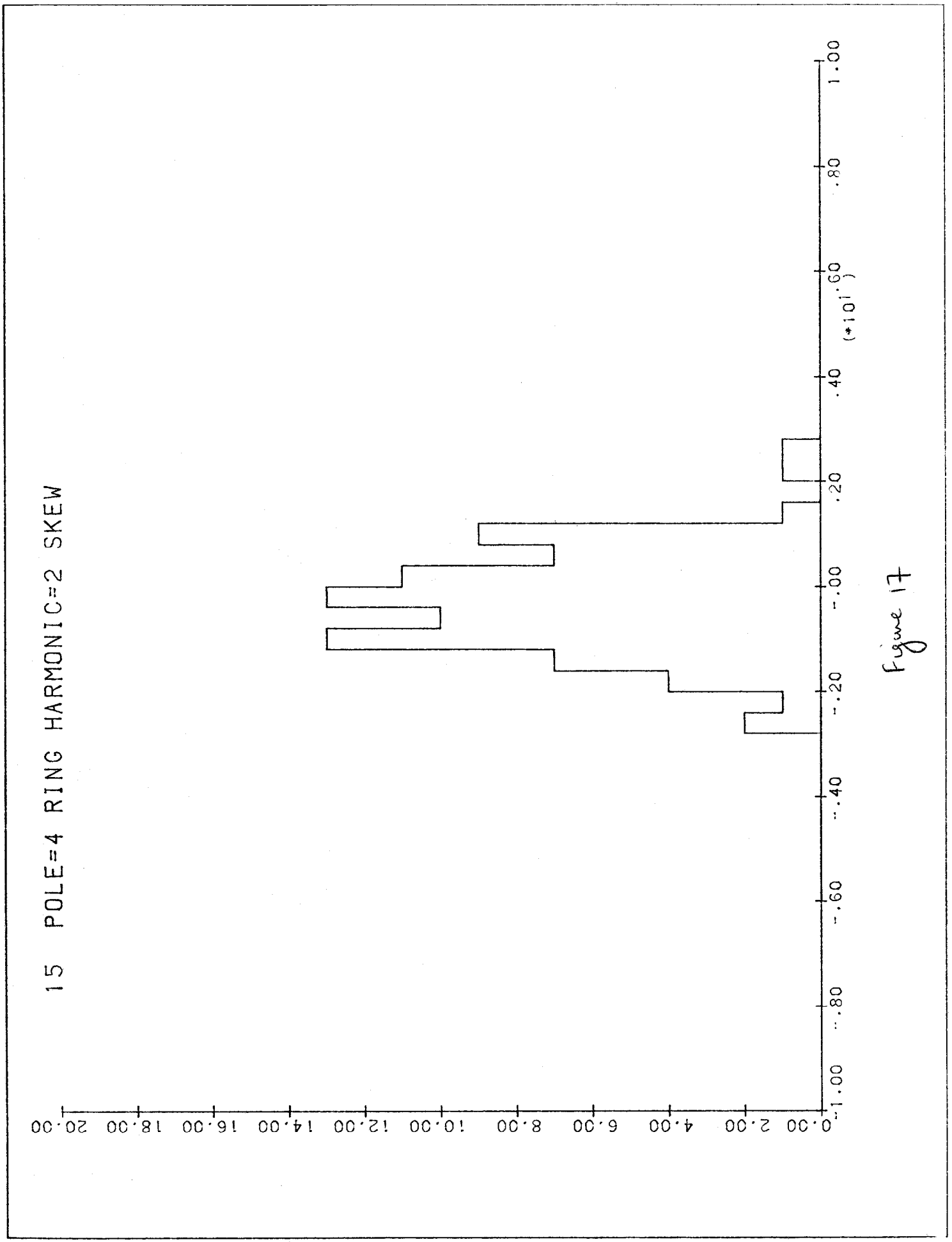
15 POLE=4 RING HARMONIC=2 SKEW
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1)

Figure 17

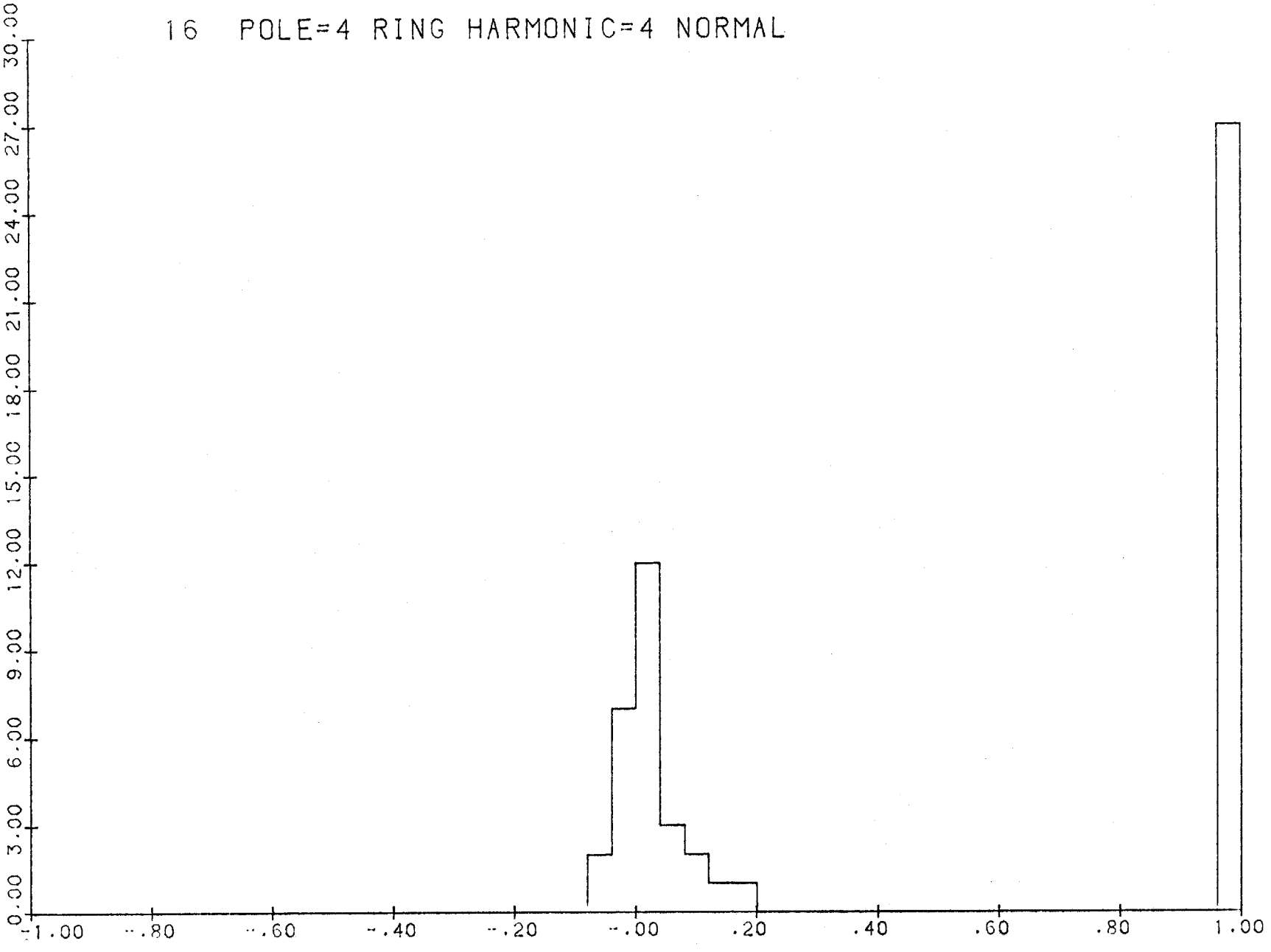
16 POLE=4 RING HARMONIC=4 NORMAL
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00

Figure 18

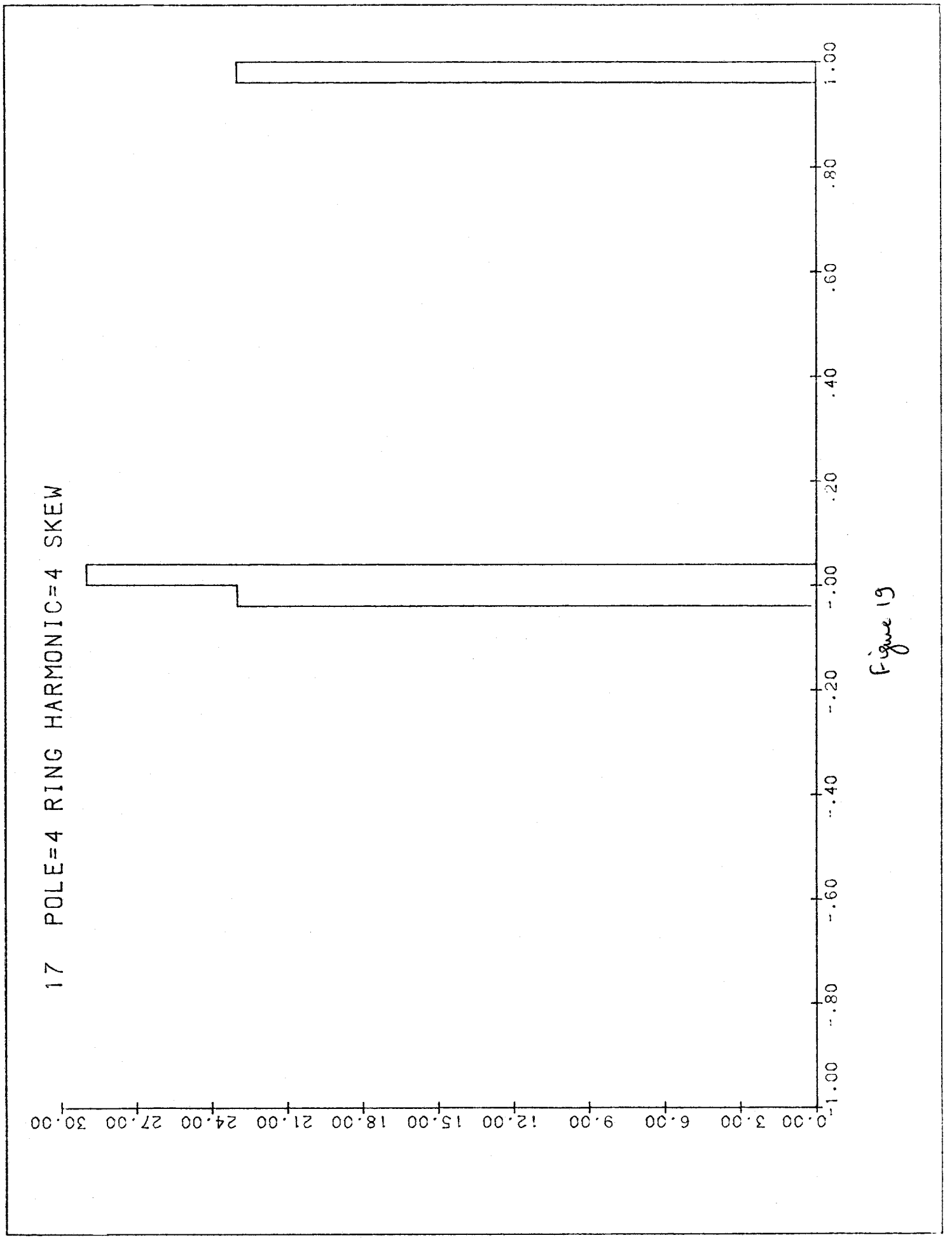
17 POLE=4 RING HARMONIC=4 SKEW
1.00
.80
.60
.40
.20
-.00
-.20
-.40
-.60
-.80
-1.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00

Figure 19

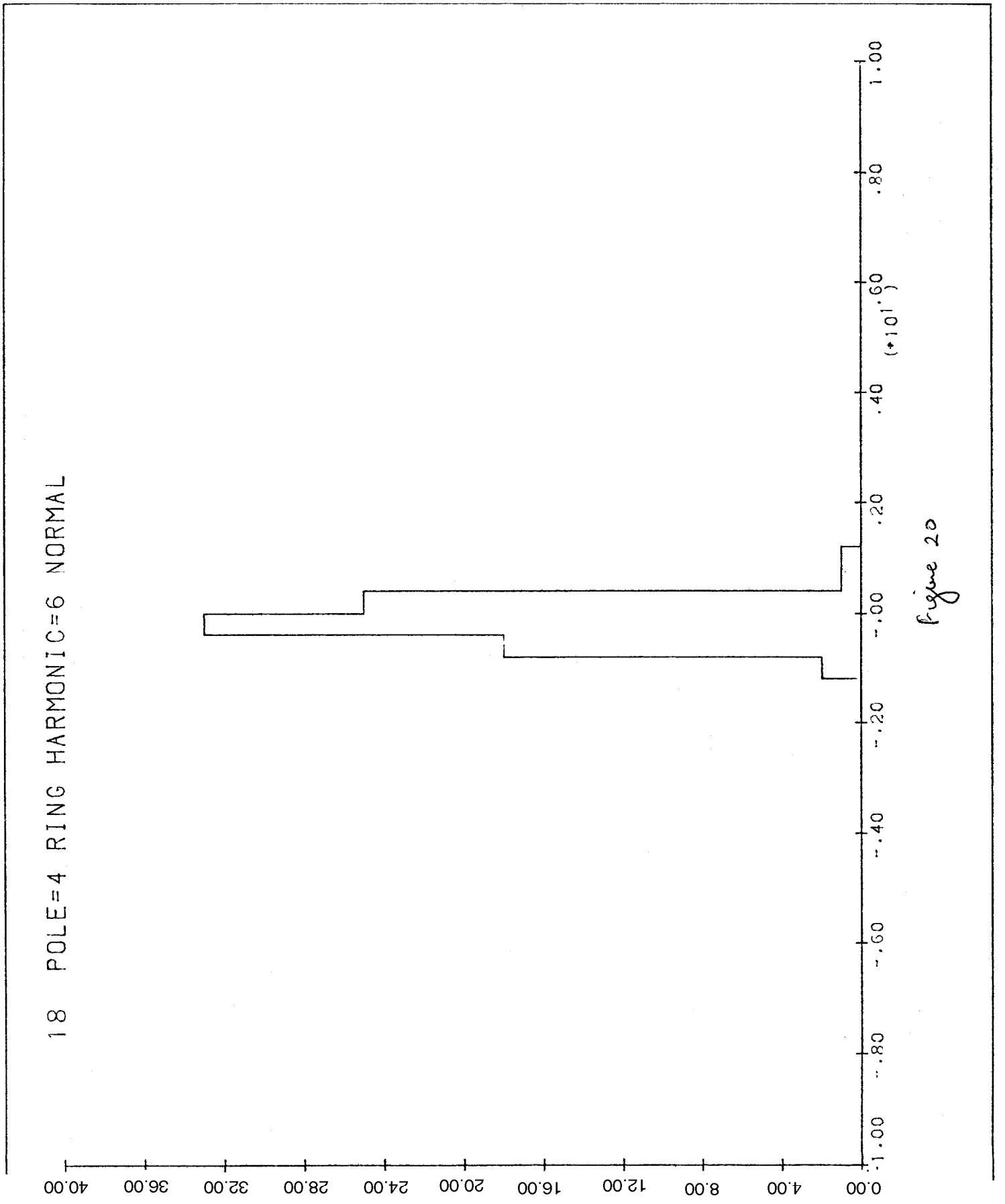
18 POLE=4 RING HARMONIC=6 NORMAL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^1.60)

figure 20

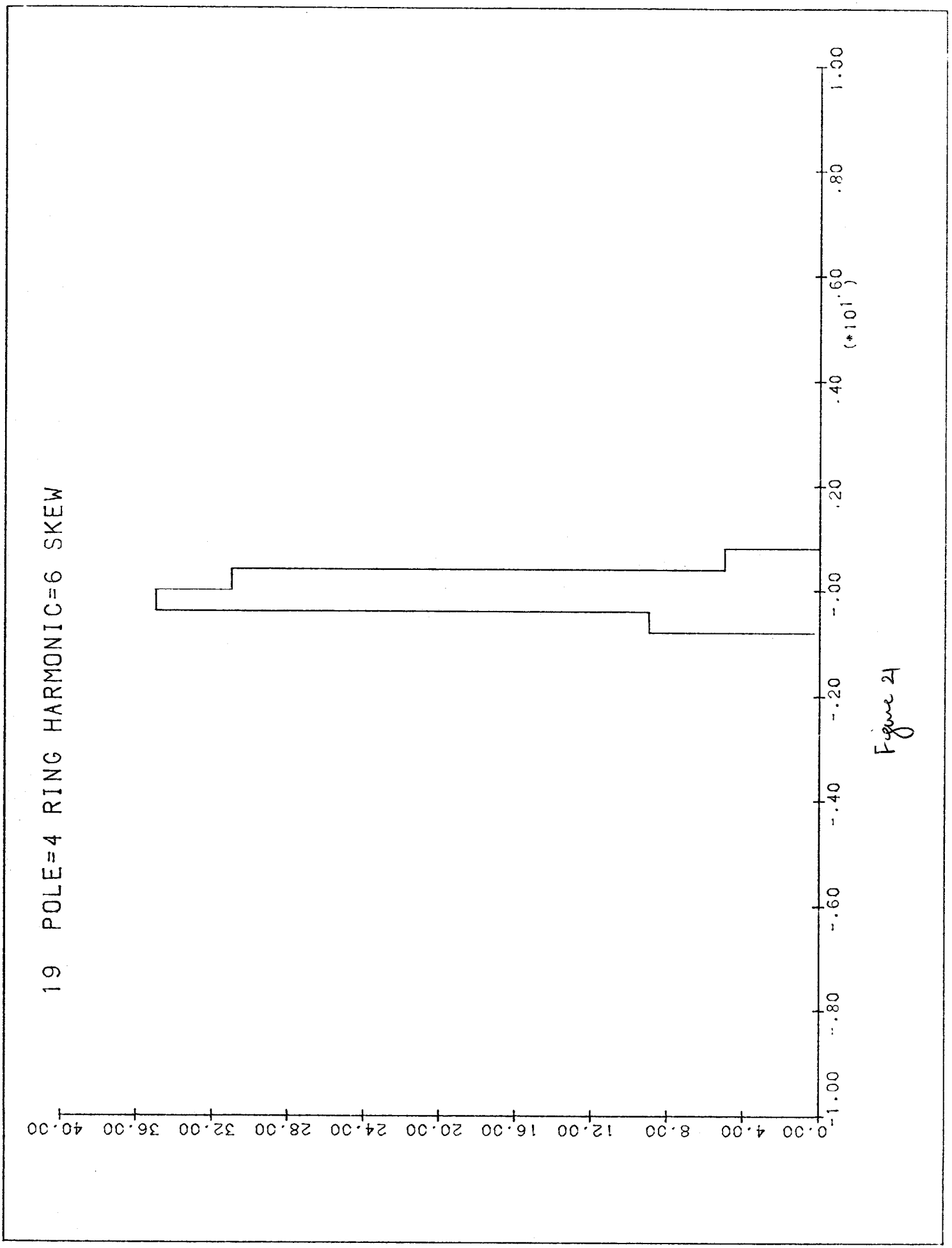
19 POLE=4 RING HARMONIC=6 SKEW
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
1.00
.80
(*10^-1)

Figure 24

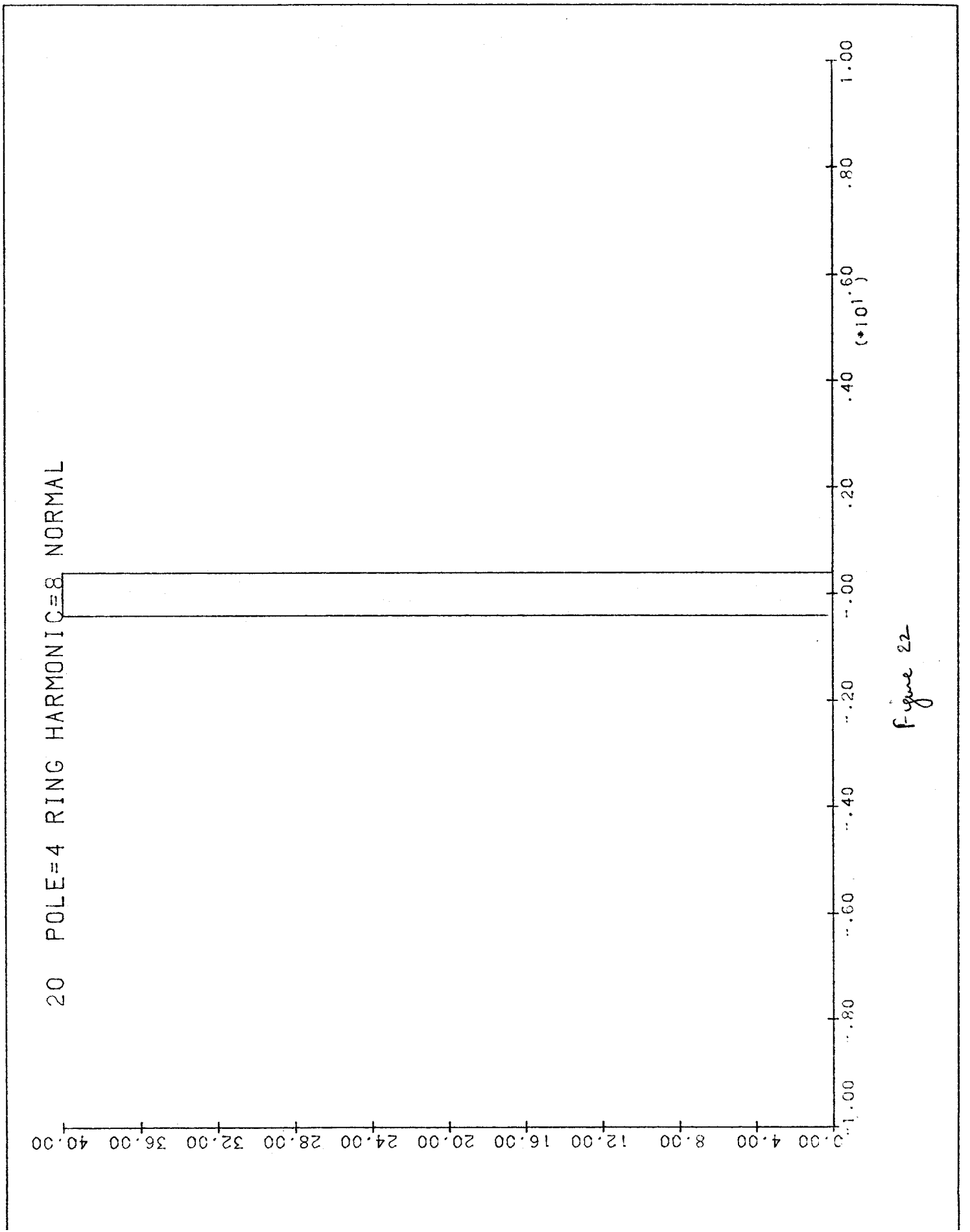
20 POLE=4 RING HARMONIC=8 NORMAL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10**)

Figure 22

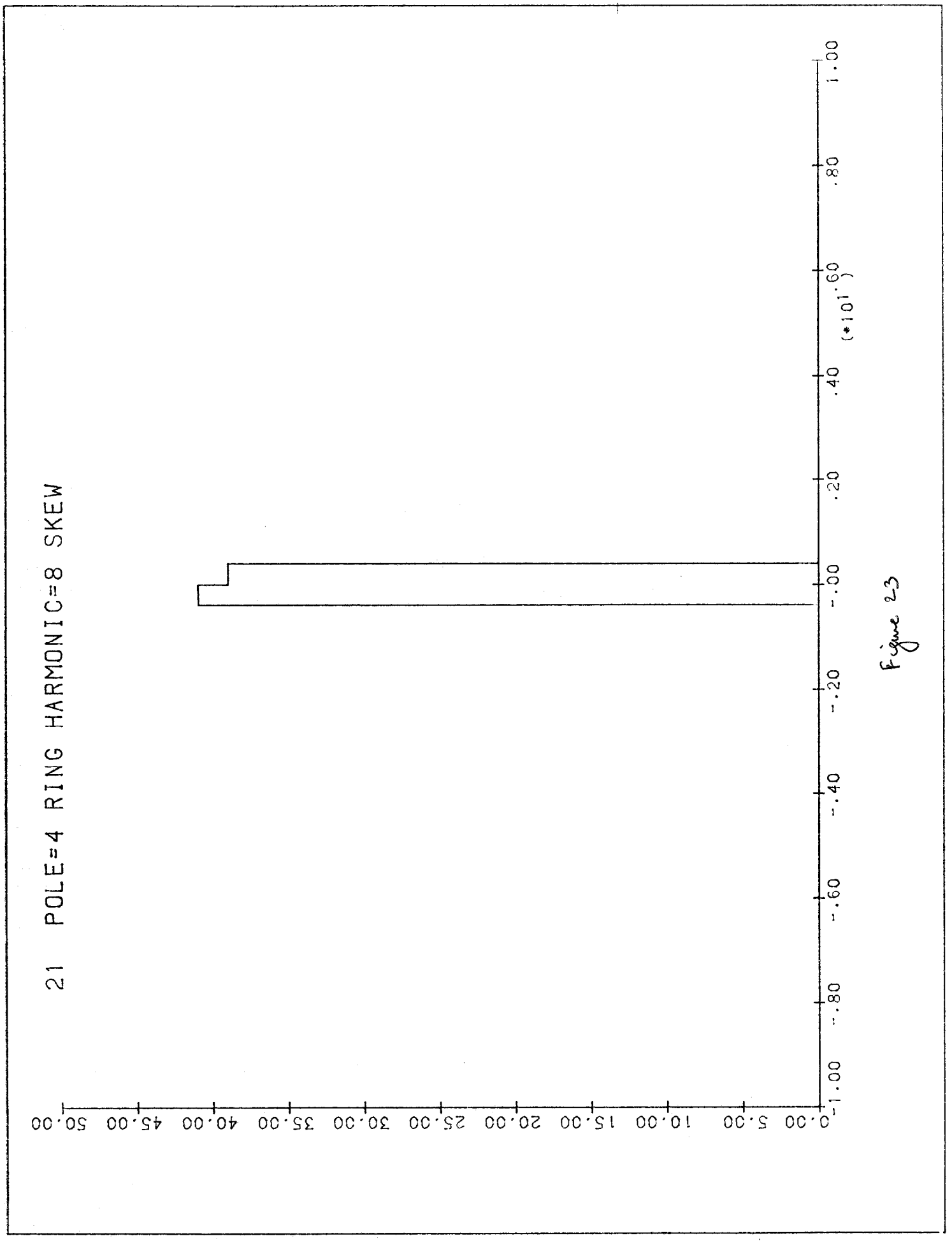
21 POLE=4 RING HARMONIC=8 SKEW
0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00 50.00
-1.00 -.80 -.60 -.40 -.20 -.00 .20 .40 (*10^-60) .80 1.00

Figure 23

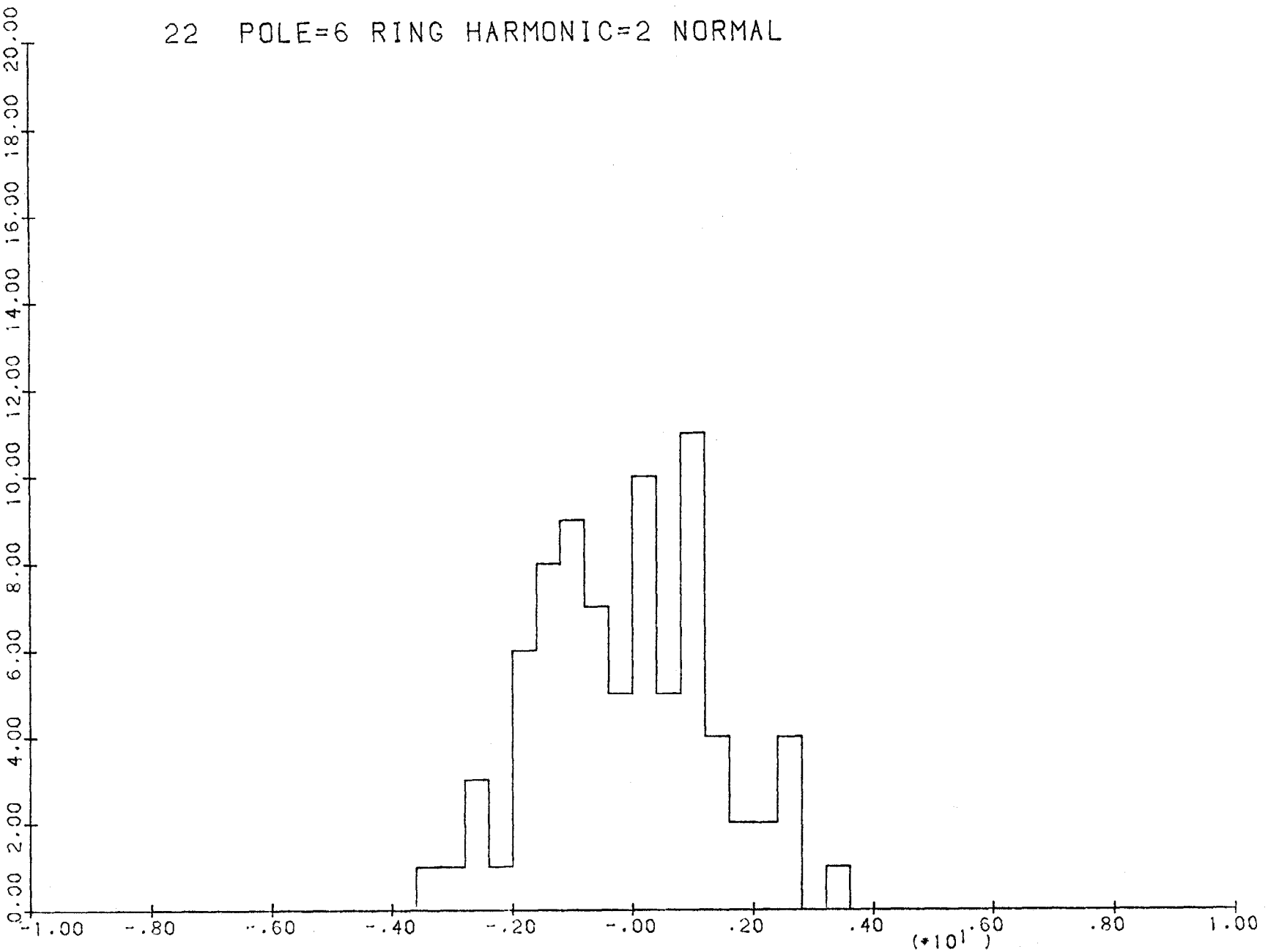
22 POLE=6 RING HARMONIC=2 NORMAL
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10¹)

Figure 24

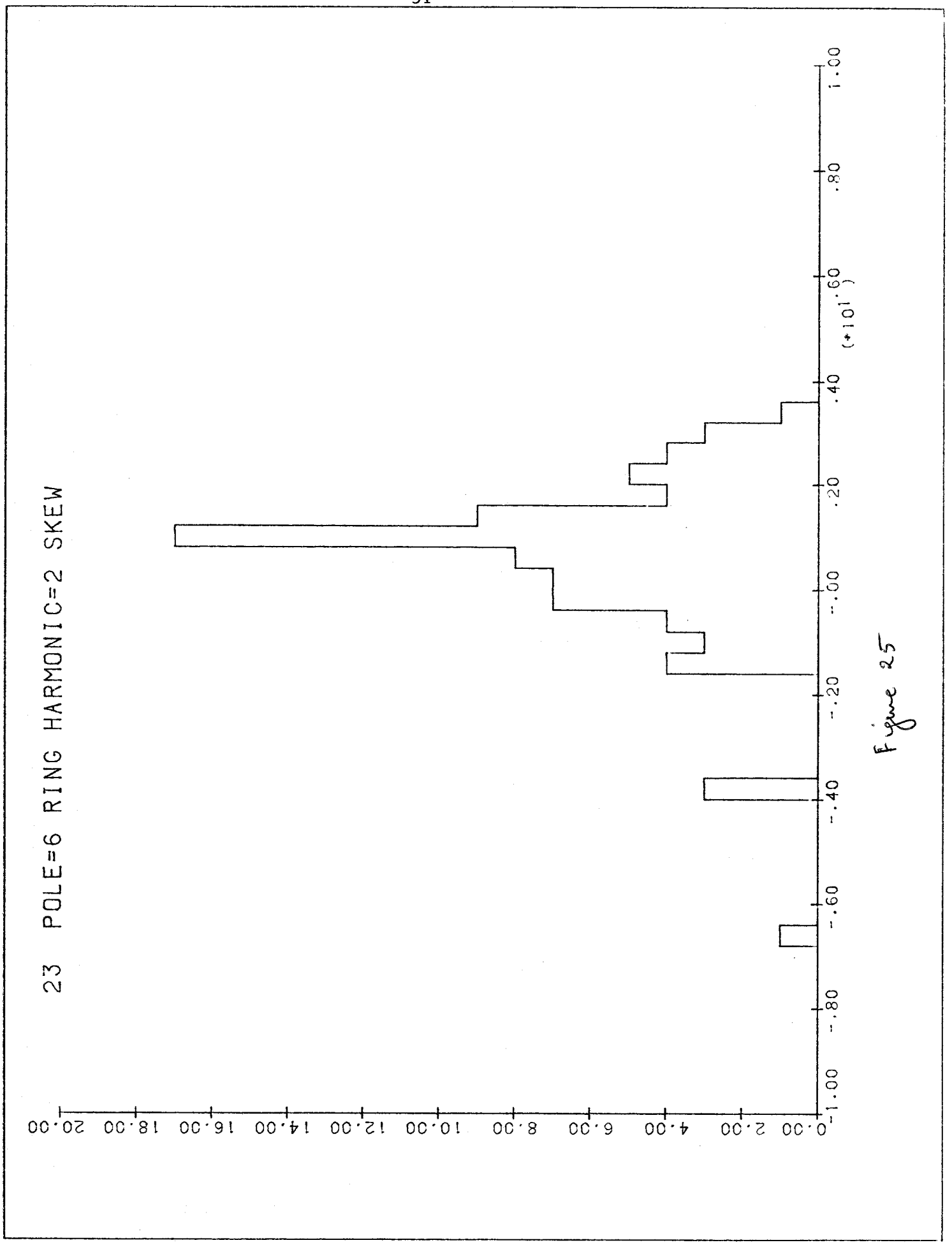
23 POLE=6 RING HARMONIC=2 SKEW
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
1.00
.80
.60
.40
.20
-.00
-.20
-.40
-.60
-.80
-1.00
(*10^-1)

Figure 25

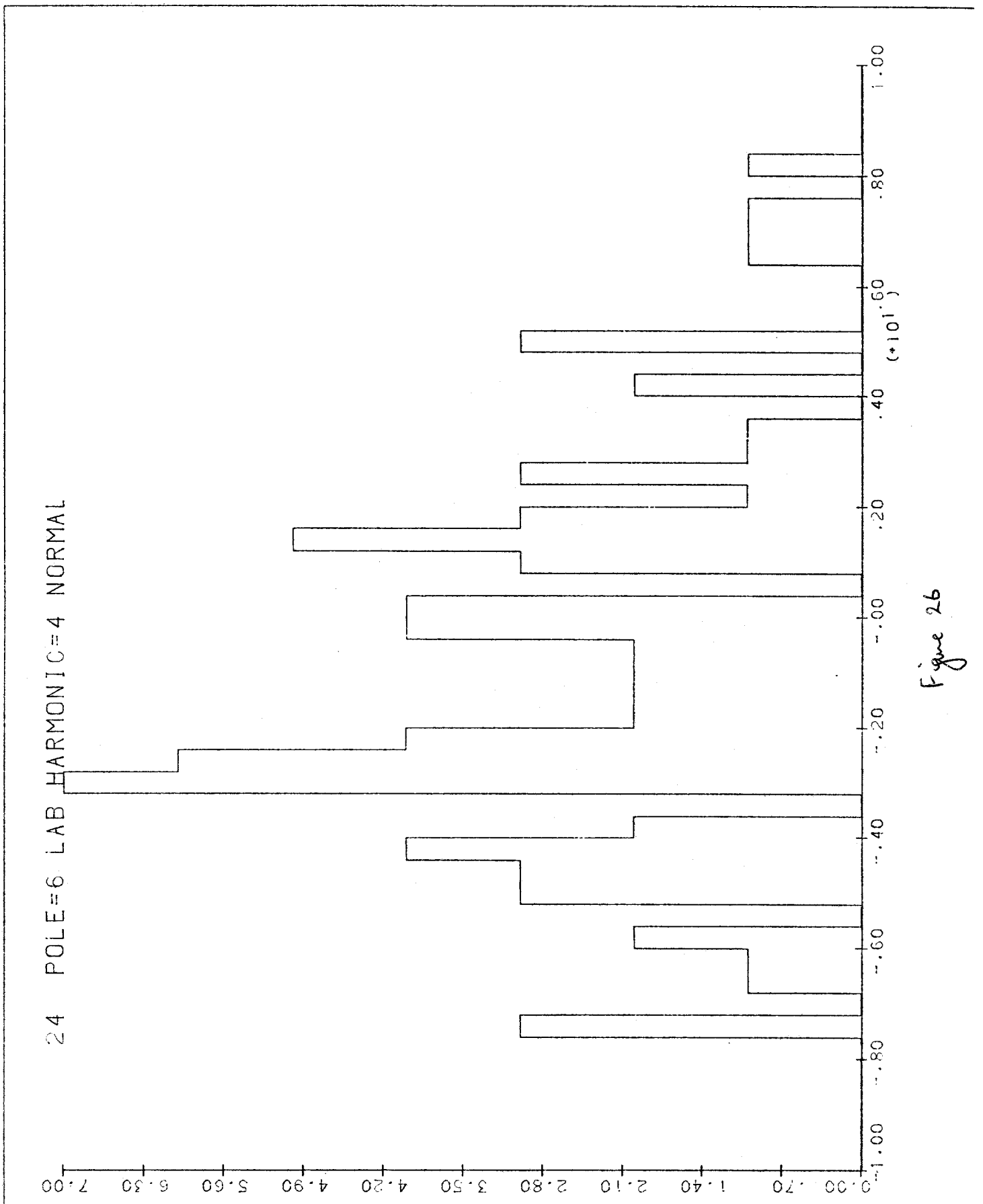
24 POLE=6 LAB HARMONIC=4 NORMAL
0.00
.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30
7.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1)

Figure 26

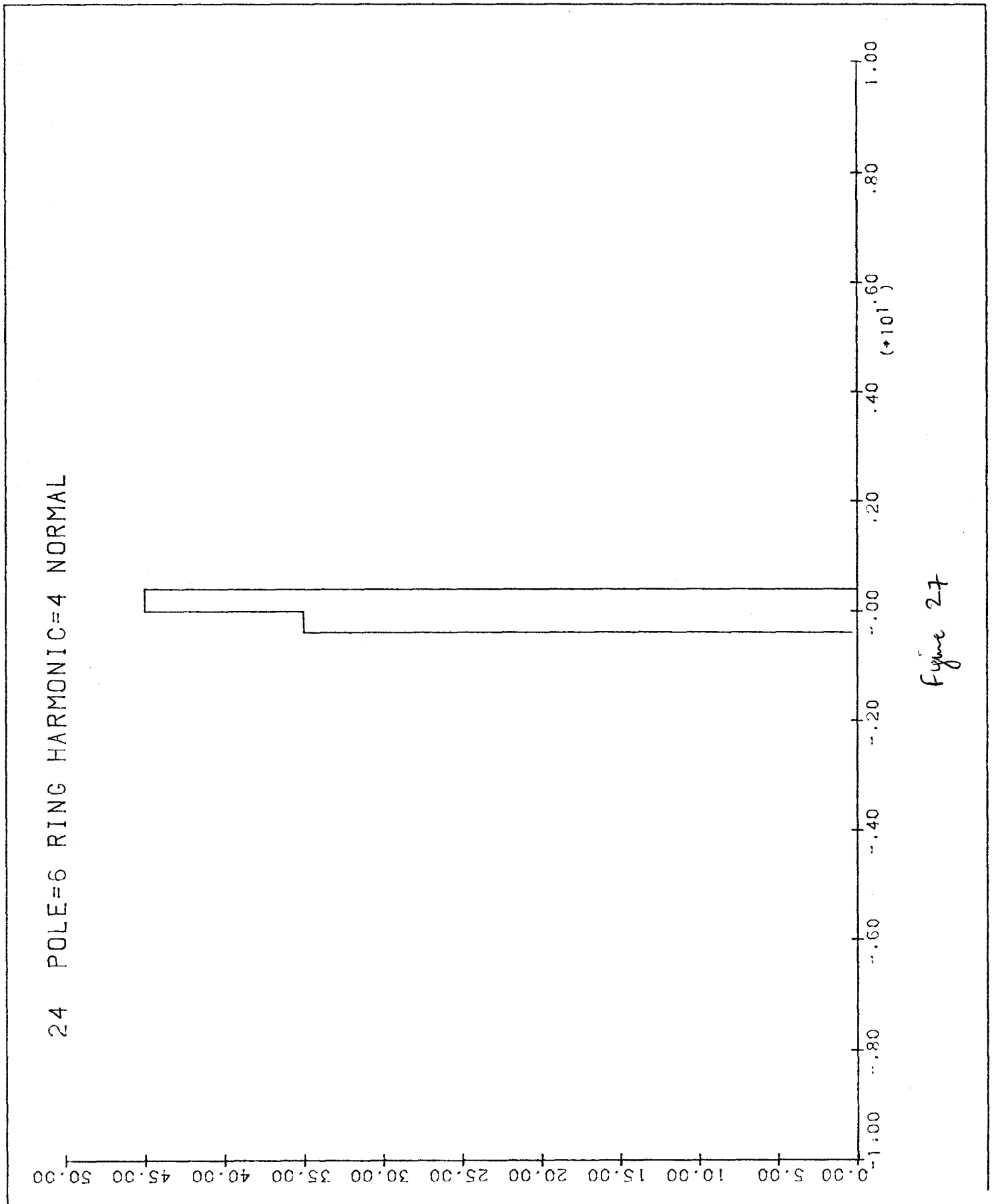
24 POLE=6 RING HARMONIC=4 NORMAL
0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00 50.00
-1.00 -.80 -.60 -.40 -.20 .00 .20 .40 .60 .80 1.00
(*10^1)

Figure 27

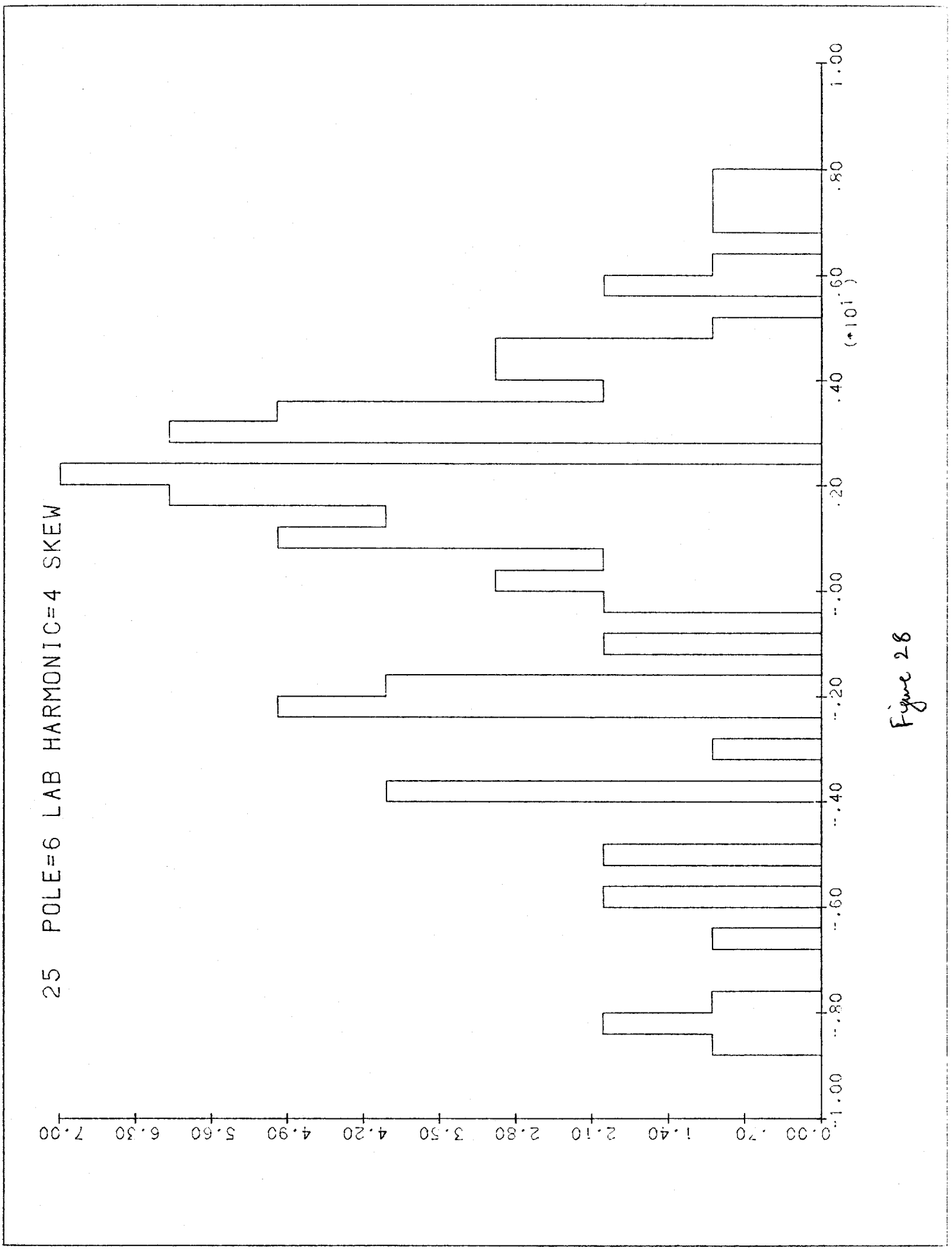
25 POLE=6 LAB HARMONIC=4 SKEW
0.00
.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30
7.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-6)

Figure 28

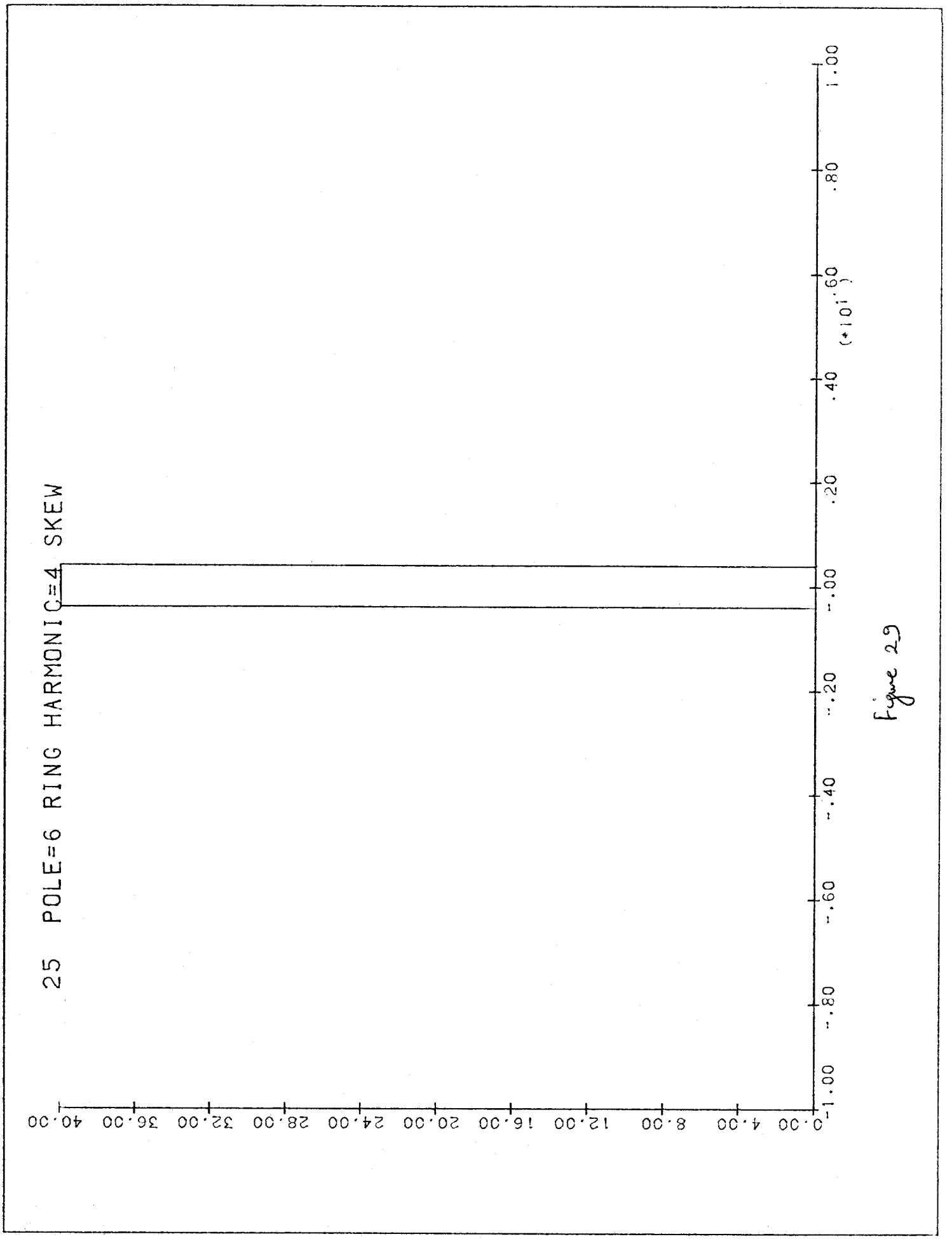
25 POLE=6 RING HARMONIC=4 SKEW
1.00
.80
.60
.40
.20
-.00
-.20
-.40
-.60
-.80
-1.00
(*10**-1)
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00

Figure 29

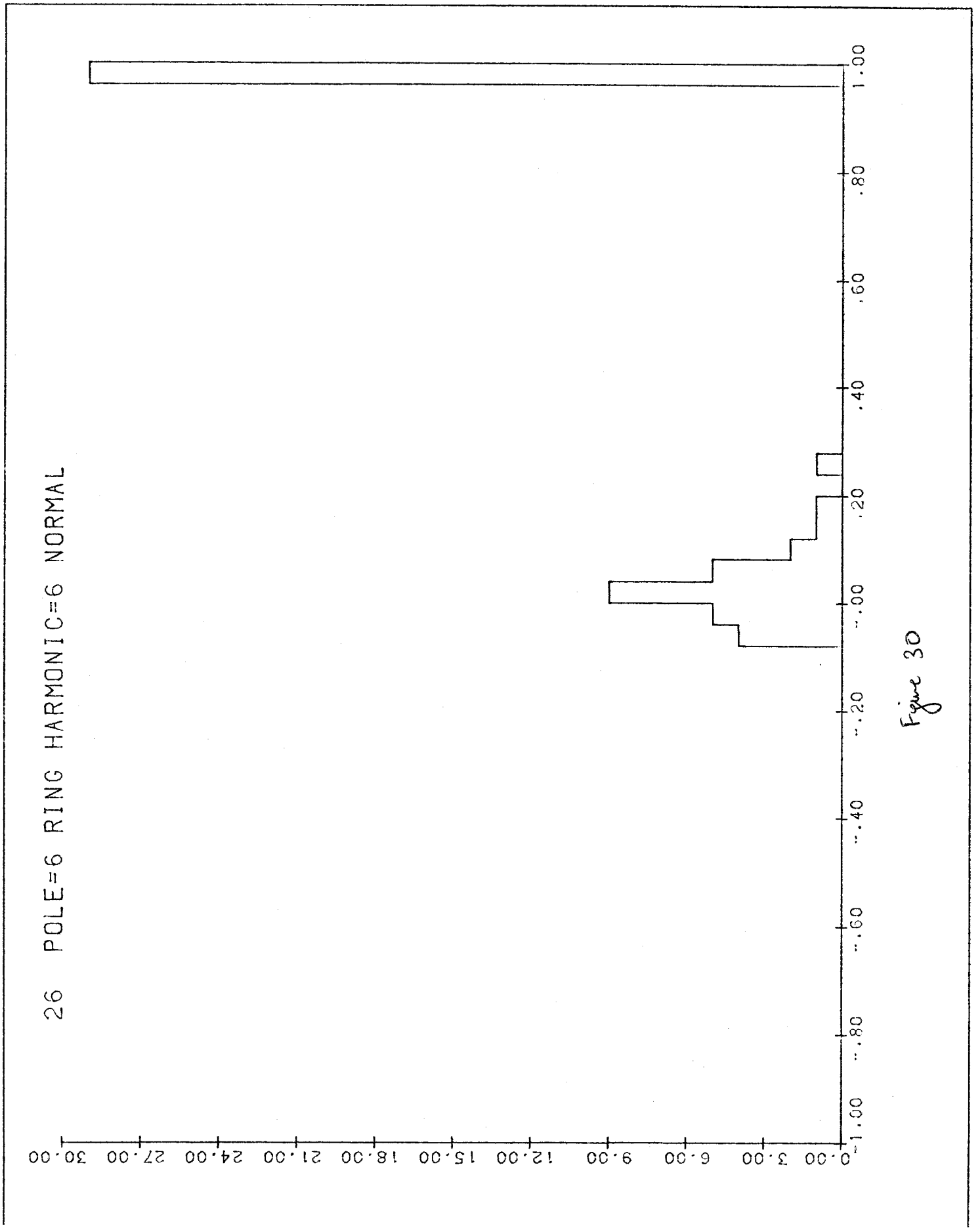
26 POLE=6 RING HARMONIC=6 NORMAL
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00

Figure 30

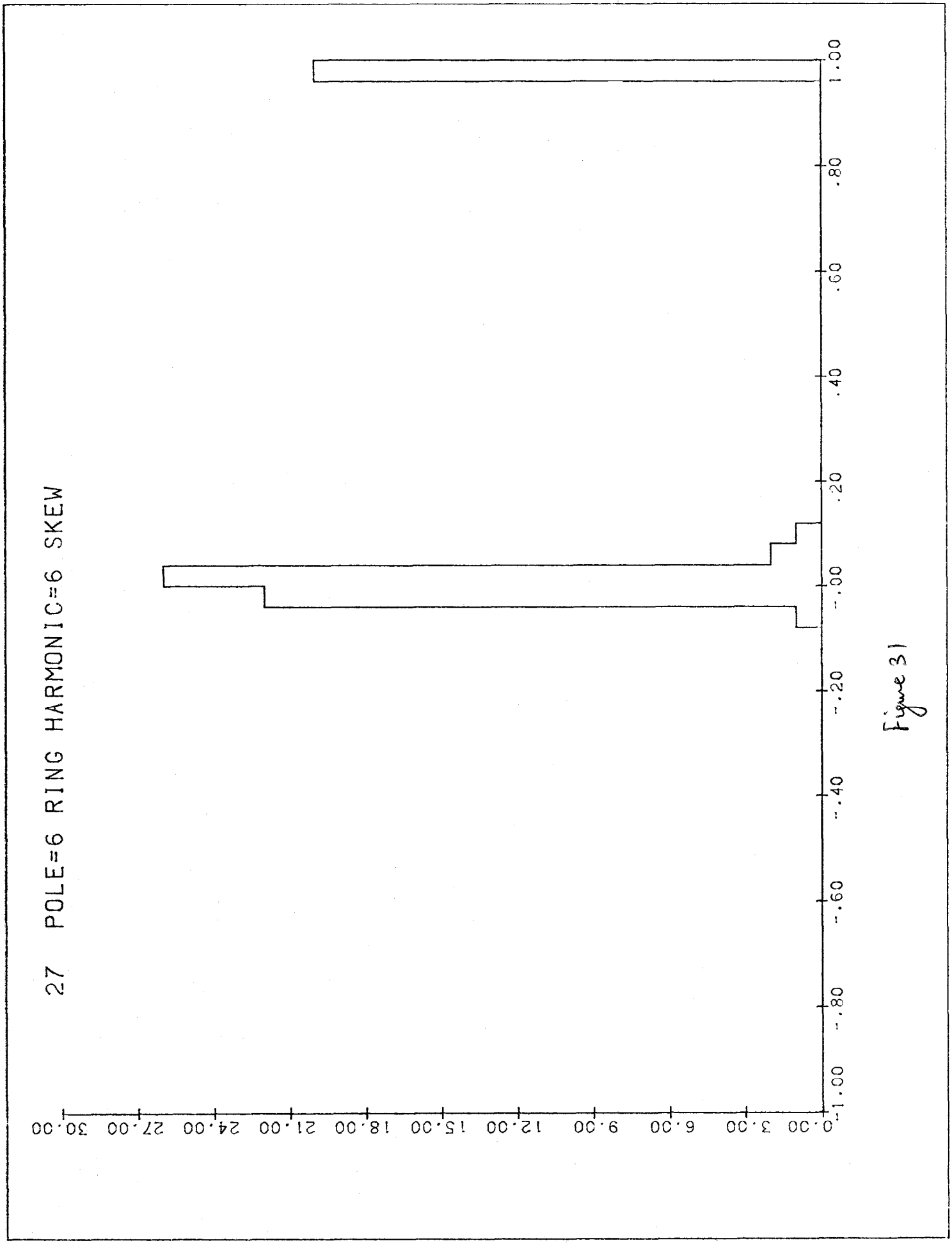
27 POLE=6 RING HARMONIC=6 SKEW
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
1.00
.80
.60
.40
.20
-.00
-.20
-.40
-.60
-.80
-1.00

Figure 31

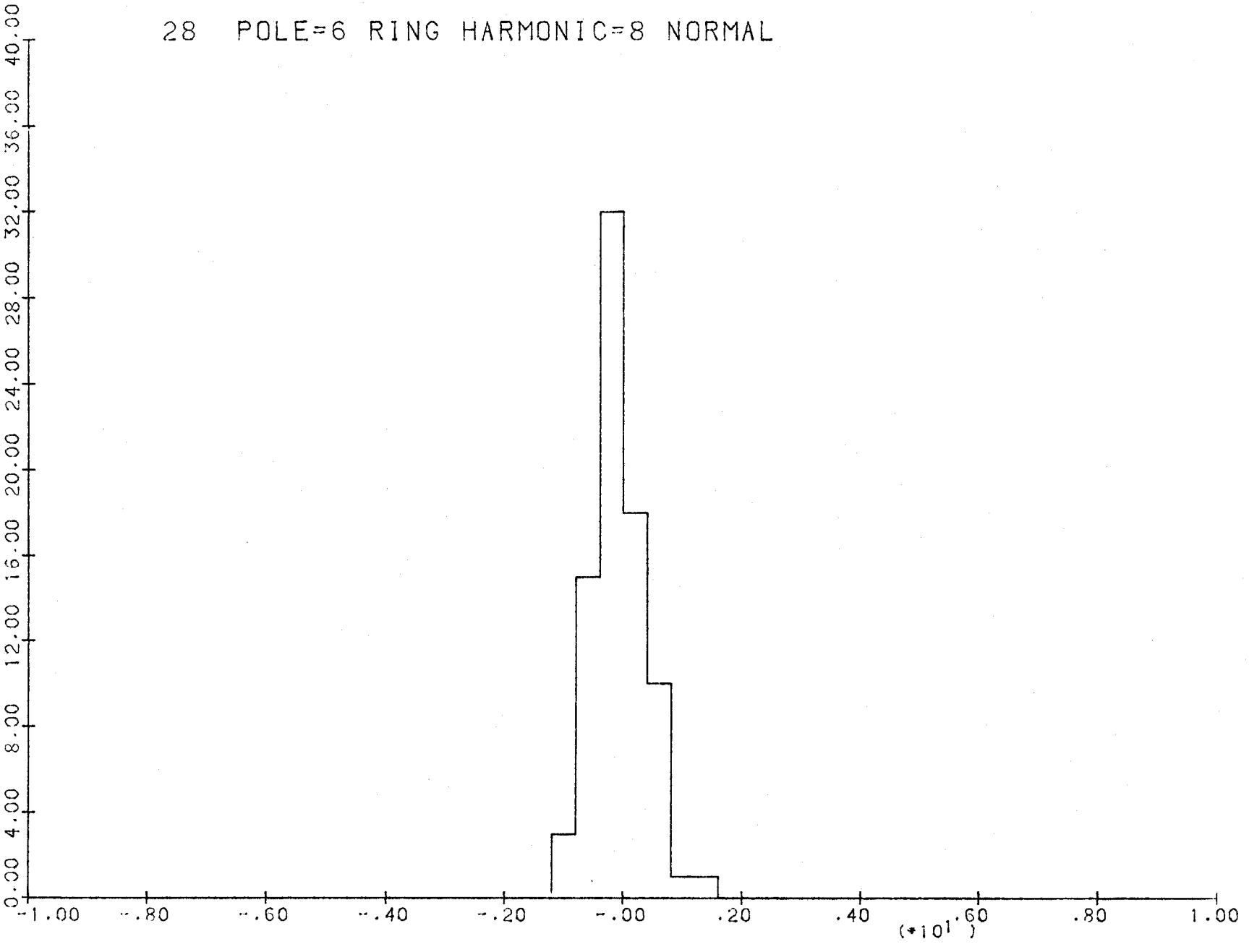
28 POLE=6 RING HARMONIC=8 NORMAL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10¹)

Figure 32

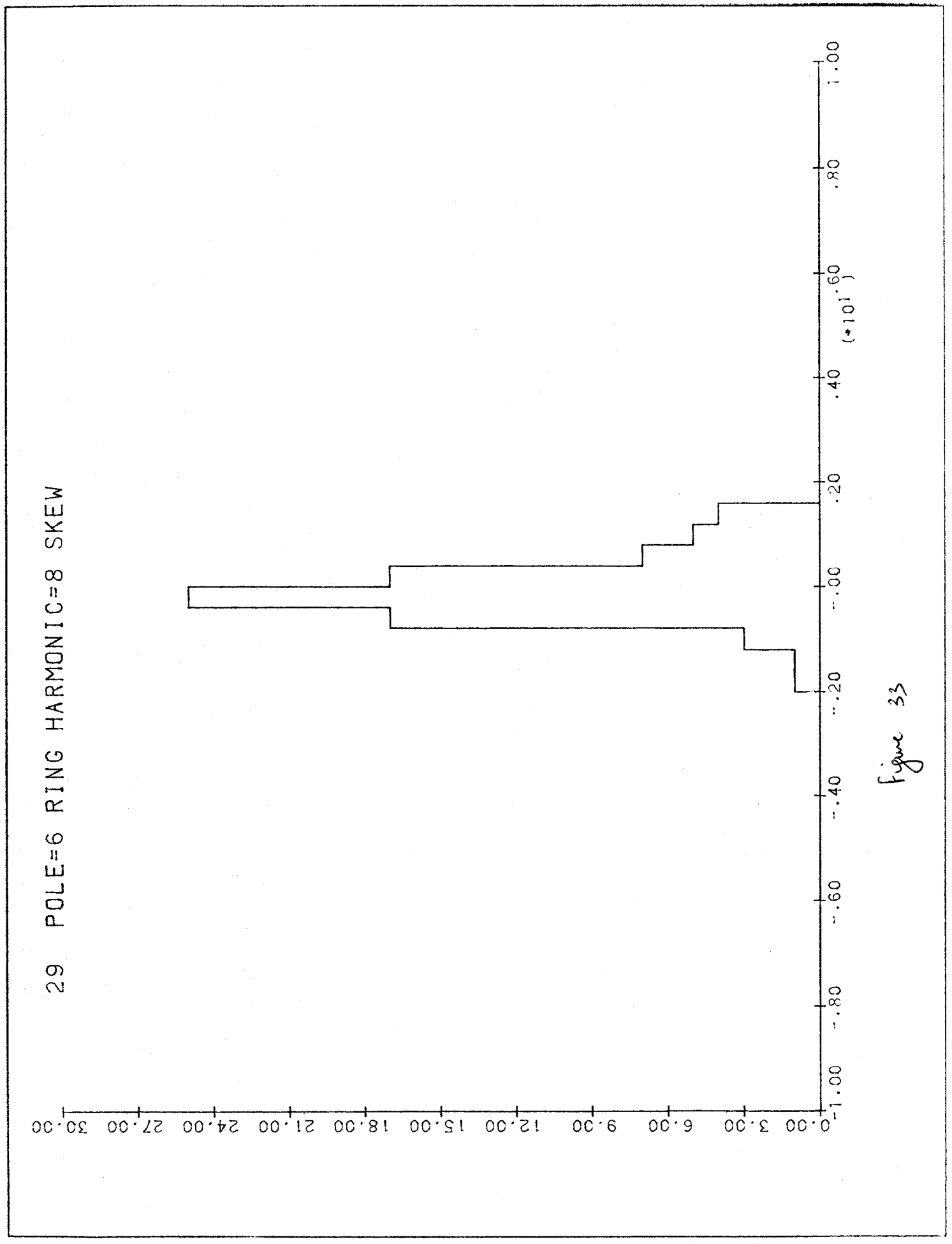
29 POLE=6 RING HARMONIC=8 SKEW
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1)

Figure 33

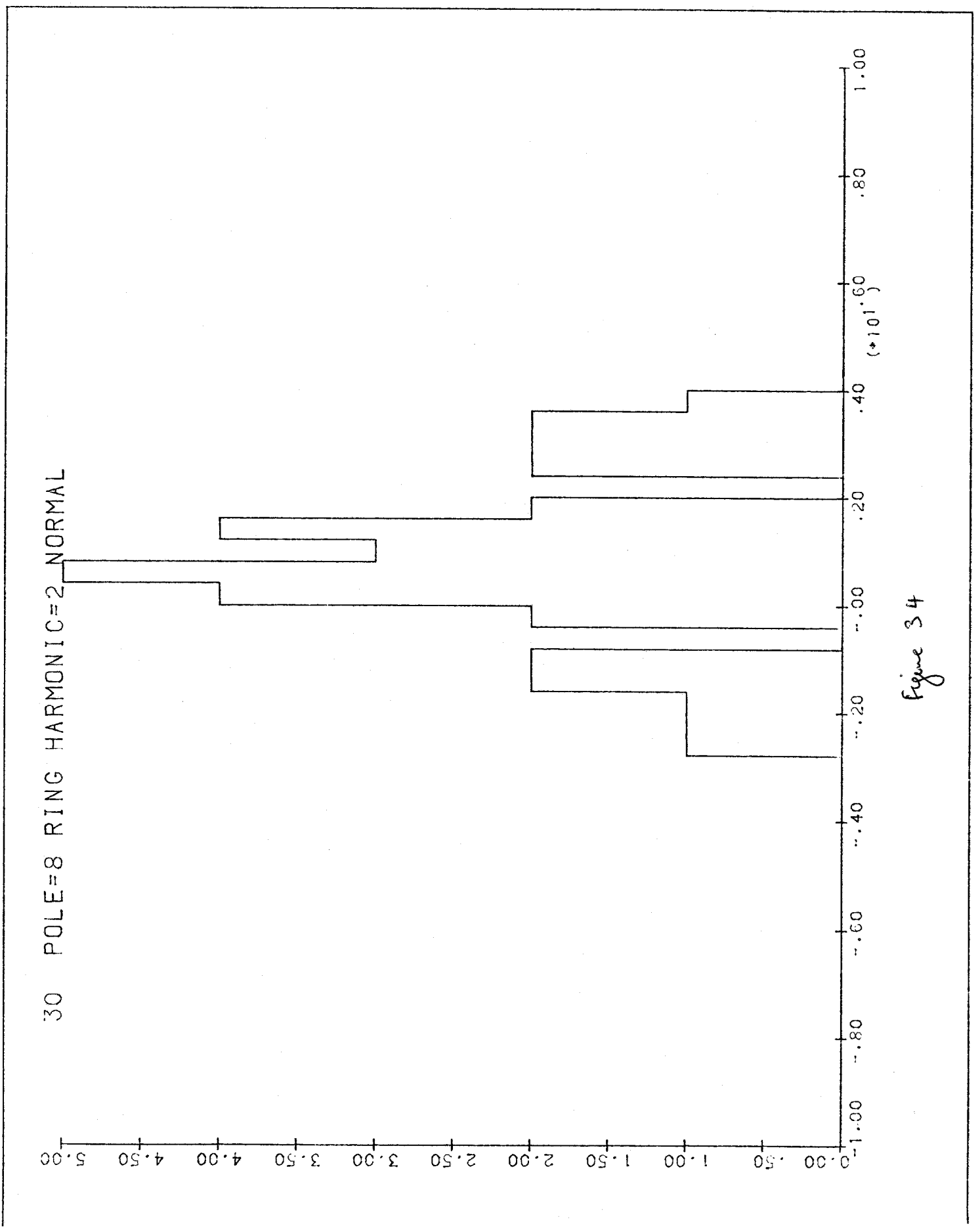
30 POLE=8 RING HARMONIC=2 NORMAL
0.00
.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1.60)

Figure 34

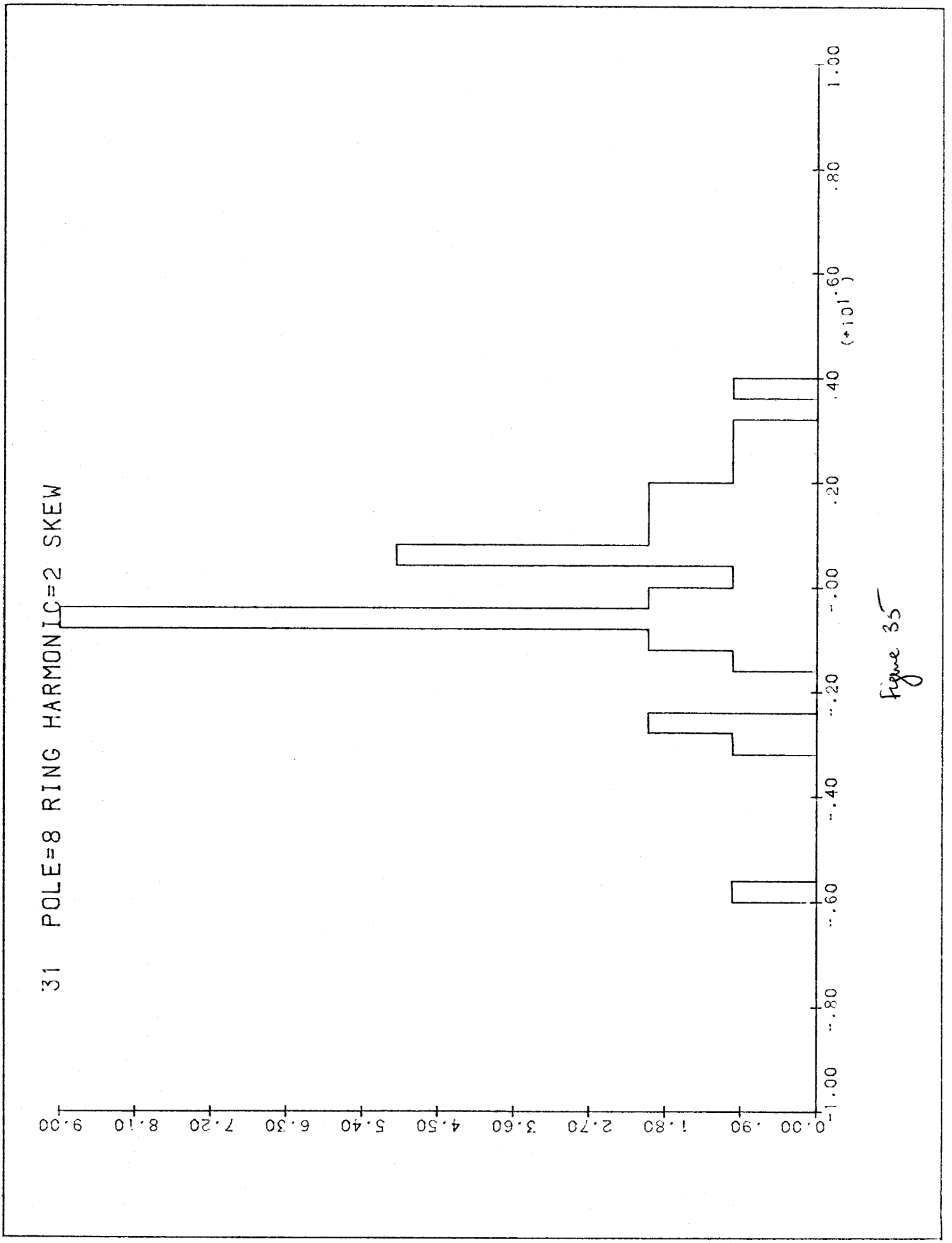
31 POLE=8 RING HARMONIC=2 SKEW
0.00
.90
1.80
2.70
3.60
4.50
5.40
6.30
7.20
8.10
9.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^1)

Figure 35

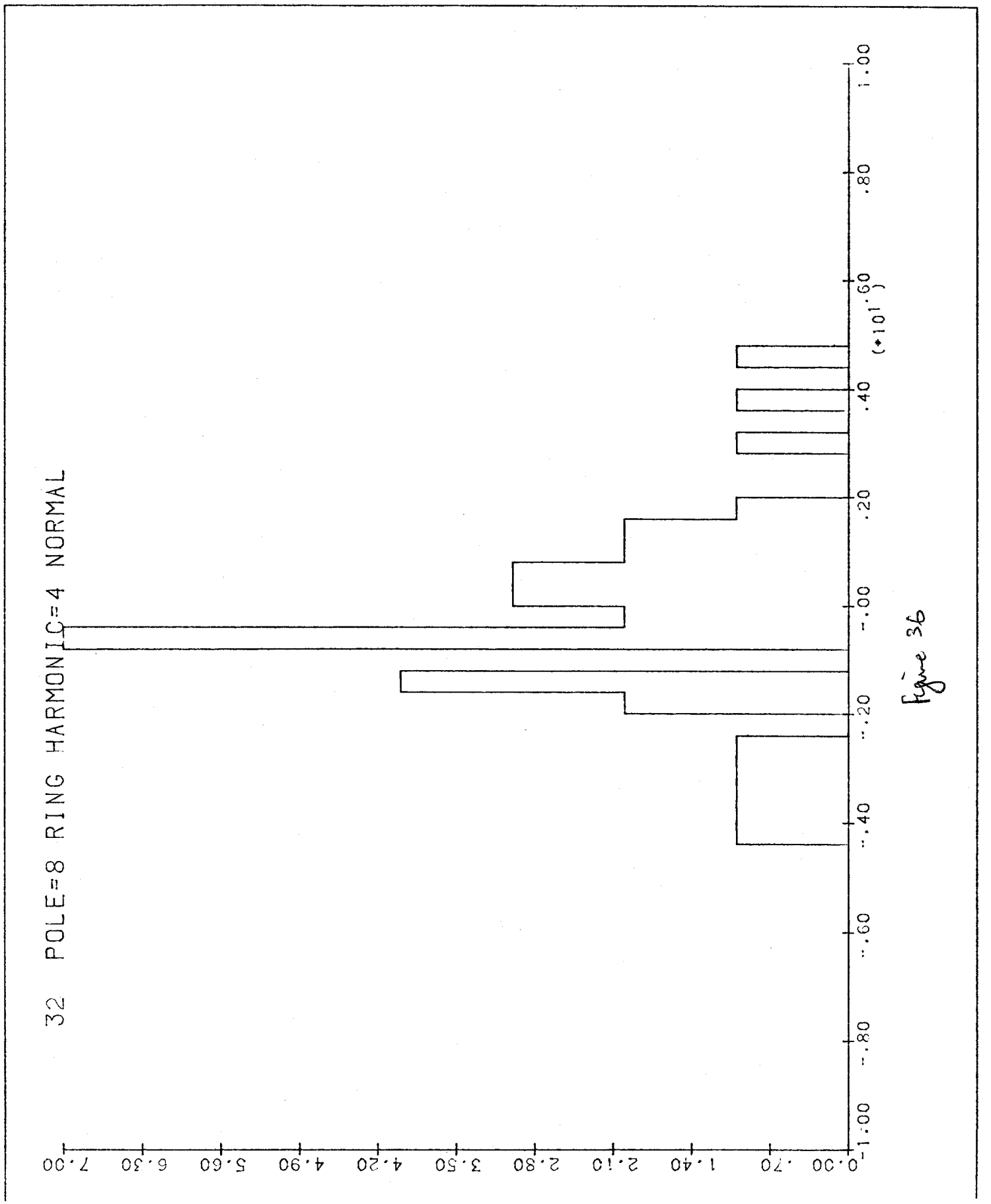
32 POLE=8 RING HARMONIC=4 NORMAL
0.00 .70 1.40 2.10 2.80 3.50 4.20 4.90 5.60 6.30 7.00
-1.00 -.80 -.60 -.40 -.20 -.00 .20 .40 .60 .80 1.00
(*10^-1)

Figure 36

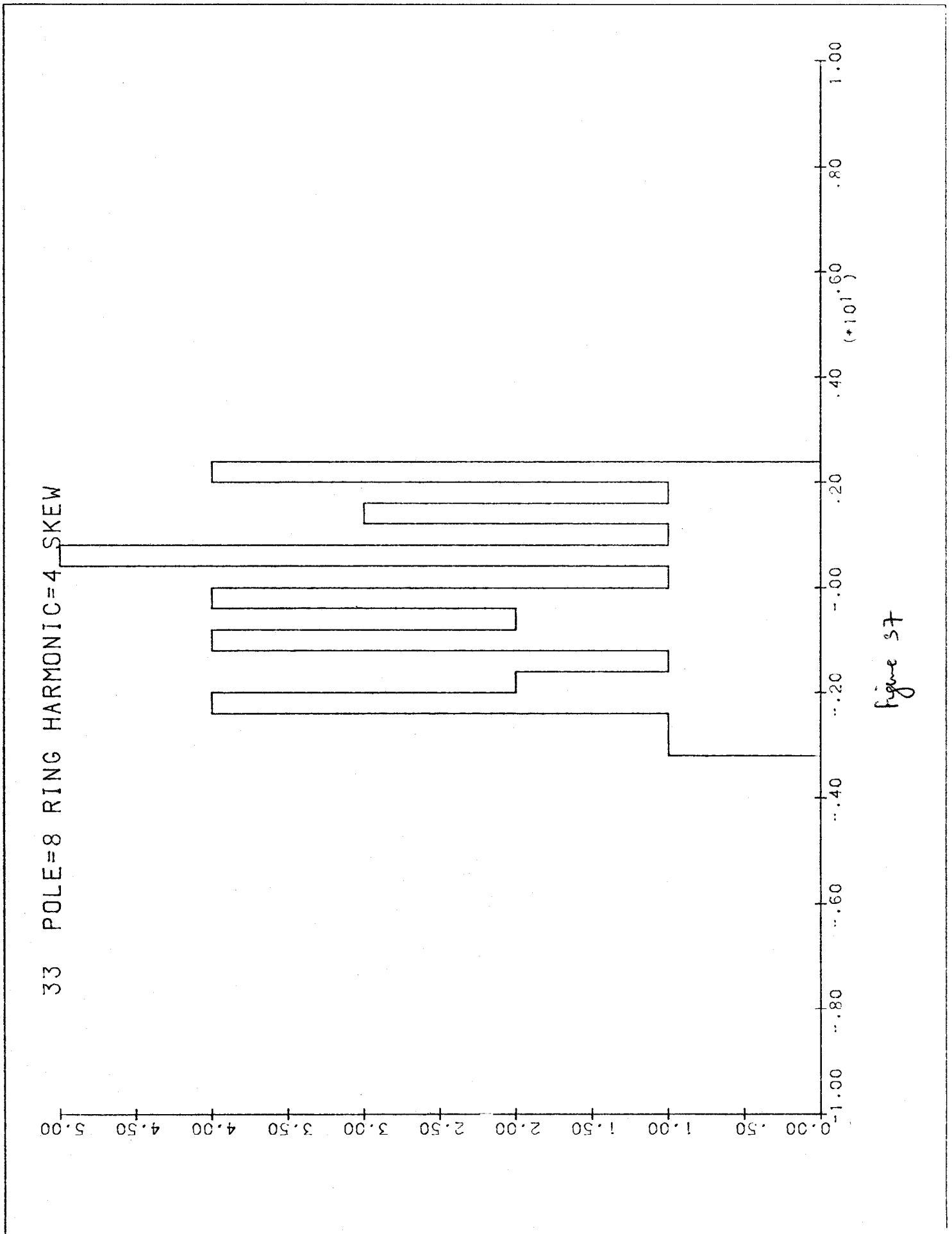
33 POLE=8 RING HARMONIC=4 SKEW
0.00
.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10**-1)

Figure 37

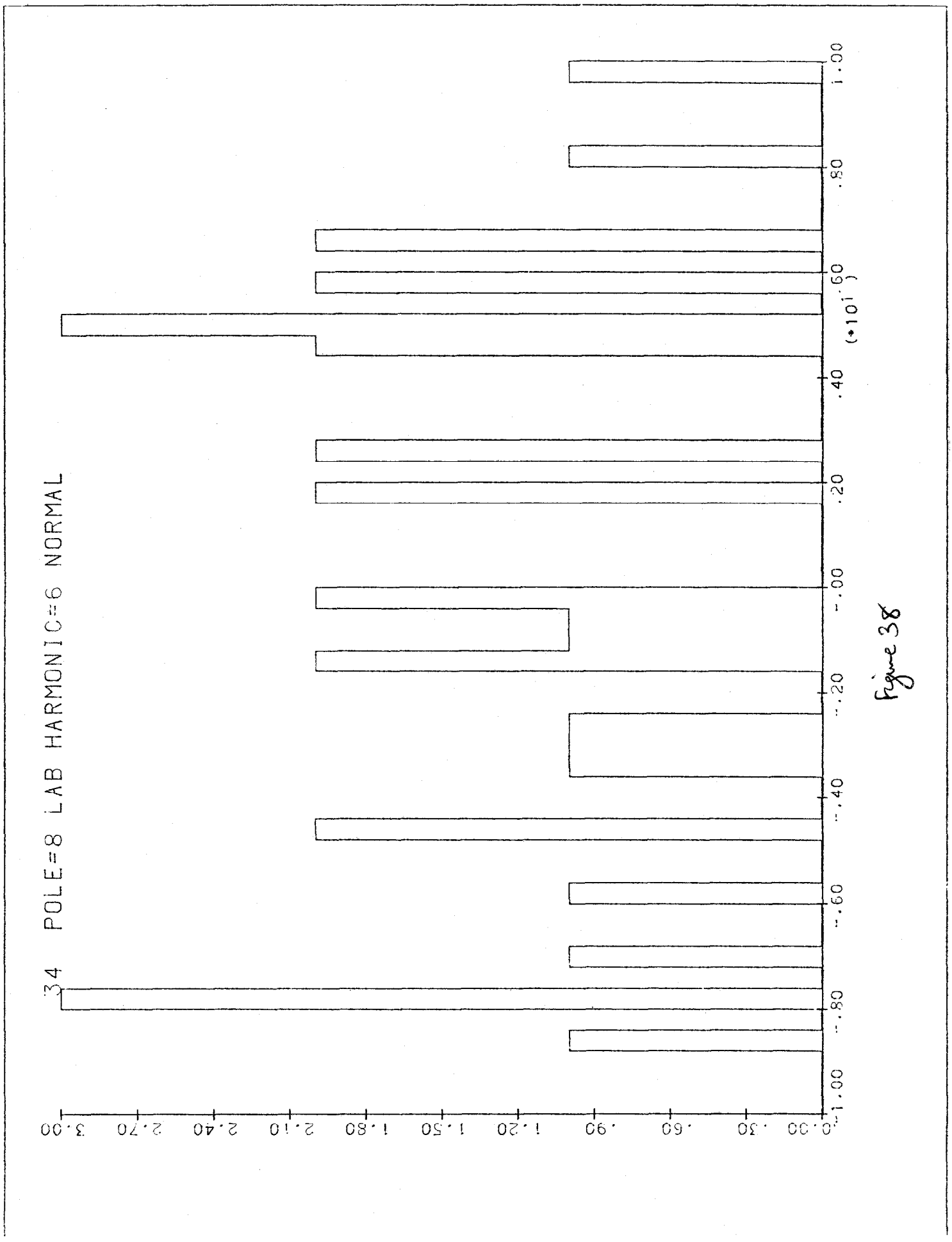
POLE=8 LAB HARMONIC=6 NORMAL
34
0.00
.30
.60
.90
1.20
1.50
1.80
2.10
2.40
2.70
3.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10^-1)

Figure 38

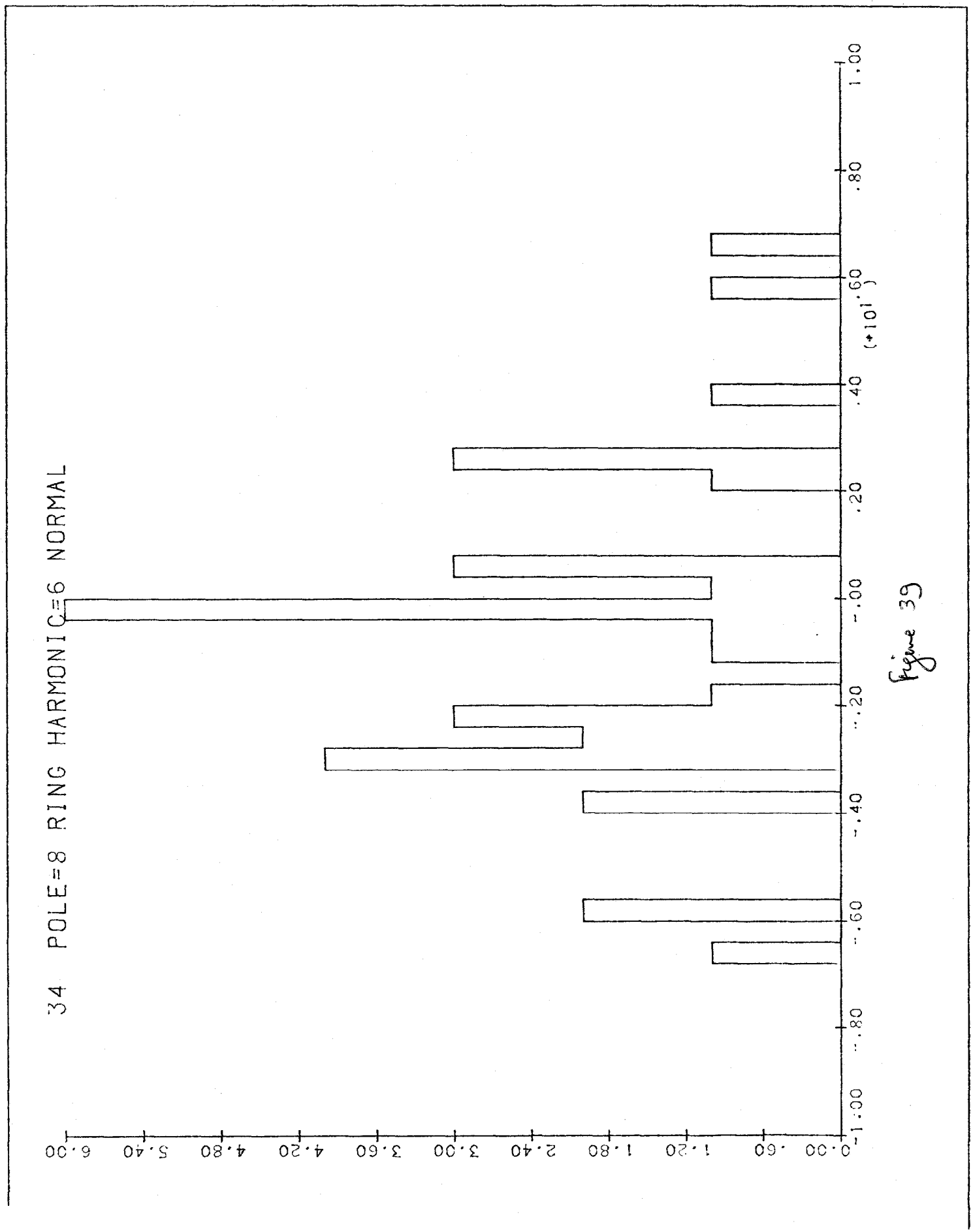
34 POLE=8 RING HARMONIC=6 NORMAL
0.00
.60
1.20
1.80
2.40
3.00
3.60
4.20
4.80
5.40
6.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00
(*10¹)

Figure 39

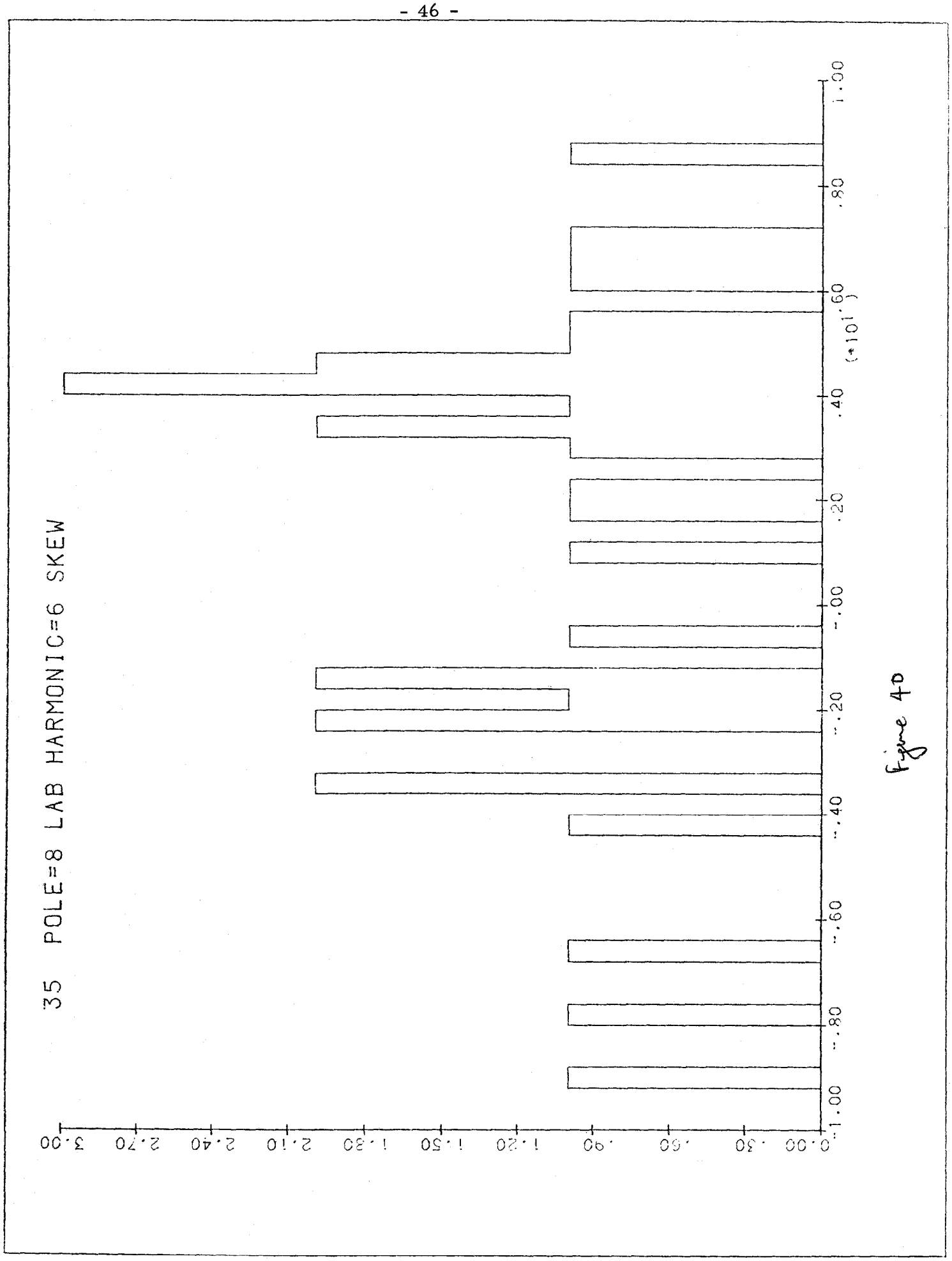
35 POLE=8 LAB HARMONIC=6 SKEW
1.00
.80
.60
.40
.20
.00
-.20
-.40
-.60
-.80
-1.00
(*10**-1)
0.00
.30
.60
.90
1.20
1.50
1.80
2.10
2.40
2.70
3.00

Figure 4D

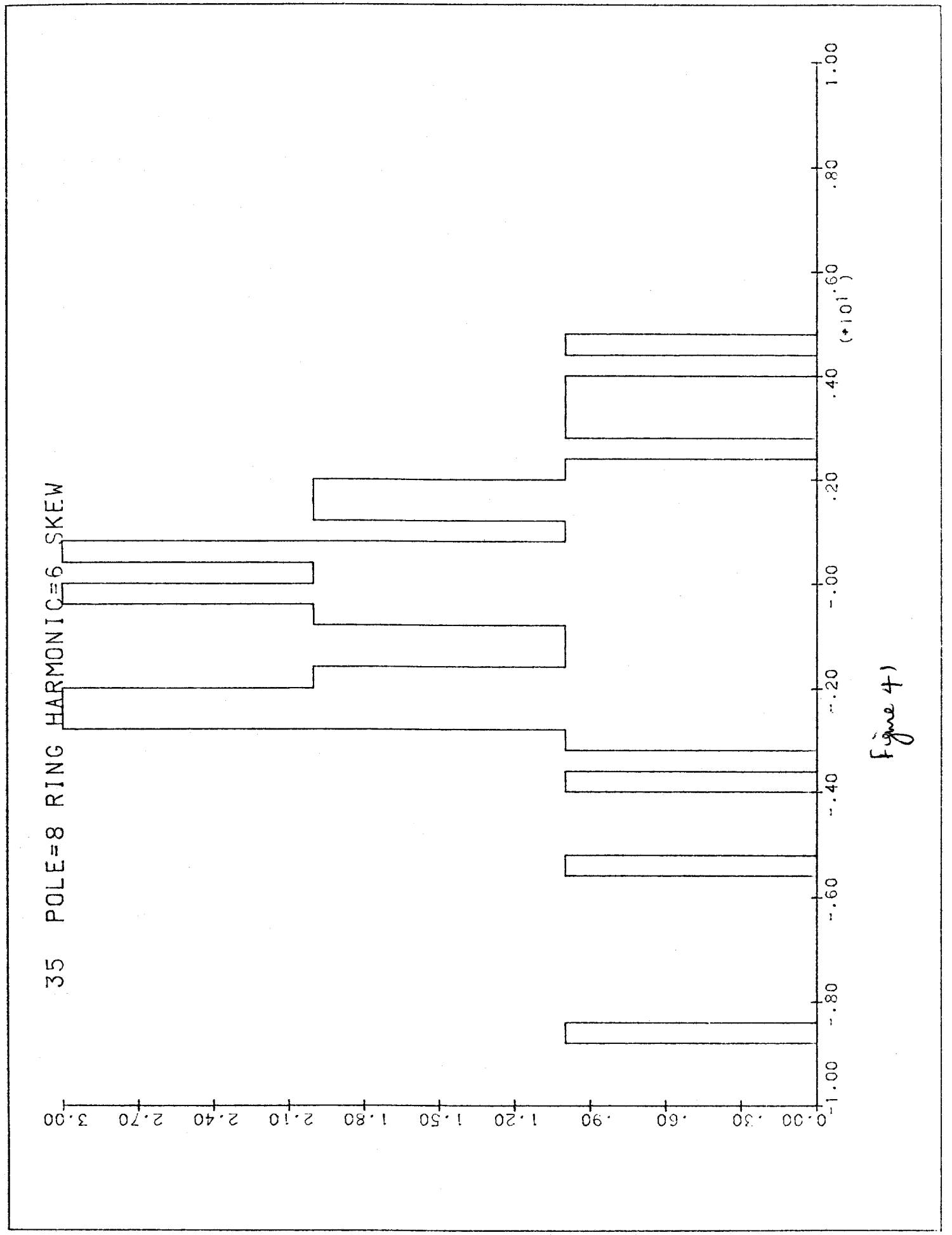
35 POLE=8 RING HARMONIC=6 SKEW
1.00
.80
.60
.40
.20
-.00
-.20
-.40
-.60
-.80
-1.00
(*10¹)
0.00
.30
.60
.90
1.20
1.50
1.80
2.10
2.40
2.70
3.00

Figure 4)

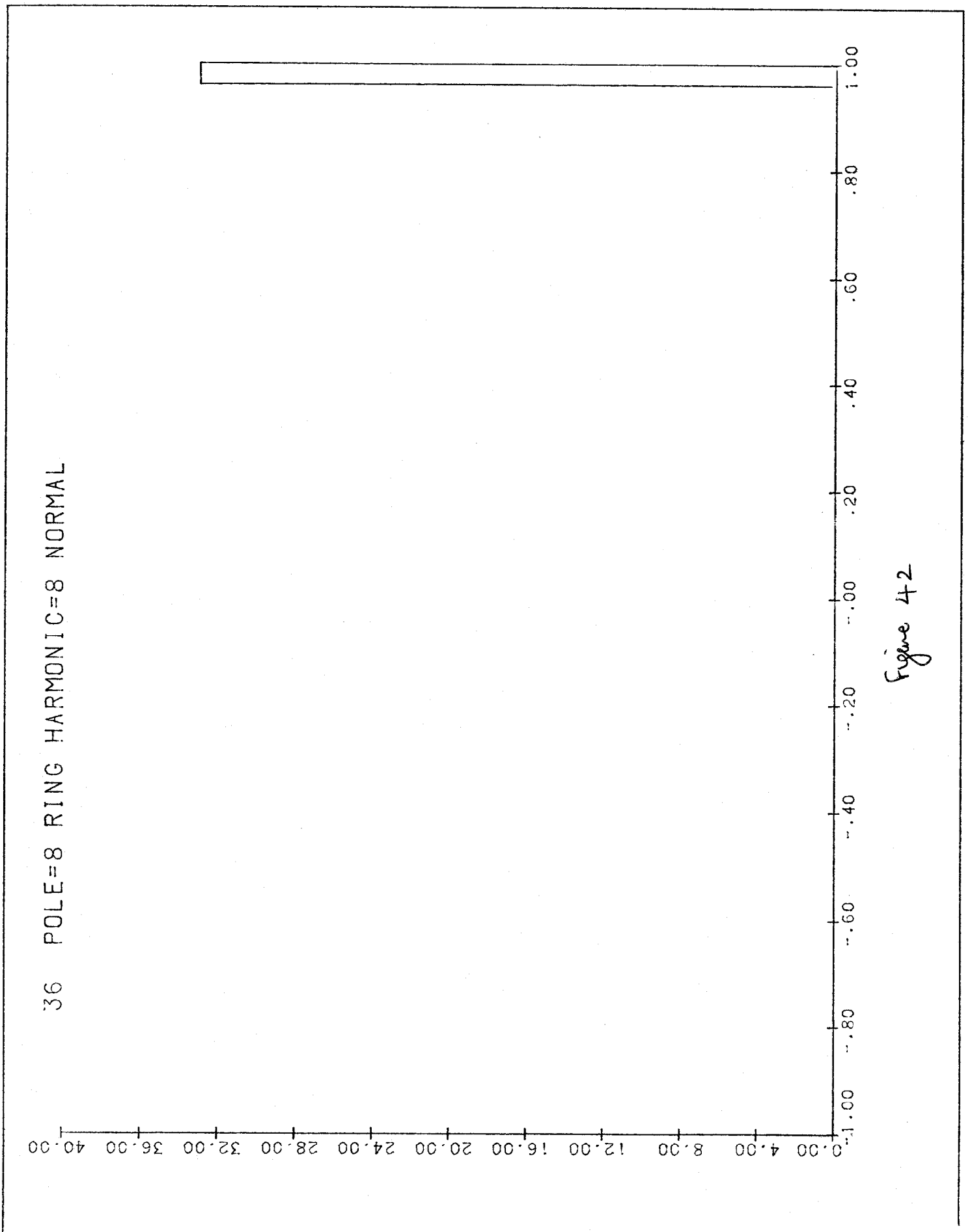
36 POLE=8 RING HARMONIC=8 NORMAL
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
1.00
.80
.60
.40
.20
.00
-.20
-.40
-.60
-.80
-1.00

Figure 42

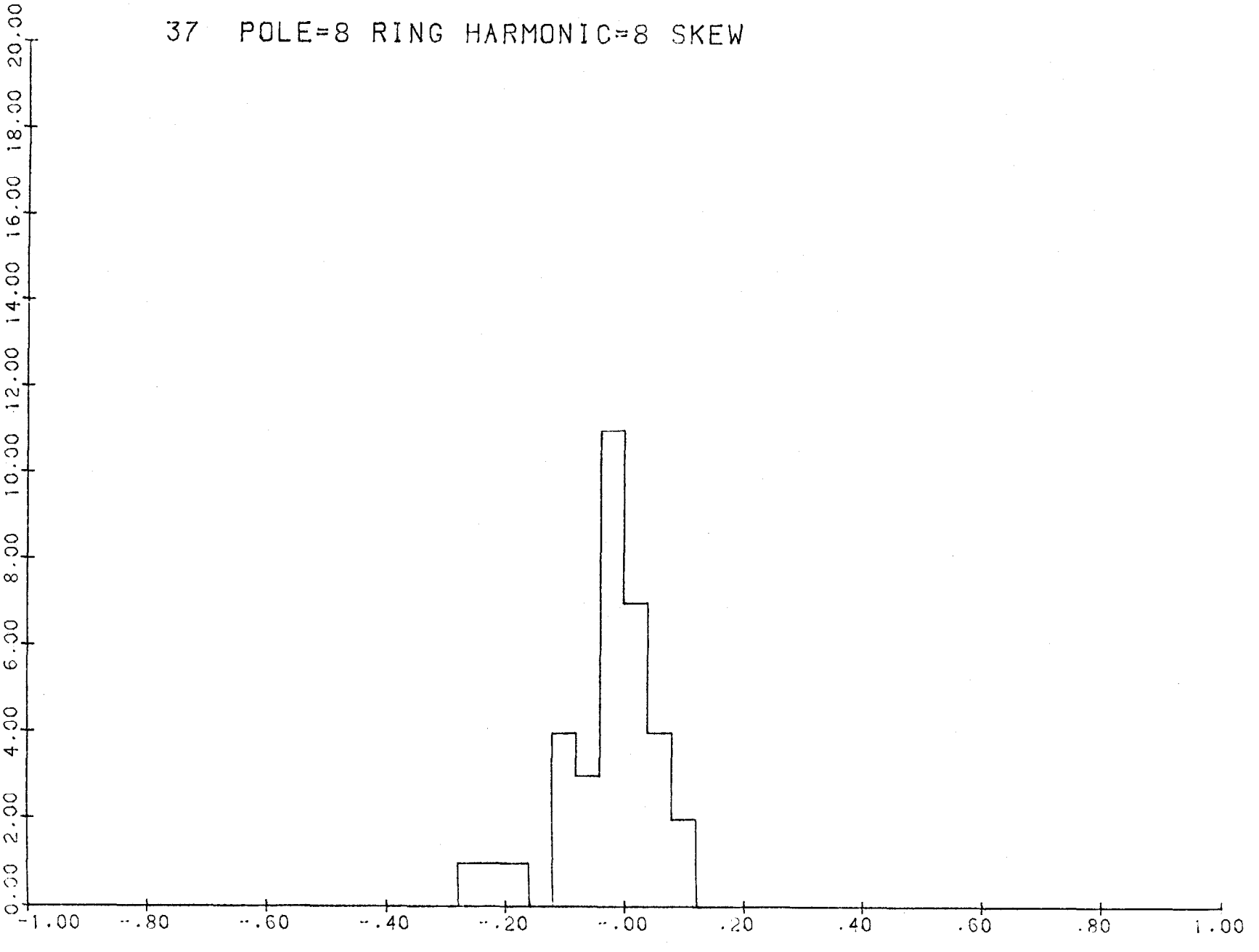
37 POLE=8 RING HARMONIC=8 SKEW
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-1.00
-.80
-.60
-.40
-.20
-.00
.20
.40
.60
.80
1.00

Figure 43

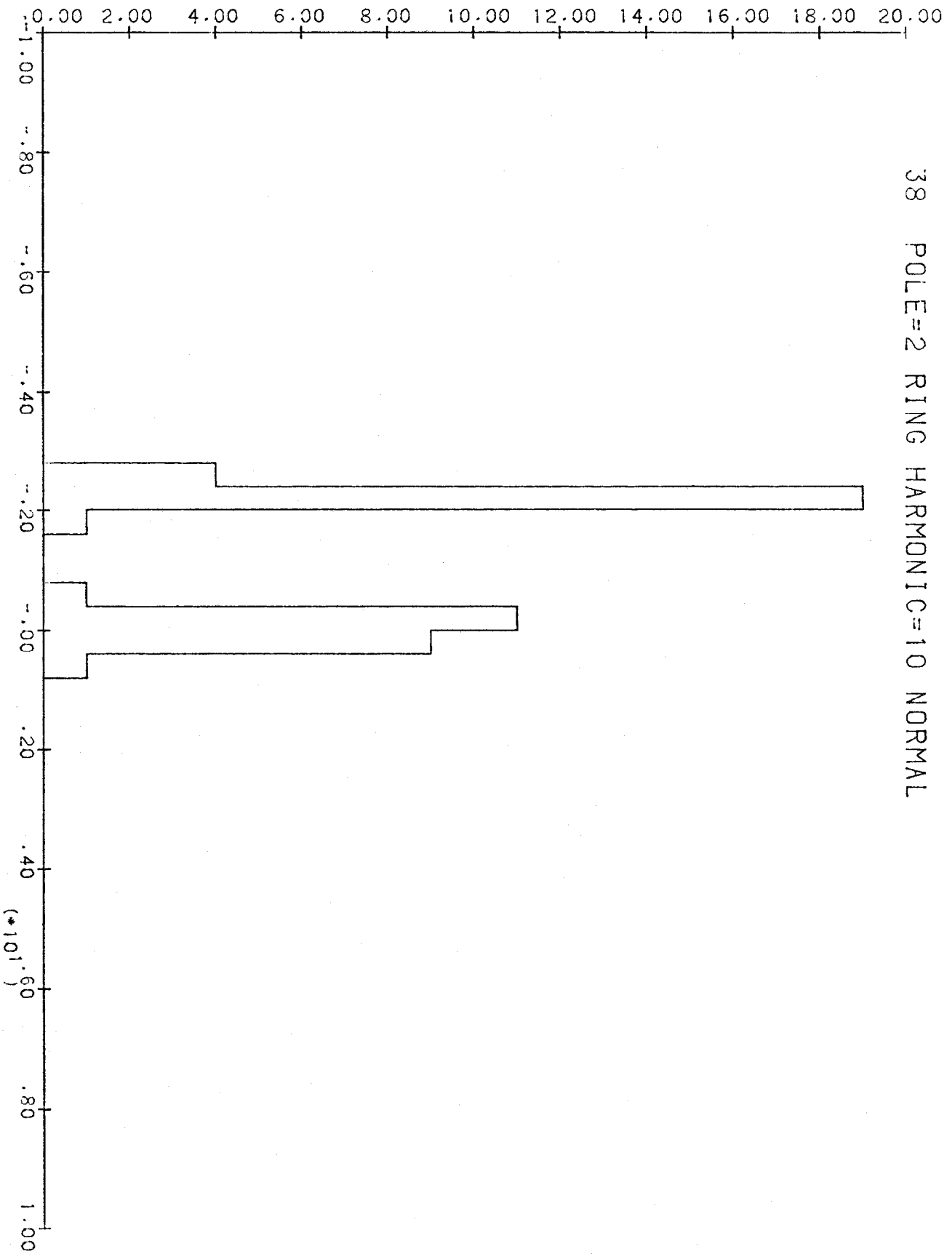
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
-1.00 -.80 -.60 -.40 -.20 -.00 .20 .40 .60 .80 1.00
(*10^-1)
38 POLE=2 RING HARMONIC=10 NORMAL

Figure 44

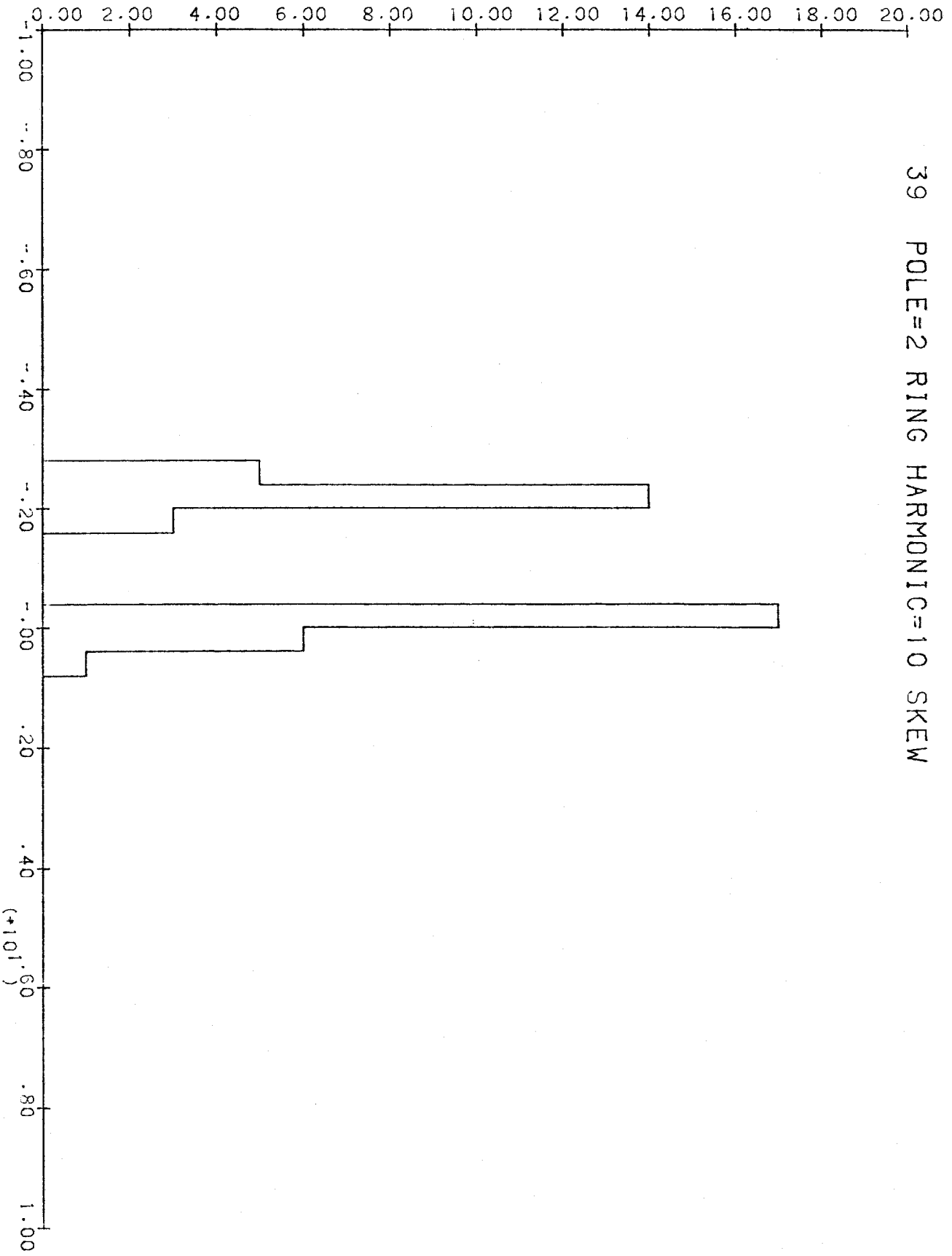
0.00 2.00 4.00 6.00 8.00 10.00 12.00 14.00 16.00 18.00 20.00
-1.00 -.80 -.60 -.40 -.20 -.00 .20 .40 .60 .80 1.00
(*10¹)
39 POLE=2 RING HARMONIC=10 SKEW

Figure 45

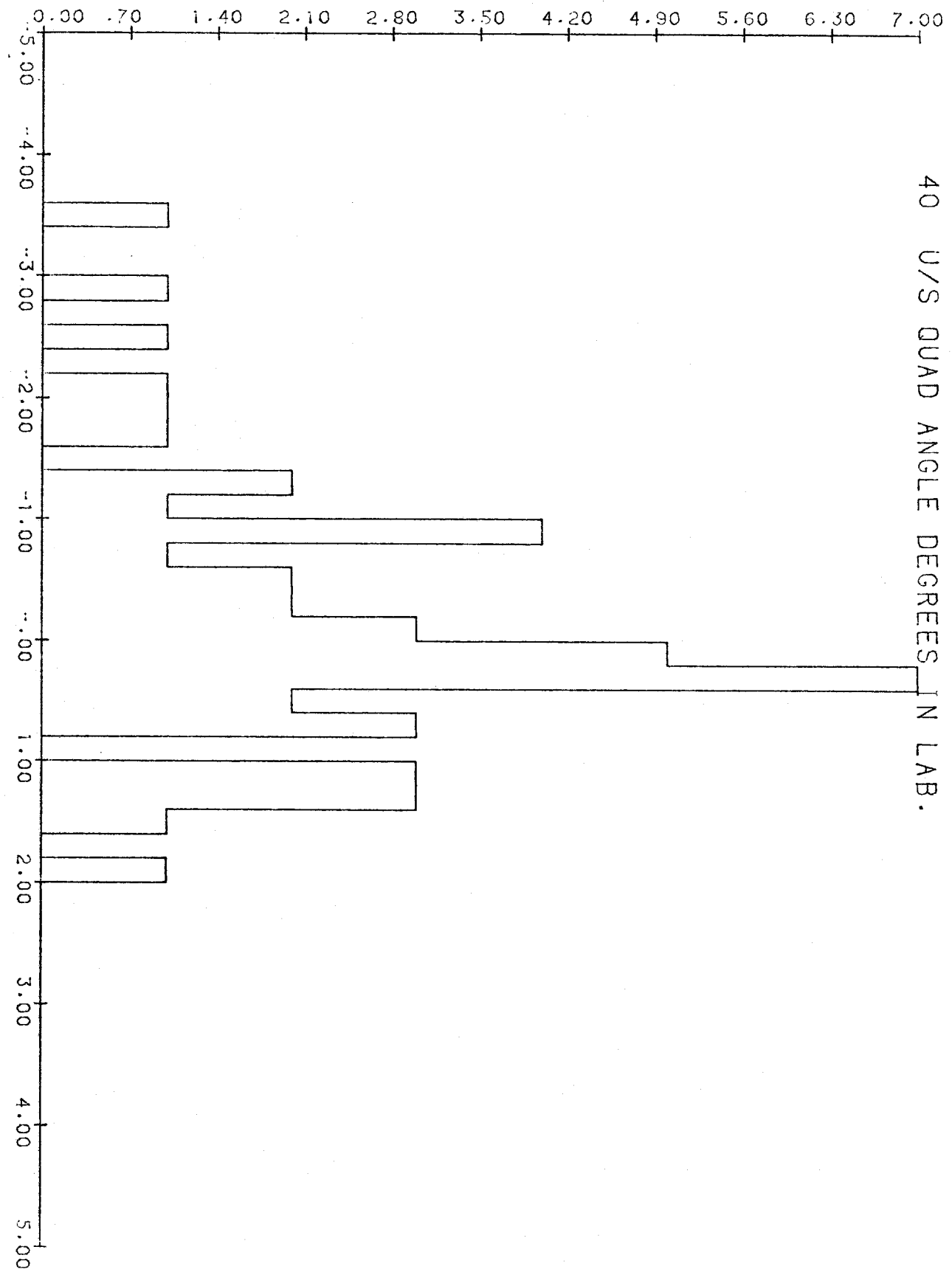
0.00
.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30
7.00
-5.00
-4.00
-3.00
-2.00
-1.00
.00
1.00
2.00
3.00
4.00
5.00
40 U/S QUAD ANGLE DEGREES IN LAB.

Figure 46

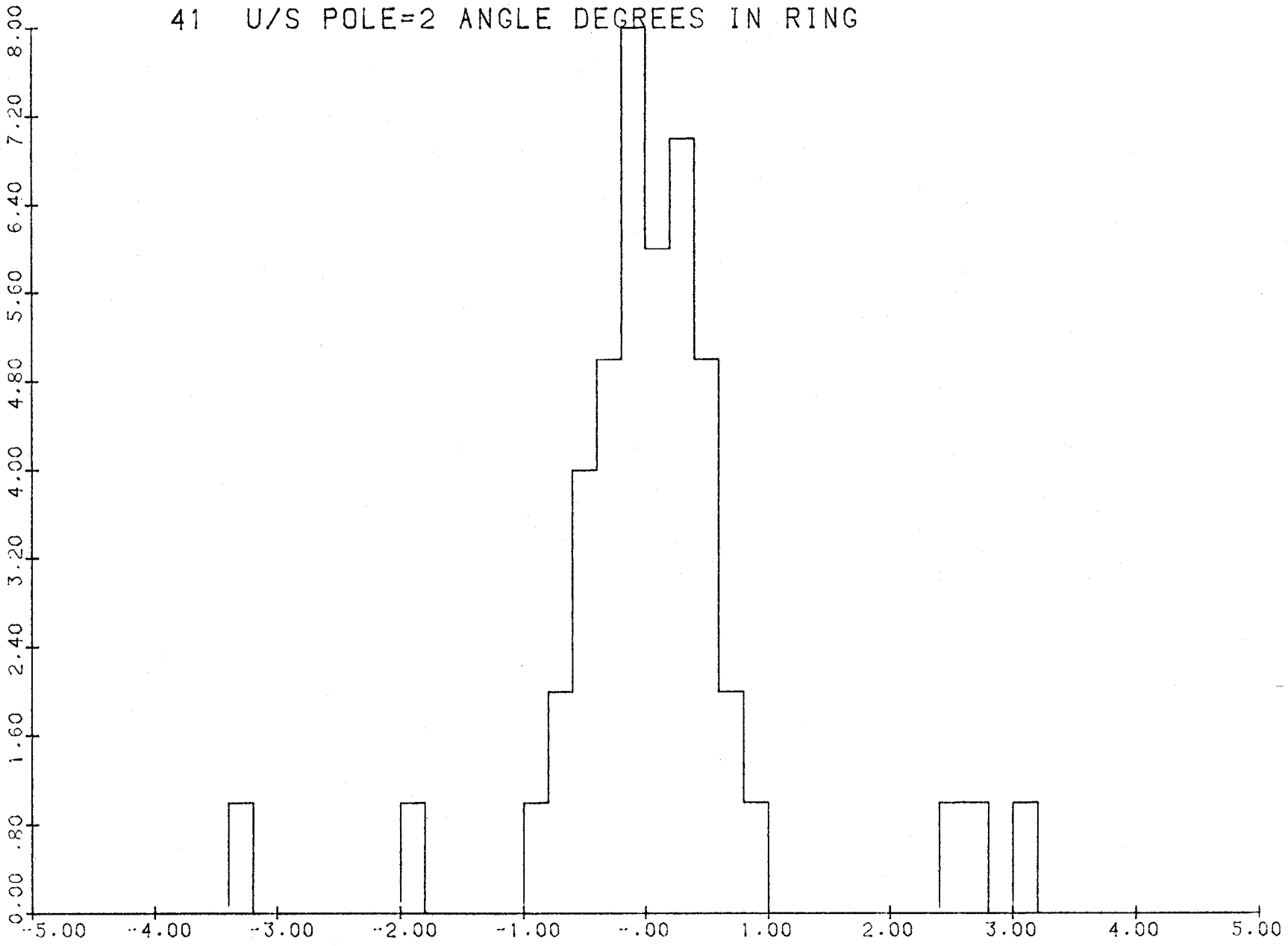

Figure 47

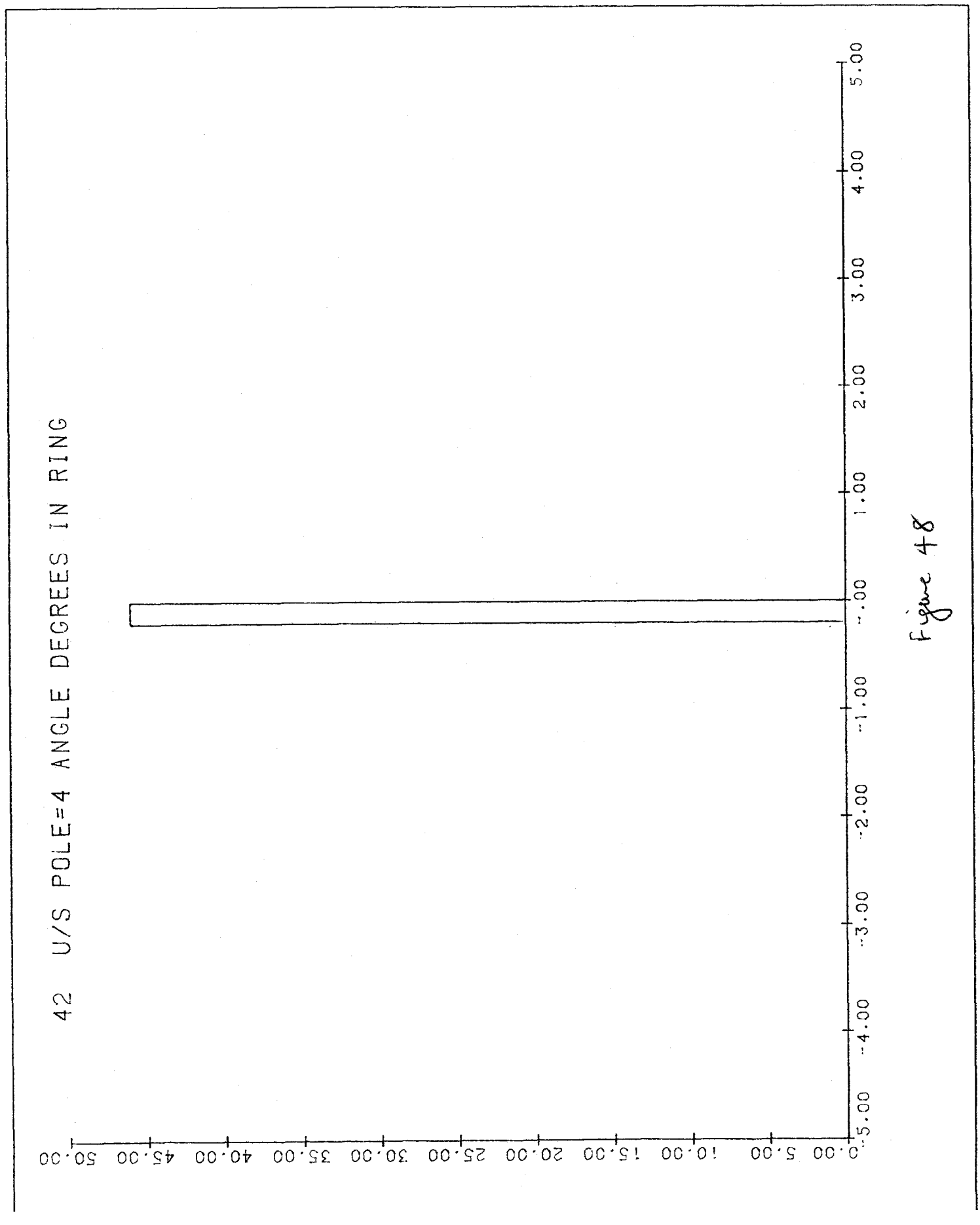
42 U/S POLE=4 ANGLE DEGREES IN RING
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00
-5.00
-4.00
-3.00
-2.00
-1.00
-.00
1.00
2.00
3.00
4.00
5.00

Figure 48

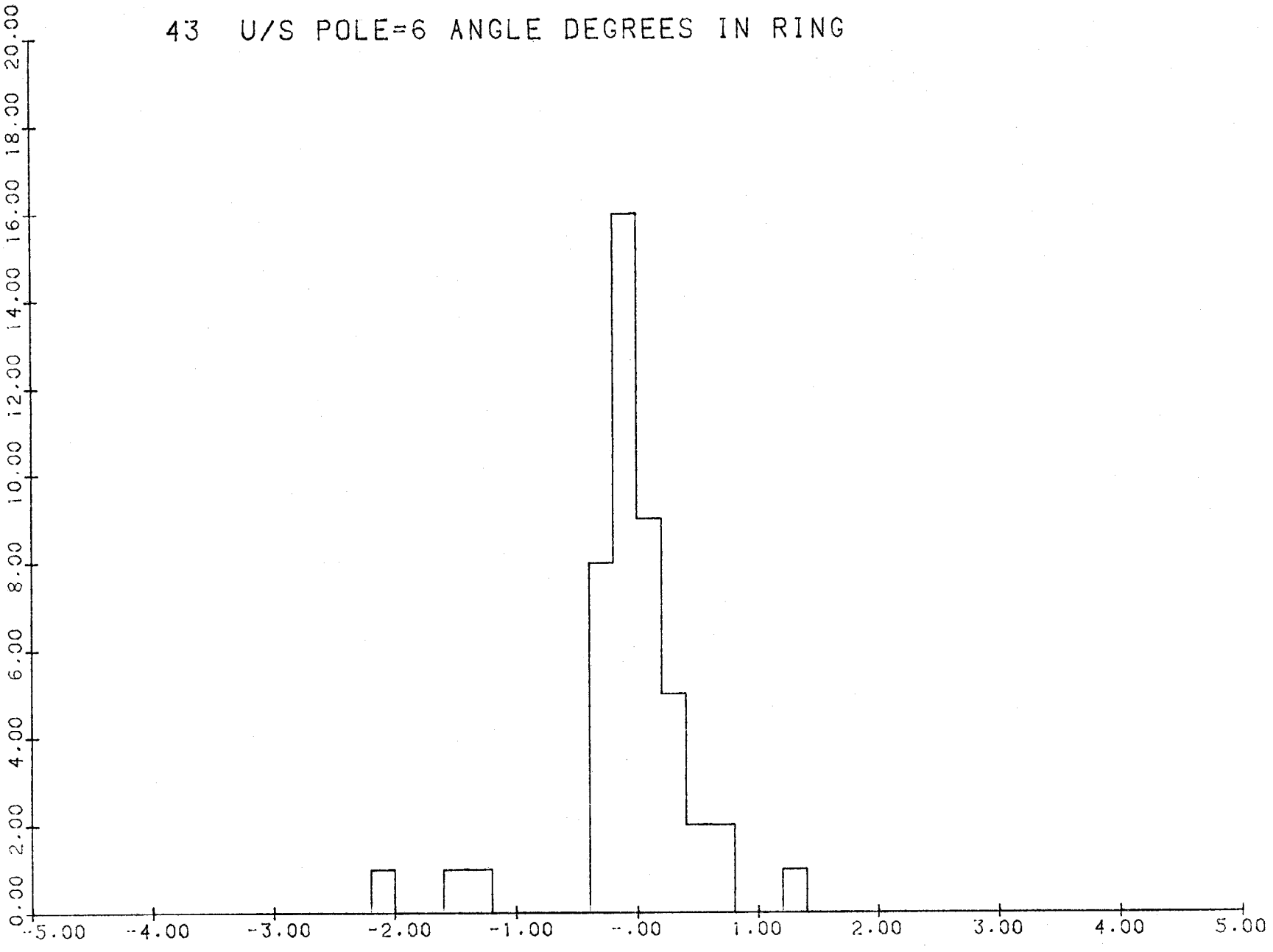
43 U/S POLE=6 ANGLE DEGREES IN RING
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
-5.00
-4.00
-3.00
-2.00
-1.00
-.00
1.00
2.00
3.00
4.00
5.00

Figure 49

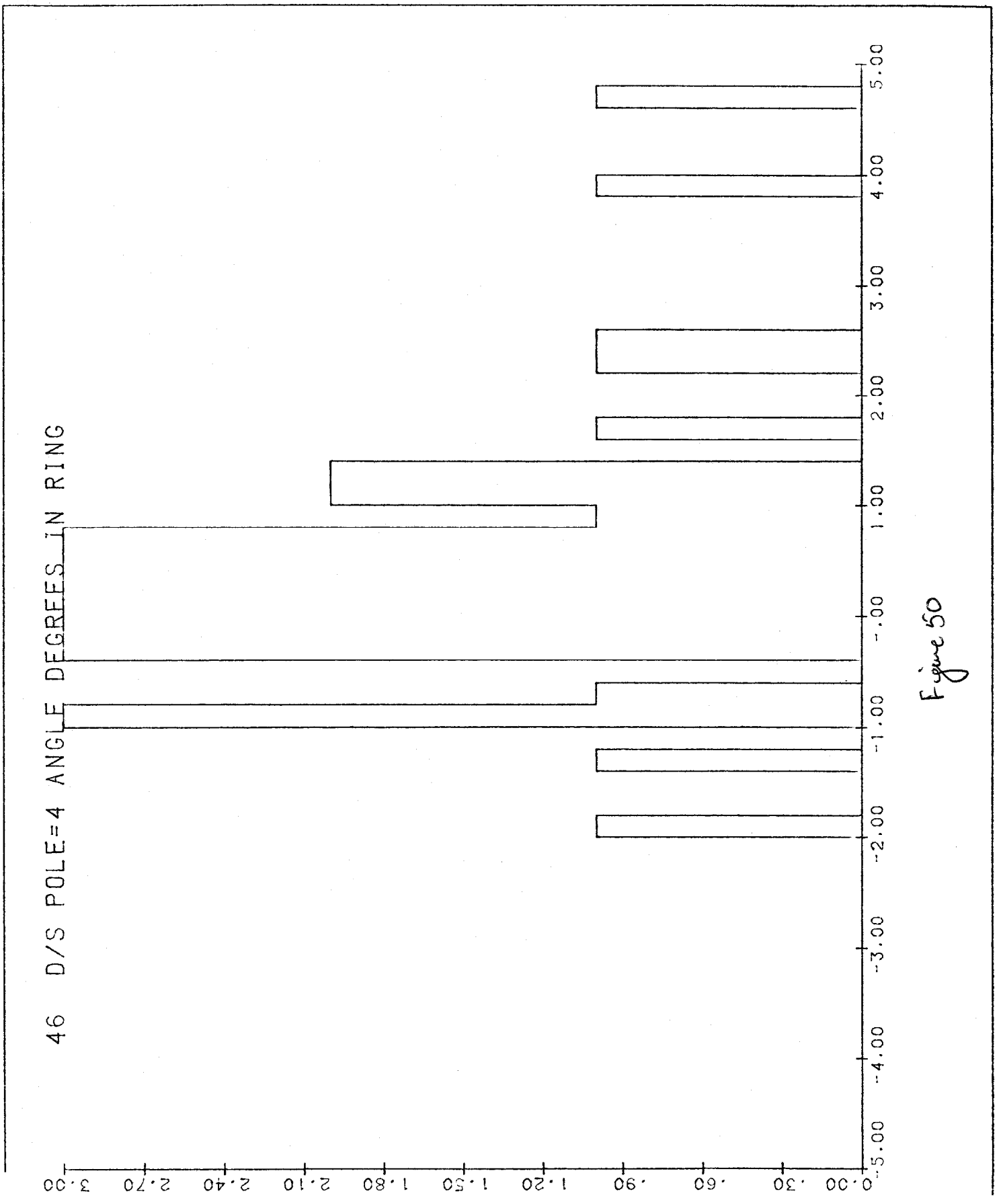
46 D/S POLE=4 ANGLE DEGREES IN RING
5.00
4.00
3.00
2.00
1.00
-.00
-1.00
-2.00
-3.00
-4.00
-5.00
0.00
.30
.60
.90
1.20
1.50
1.80
2.10
2.40
2.70
3.00

Figure 50

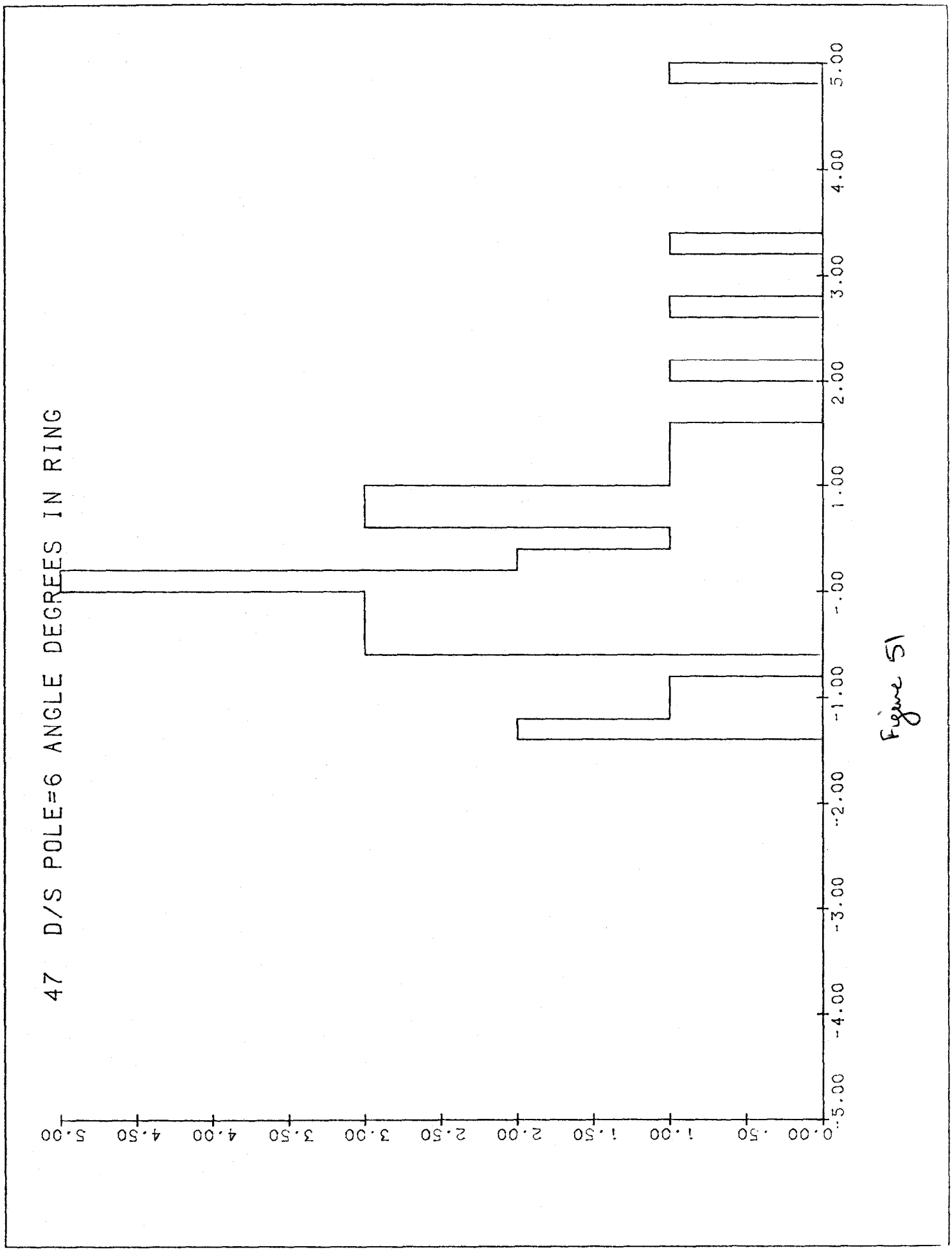
47 D/S POLE=6 ANGLE DEGREES IN RING
5.00
4.00
3.00
2.00
1.00
-.00
-1.00
-2.00
-3.00
-4.00
-5.00
0.00
.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00

Figure 51

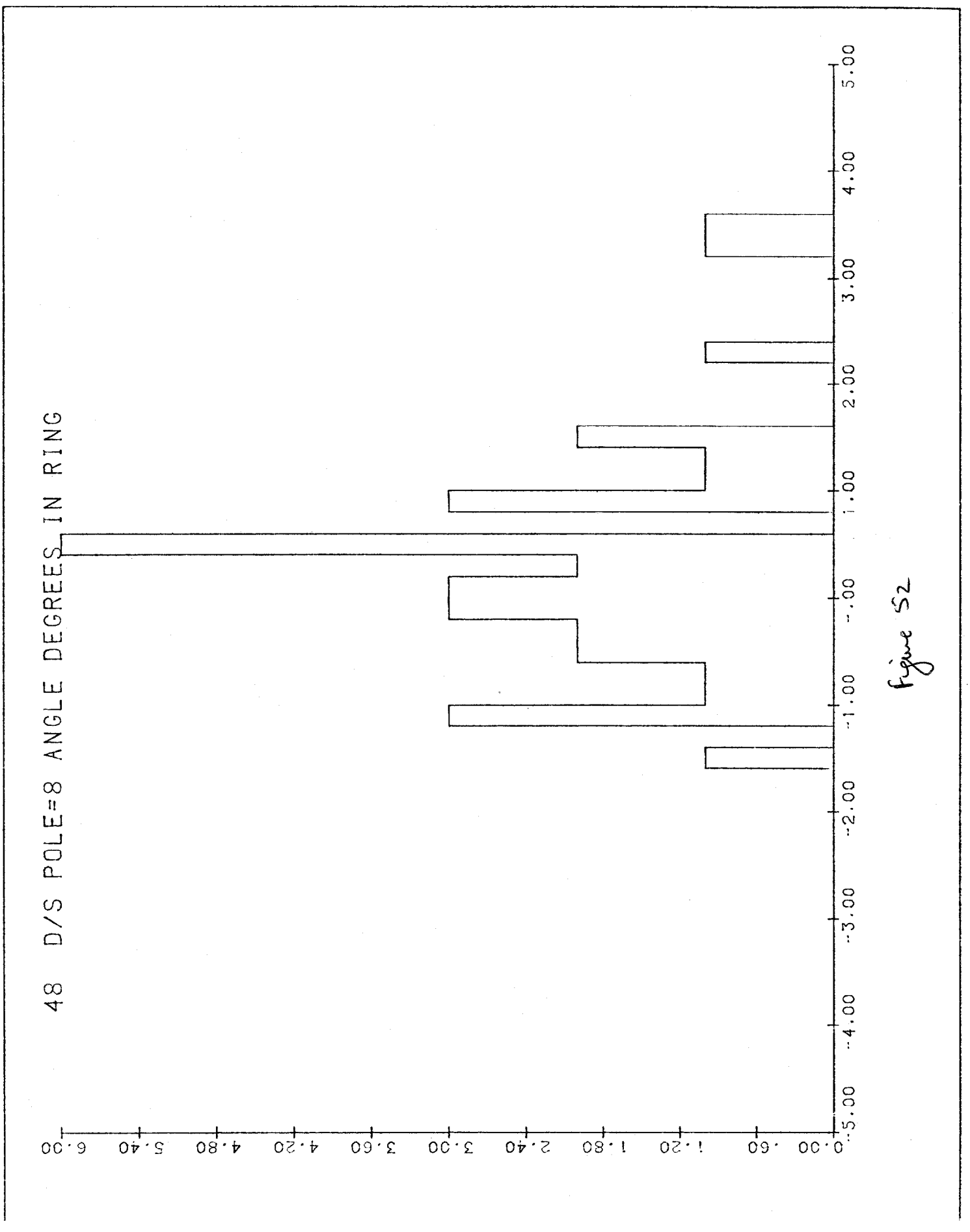
48 D/S POLE=8 ANGLE DEGREES IN RING
0.00
.60
1.20
1.80
2.40
3.00
3.60
4.20
4.80
5.40
6.00
-5.00
-4.00
-3.00
-2.00
-1.00
-.00
1.00
2.00
3.00
4.00
5.00

Figure 52

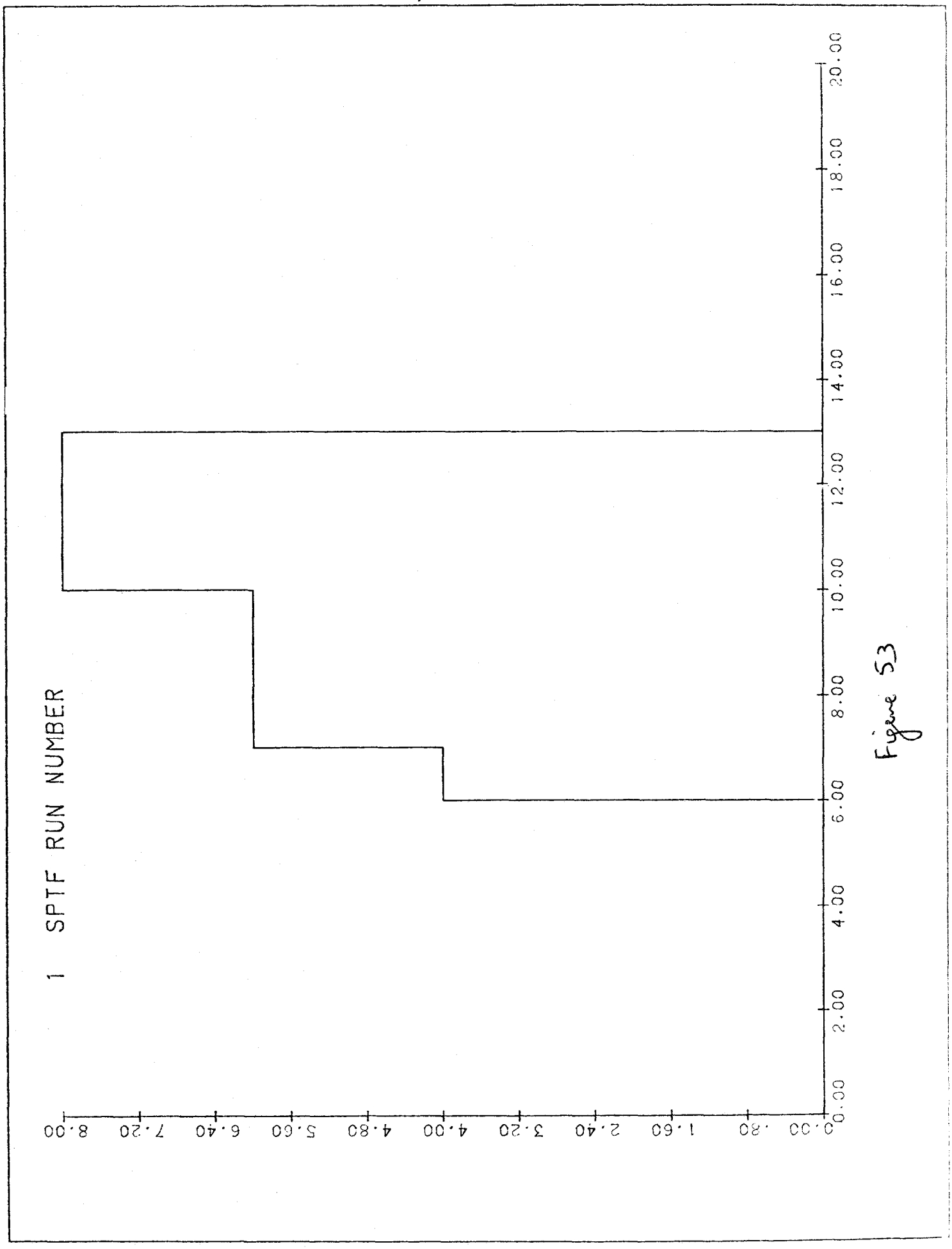
1 SPTF RUN NUMBER
0.00
.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40
7.20
8.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 53

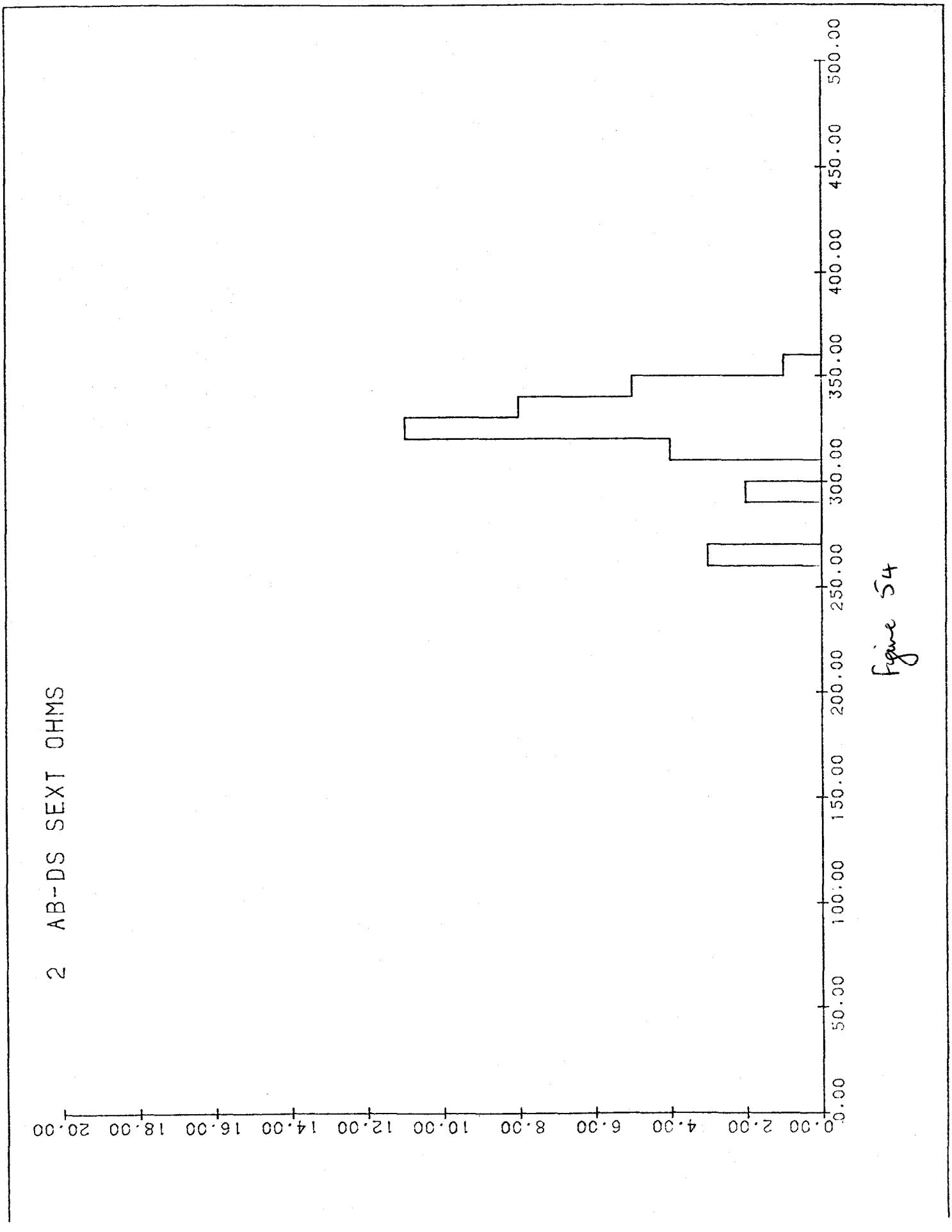
2 AB-DS SEXT OHMS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 54

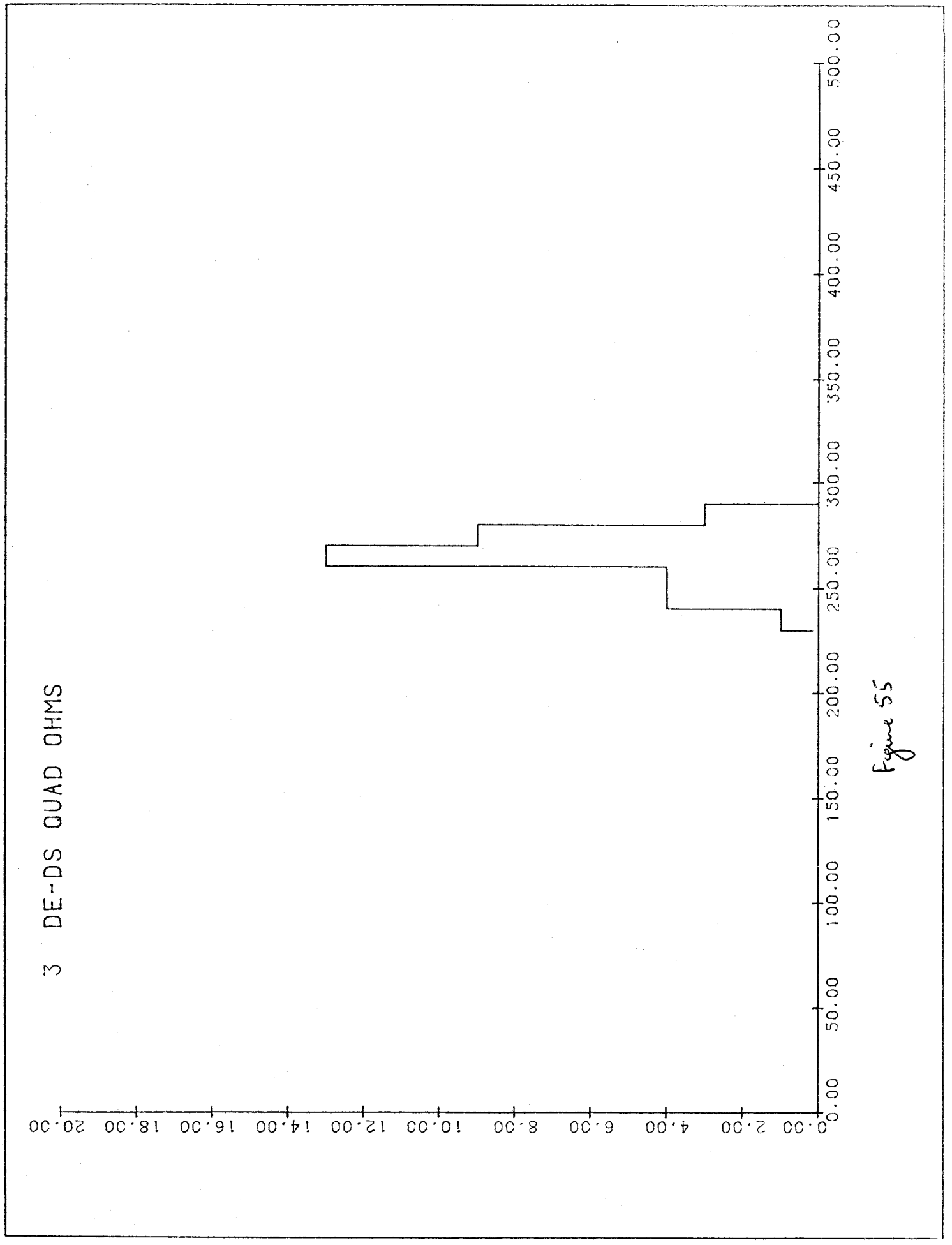
3 DE-DS QUAD OHMS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 55

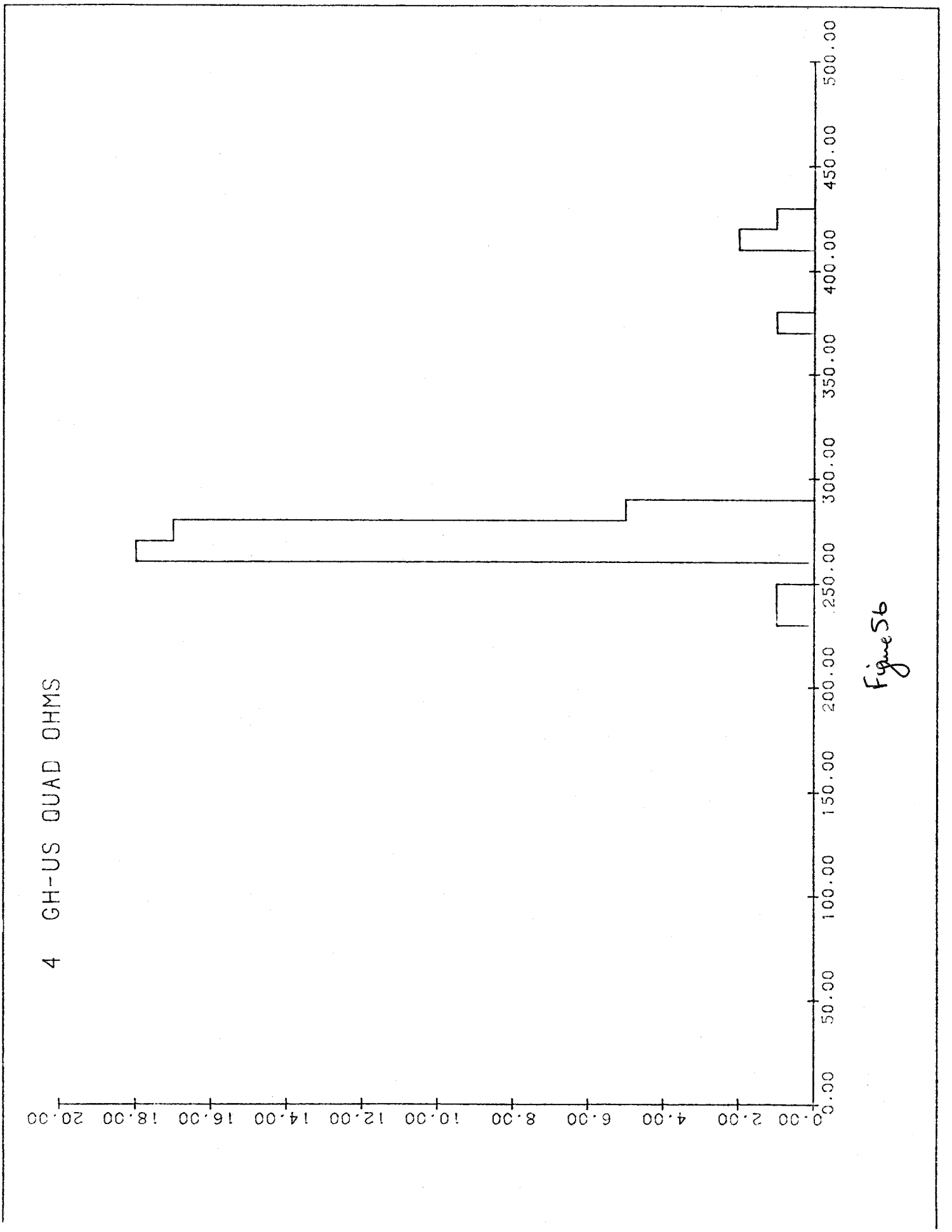
4 GH-US QUAD OHMS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 56

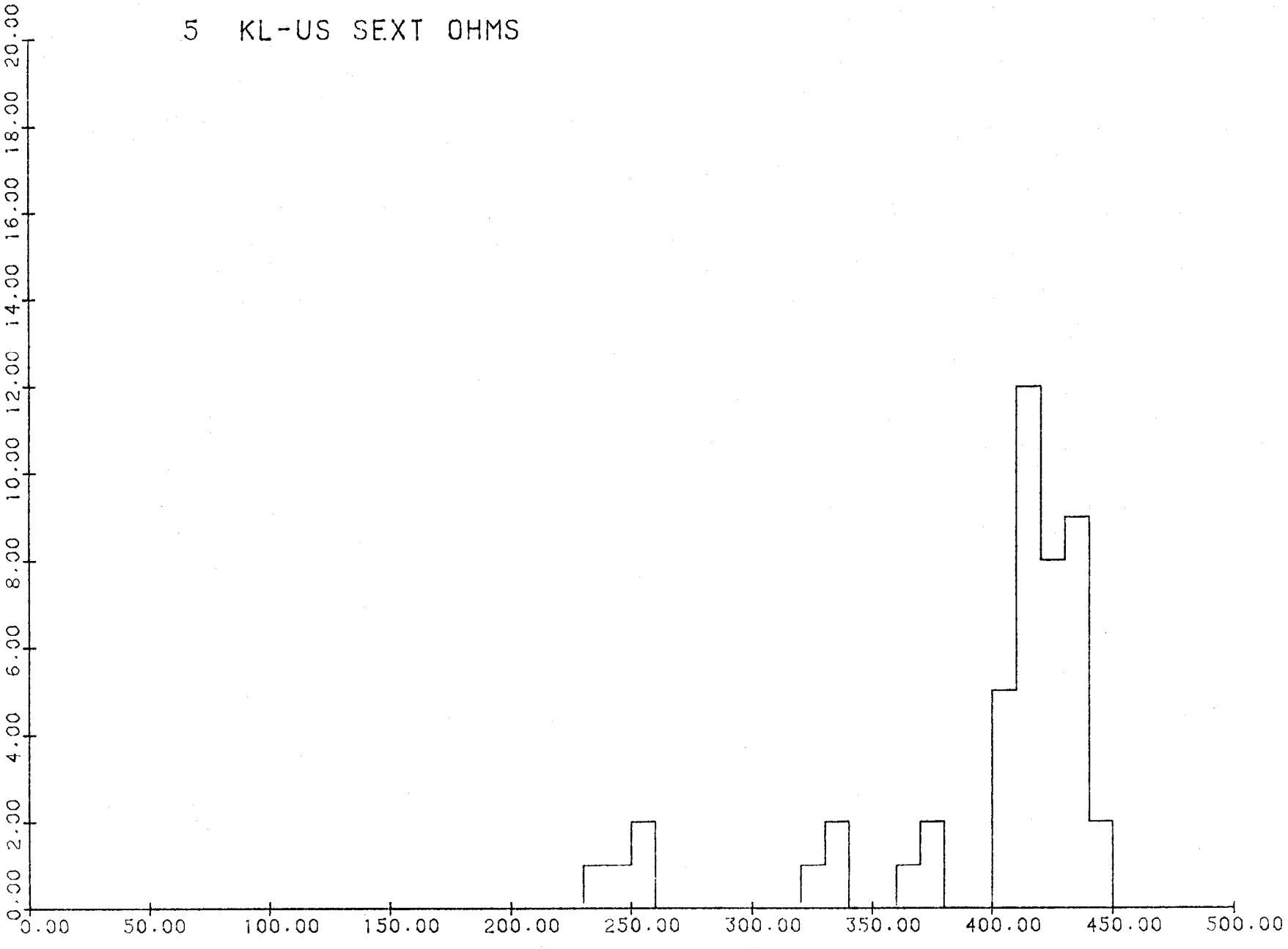
5 KL-US SEXT OHMS
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00

Figure 57

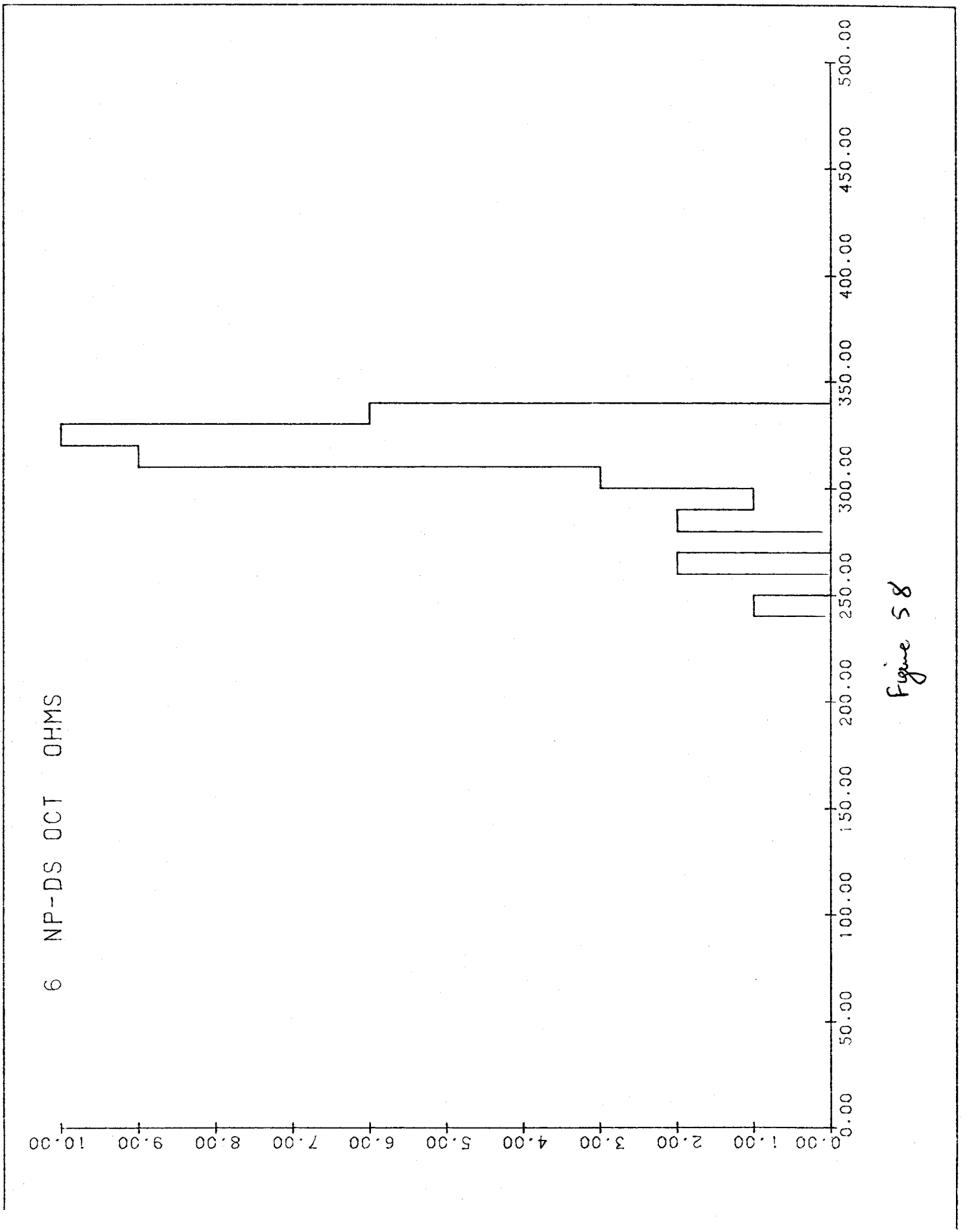
6 NP-DS OCT OHMS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
0.00
1.00
2.00
3.00
4.00
5.00
6.00
7.00
8.00
9.00
10.00

Figure 58

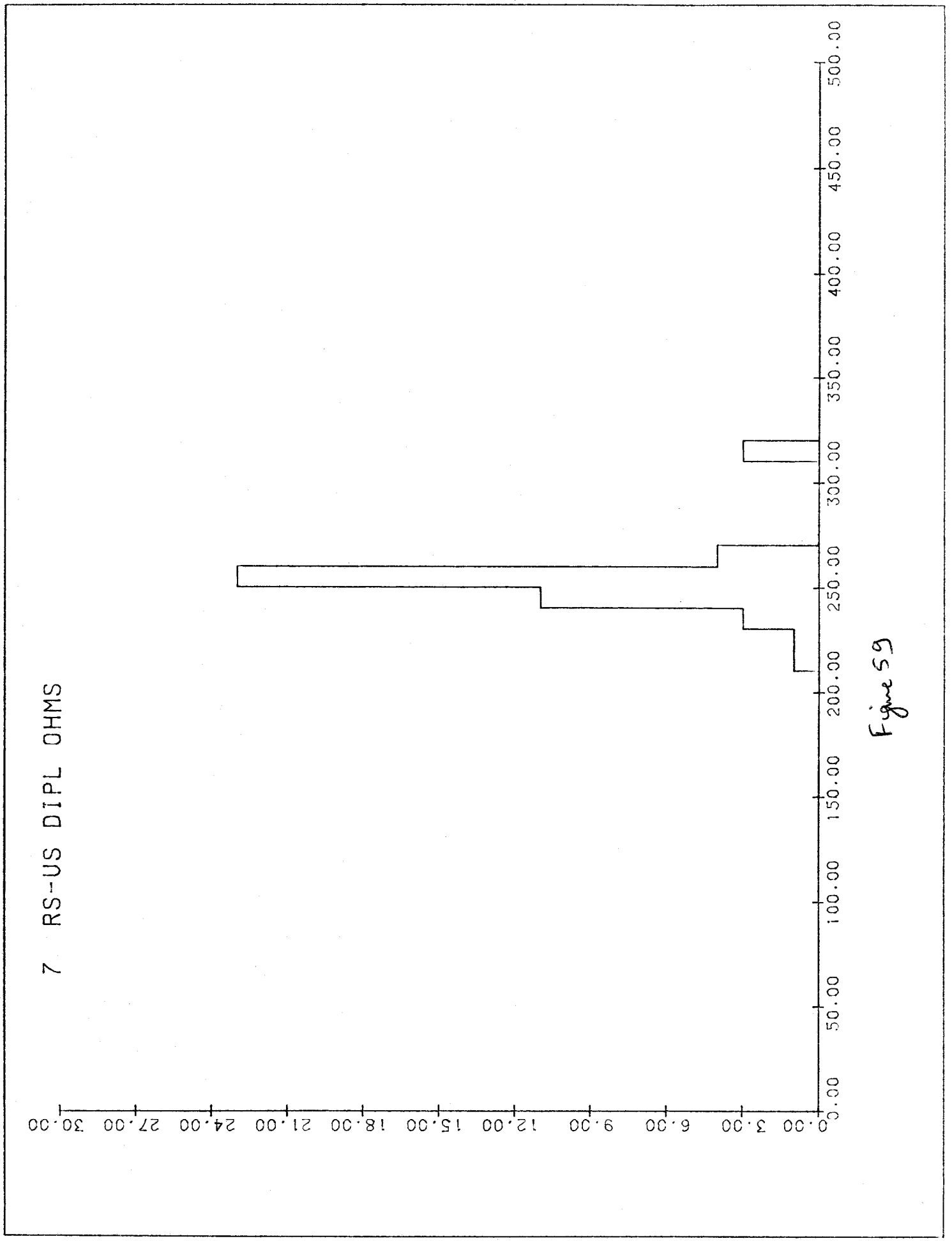
7 RS-US DIPL OHMS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
450.00
500.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00

Figure 59

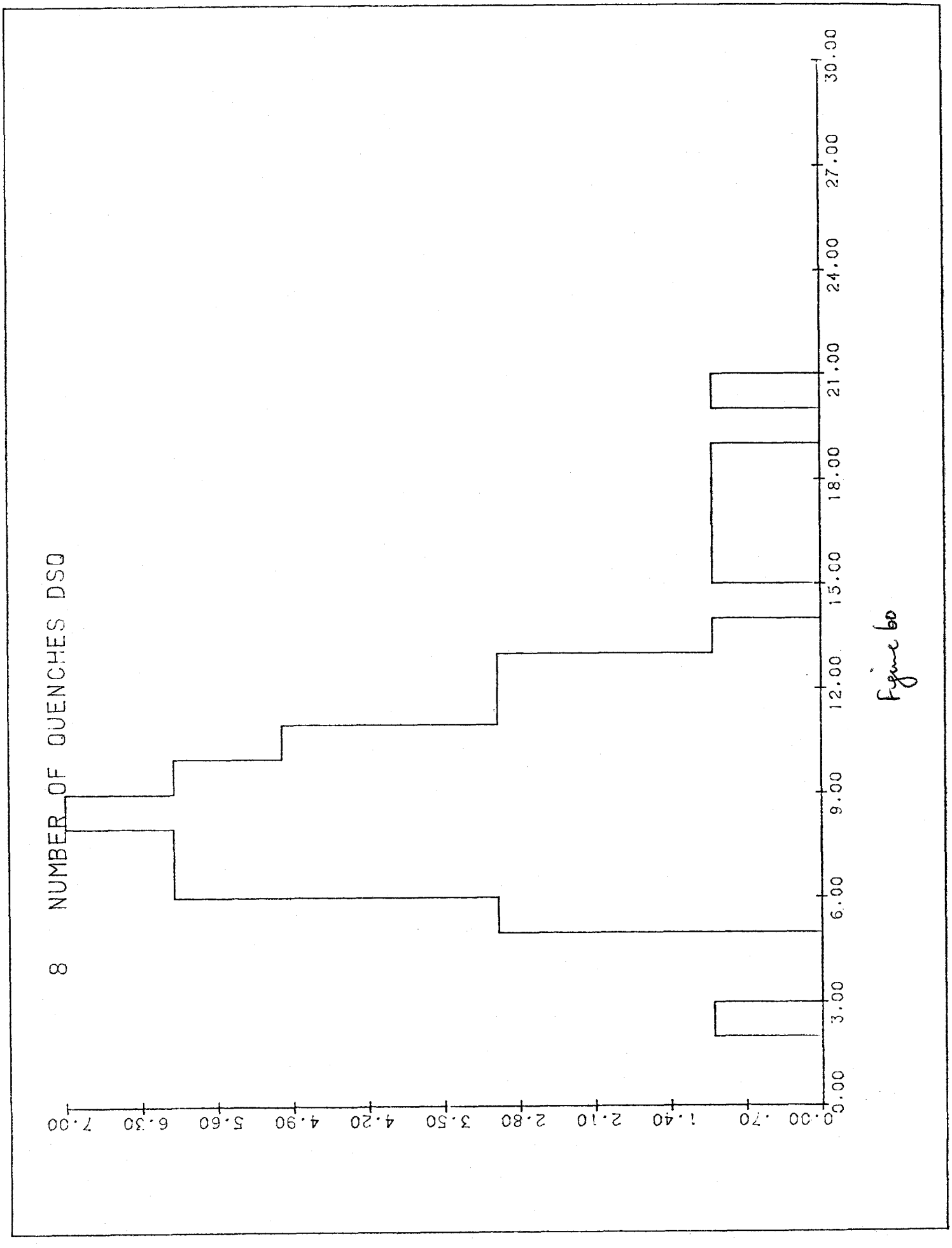
8 NUMBER OF QUENCHES DSO
0.00
.70
1.40
2.10
2.80
3.50
4.20
4.90
5.60
6.30
7.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00

Figure 60

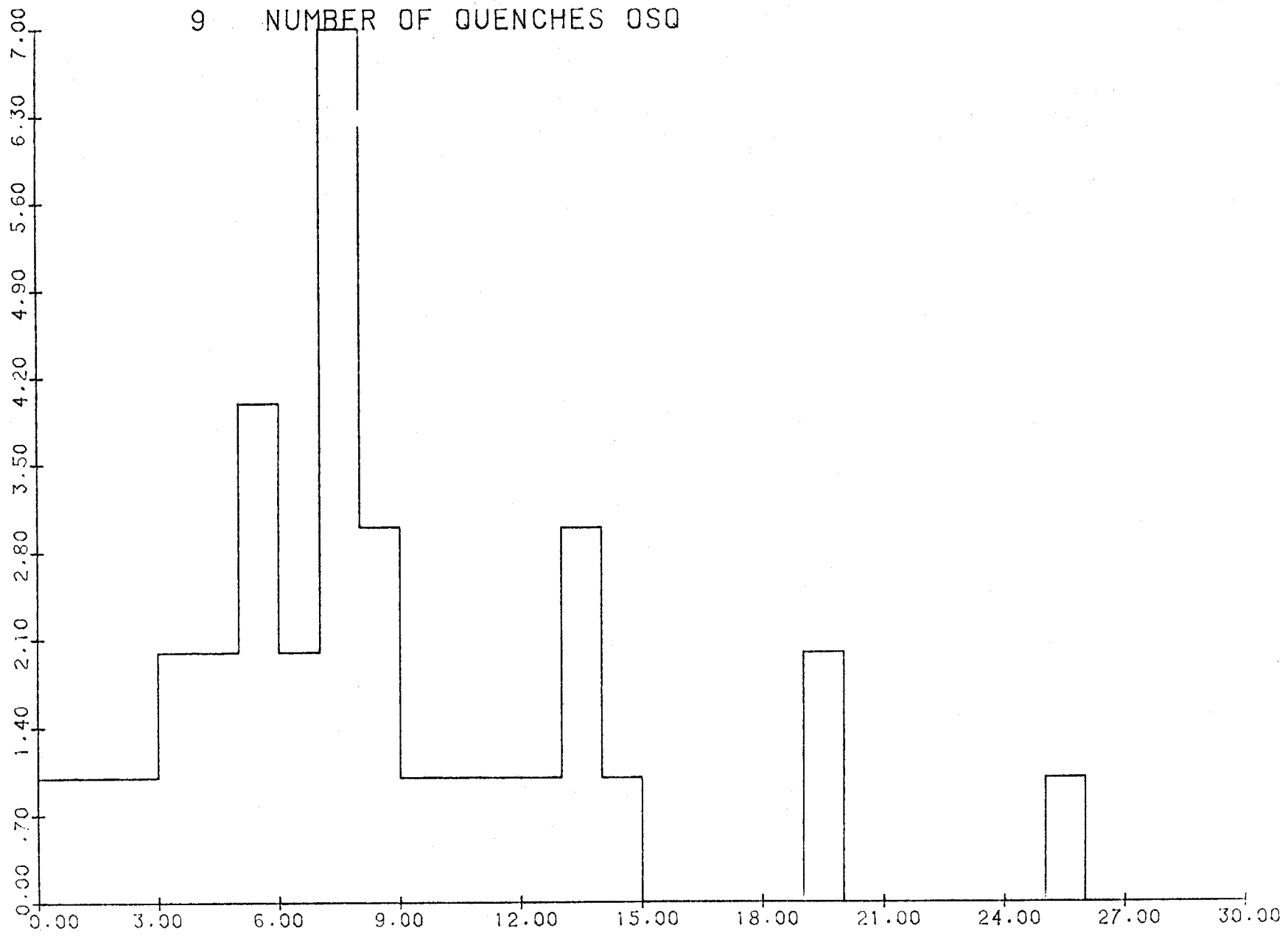
9 NUMBER OF QUENCHES OSQ
7.00
6.30
5.60
4.90
4.20
3.50
2.80
2.10
1.40
.70
0.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00

Figure 6.1

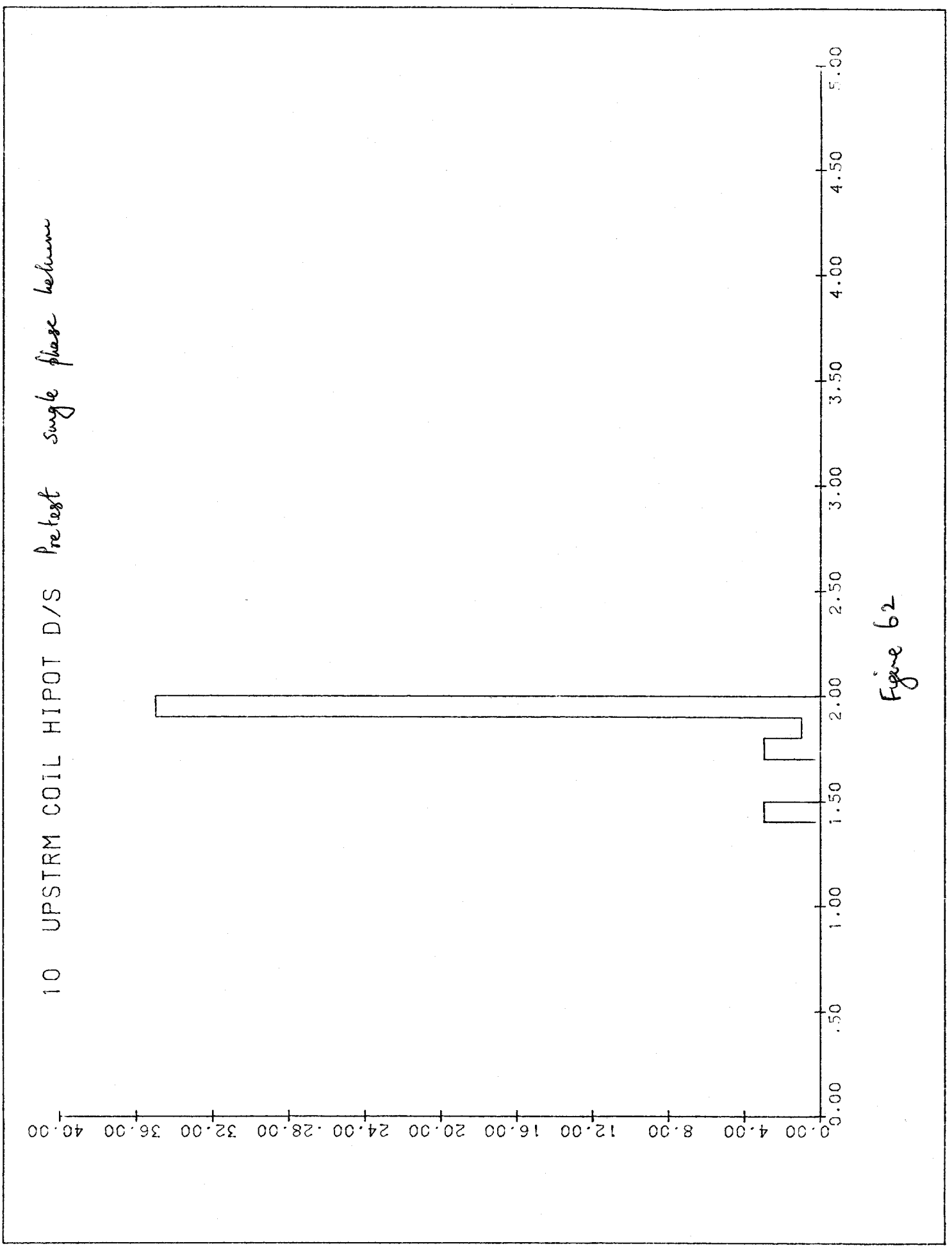
10 UPSTRM COIL HIPOT D/S Pretest single phase helium
0.00
4.00
8.00
12.00
16.00
20.00
24.00
28.00
32.00
36.00
40.00
.50
1.00
1.50
2.00
2.50
3.00
3.50
4.00
4.50
5.00

Figure 62

```
LENGTH OF MAGNETIC DATA       145
LENGTH OF VACUUM DATA       245
SPOOL NUMBER     50
SPOOL NAME TSC050
UPSTREAM COIL NAME DSQI-031    DOWNSTREAM COIL NAME DSQI-037

ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZMAGNET SUMMARYZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ

****** MAGNET SUMMARY *****  S050U      DATE: 23-SEP-81

      PRIMARY/SECONDARY              NORMAL/SKEW               ANGLE/CENTER
  RUN  RUN      POLE POLE              MOMENT

    5    5        2    2      0.99990E+00 0.13962E-01           90.80009
SEXTUPOLE MOMENT FROM DIPOLE -0.59083E-02 0.63156E-03
TEN POLE MOMENT FROM DIPOLE -0.20266E-01 0.12025E-02
    5    6        2    4     -0.61961E-03-0.32176E-02
    5    6        2    6     -0.94793E-02 0.56314E-03
    5    6        2    8      0.15491E-03 0.15940E-02

    1    1        4    4      0.10000E+01 0.34906E-04           90.00208
    1    2        4    2      0.35837E-02-0.23810E-02 -0.00358 -0.00238
DIPOLE CONTRIBUTION TO SEXTUPOLE SUBTRACTED.
    1    2        4    6     -0.25984E-02-0.41823E-03
    1    2        4    8     -0.26374E-03 0.67857E-03

    3    3        6    6      0.99980E+00-0.19900E-01           88.85979
    3    4        6    2      0.19056E-01-0.11359E-01
    3    4        6    4      0.11680E-01 0.20692E-02 -0.00582  0.00115
    3    4        6    8     -0.56220E-02 0.23288E-02
****** MAGNET SUMMARY *****  S050D        DATE: 23-SEP-81

      PRIMARY/SECONDARY              NORMAL/SKEW               ANGLE/CENTER
  RUN  RUN      POLE POLE              MOMENT

    7    7        4    4     -0.28793E-01-0.99959E+00           -1.64994
    7    8        4    2     -0.22075E-01 0.11316E-01  0.01068 -0.02239
DIPOLE CONTRIBUTION TO SEXTUPOLE SUBTRACTED.
    7    8        4    6     -0.46165E-02 0.39858E-02
    7    8        4    8     -0.31001E-03 0.35275E-03

    9    9        6    6     -0.72546E-01-0.99736E+00           -4.16021
    9   10        6    2      0.70792E-02-0.17890E-01
    9   10        6    4     -0.42929E-01 0.25505E-02 -0.00029 -0.02150
    9   10        6    8     -0.34498E-02 0.57629E-02

   11   11        8    8      0.99523E+00-0.97592E-01           84.39954
   11   12        8    2     -0.20372E-01-0.18904E-01
   11   12        8           0.46492E-01 0.36558E-02

DIPOLE CONTRIBUTION TO SEXTUPOLE SUBTRACTED.
   11   12        8    6     -0.27443E-01-0.43534E-01  0.00769 -0.01533

**** UPSTREAM FILE DATA ****
  POLE        ANGLE                  CENTER               POLARITY      TC

    2        90.800                                           1       158.554
    4        90.002         -.00358          -.00238          1        70.261
    6        88.860         -.00582           .00115          1        55.125

**** DOWNSTREAM FILE DATA ****
  POLE        ANGLE                  CENTER               POLARITY      TC

    4        -1.650          .01068          -.02239          1        69.699
    6        -4.160         -.00029          -.02150          1        42.581
    8        84.400          .00769          -.01533          1        31.658

ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZDIAGNOSTICSZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ

 IUP POLE        ANGLE OF COIL              TRUE CENTER
   1    2           0.80009
   1    4           0.00104         -0.00033        -0.02509
   1    6          -0.38007         -0.00257        -0.02156

   2    4          -0.92497          0.01393        -0.04510
   2    6          -1.38670          0.00296        -0.04421
   2    8          -1.40011          0.01094        -0.03804

**** DIFFERENCE ANALYSIS ****

**** UPSTREAM DATA ****
MAXIMUM ANGLE  DIFFERENCE            1.18016 BETWEEN   POLES     2      6
MAXIMUM CENTER DIFFERENCE            0.00418 BETWEEN   POLES     4      6
RECOMMEND THAT MAGNET BE REJECTED BECAUSE THE
MAXIMUM ANGLE DIFFERENCE        1.18016 IS GREATER THAN       1.00000

**** DOWNSTREAM DATA ****
MAXIMUM ANGLE  DIFFERENCE            0.57514 BETWEEN   POLES     4      8
MAXIMUM CENTER DIFFERENCE            0.01101 BETWEEN   POLES     4      6

**** UPSTREAM/DOWNSTREAM DATA ****
MAXIMUM ANGLE  DIFFERENCE            2.20020 BETWEEN   POLES     2      8 IUP 1  2
MAXIMUM CENTER DIFFERENCE            0.02875 BETWEEN   POLES     6      4 IUP 1  2
RECOMMEND THAT MAGNET BE REJECTED BECAUSE THE
MAXIMUM ANGLE DIFFERENCE        2.20020 IS GREATER THAN       1.00000

ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZNEW SHIMS DATAZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ
```

Lab harmonics ← Skew sign convention is −ve to that of the Skew in ring harmonics

Transfer constants. (← TC)

misalignment of Coils (← ANGLE OF COIL)

Figure 63

ANY COORDS OF DOWNSTREAM LUG IN INCHES SURVEYED -7.63100 1.78400

Figure 64 (a)

ELECTRICAL DATA-SPOOL PIECE TEST

SPOOL PIECE: TSC050 SPTF RUN : 9 DATE: 810904

CONNECTOR CORRECTION COIL(OHMS)

AB-DS SEXT:	341.2
DE-DS QUAD:	277
GH-US QUAD:	275.8
KL-US SEXT:	432.8
NP-DS DCT:	327.6
RS-US DIPOLE:	259.2

THERMOMETERS(OHMS)

AH "I" TEMP 1:	61.2
BG "V" TEMP 1:	60.9
CE "I" TEMP 2:	65.1
DF "V" TEMP 2:	65.4

BUSS +4 PIN CONNECTOR CONTINUITY.

UPPER TO 1:	
UPPER TO 2:	
UPPER TO 3:	
1 TO 2:	0.8
LOWER TO 1:	
LOWER TO 3:	
LOWER TO 4:	0.8
3 TO 4:	0.8

VACUUM SNIFFER(OHMS)

AC TO HEATER 1:	62.9
BG TO HEATER 2:	63.2
AH :	DF-3.7
A-GND :	D-GRD=INFI
H-GND :	E-GRD=INFI

COIL PERFORMANCE

COIL US: DSOI-031

D S Q CURRENT(AMPS)	
+ + +	55
+ + -	55
+ - +	55
+ - -	55

LEAD FLOW OFF 3 MIN. OK
NUMBER OF QUENCHES 6
COMMENTS ALL HIPOTS

COIL DS: DSOI-037

D S Q CURRENT(AMPS)	
+ + +	55
+ + -	55
+ - +	55
+ - -	55

LEAD FLOW OFF 3 MIN. OK
NUMBER OF QUENCHES 7
COMMENTS WET HIPOTS

HIGH VOLTAGE TEST SUMMARIES

COILS(KV)

	BUSS LEADS	UPSTREAM COIL	DOWNSTREAM COIL	UPSTREAM/DOWNSTREAM
PRETEST - 1 PHASE HELIUM AT AMBIENCE.				
	+/- 2.1	D/S 1.7	D/S 1.8	D/D 2.0
	+/GD 1.6	D/D 2.0	D/D 1.8	D/S 1.9
	-/GD 2.4	S/D 2.0	S/D 1.9	D/D 2.0
		D/GD 1.7	D/GD 2.0	S/D 1.8
		S/GD 1.6	S/GD 1.7	S/S 1.8
		Q/GD 1.7	Q/GD 2.0	S/D 1.6
				D/D 2.0
				D/S 1.6
				D/D 2.0
PRETEST - 1 PHASE HELIUM AT 22 PSIG				
TERMINALS(1=DRY) 1	+/- 1.6	D/S 2.0	D/S 2.0	D/D 2.0
	+/GD 1.6	D/D 2.0	D/D 2.0	D/S 2.0
	-/GD 3.0	S/D 2.0	S/D 2.0	D/D 2.0
		D/GD 2.0	D/GD 2.0	S/D 2.0
		S/GD 2.0	S/GD 2.0	S/S 2.0
		Q/GD 2.0	Q/GD 2.0	S/D 2.0
				D/D 2.0
				D/S 2.0
				D/D 2.0

Figure 4(b)

COOLDOWN

TEMPERATURE(K) 67.1	+/- 3.0	D/S 1.7	D/S 1.45	D/D 1.6
PRESSURE 1 PHASE(AT) 1.3	+/GD 3.0	D/D 1.7	D/D 2.0	D/S 1.65
	-/GD 3.0	S/D 1.9	S/D 1.45	D/D 1.65
		D/GD 1.6	D/GD 1.9	S/D 1.8
		S/GD 1.7	S/GD 1.45	S/S 1.2
		Q/GD 1.7	Q/GD 2.0	S/D 1.45
				Q/D 1.7
				Q/S 1.15
				Q/D 1.6

COLD LIQUID HELIUM

TEMPERATURE(K) 4.5	+/-	D/S 2.0	D/S 1.9	D/D 2.0
PRESSURE 1 PHASE(AT) 1.3	+/GD	D/D 2.0	D/D 2.0	D/S 2.0
	-/GD	S/D 2.0	S/D 2.0	D/D 2.0
		D/GD 2.0	D/GD 1.9	S/D 1.4
		S/GD 1.7	S/GD 2.0	S/S 1.8
		Q/GD 2.0	Q/GD 1.8	S/D 2.0
				Q/D 2.0
				Q/S 1.7
				Q/D 2.0

WARMUP

TEMPERATURE(K)	+/-	D/S	D/S	D/D
PRESSURE 1 PHASE(AT)	+/GD	D/D	D/D	D/S
	-/GD	S/D	S/D	D/D
		D/GD	D/GD	S/D
		S/GD	S/GD	S/S
		Q/GD	Q/GD	S/D
				Q/D
				Q/S
				Q/D

POST TEST IN NITROGEN AT AMBIENCE.

	+/- 3.0	D/S 2.0	D/S 2.0	D/D 2.0
	+/GD 3.0	D/D 2.0	D/D 2.0	D/S 2.0
	-/GD 3.0	S/D 2.0	S/D 2.0	D/D 2.0
		D/GD 2.0	D/GD 2.0	S/D 2.0
		S/GD 2.0	S/GD 2.0	S/S 2.0
		Q/GD 2.0	Q/GD 2.0	S/D 2.0
				Q/D 2.0
				Q/S 2.0
				Q/D 2.0

THERMOMETER RESISTOR

T1(SERIAL NO.) 810526-21	TEMPERATURE(K) 4.6	RESISTANCE	97.1
T2(SERIAL NO.)	TEMPERATURE(K) 4.6	RESISTANCE	OA.4

LENGTH OF MAGNETIC DATA 143
LENGTH OF VACUUM DATA 245
SPOOL NUMBER 51
SPOOL NAME TS0051
UPSTREAM COIL NAME DSQII031 DOWNSTREAM COIL NAME DSQI041

ZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZMAGNET SUMMARYZZZZZZZZZZZZZZZZZZZZZZZZZZZZZZ

****** MAGNET SUMMARY ***** S051U DATE: 10-NOV-91

RUN	PRIMARY/SECONDARY RUN	POLE	POLE	NORMAL/SKEW MOMENT	ANGLE/CENTER
5	5	2	2	0.11079E-01-0.99994E+00	0.63479

SEXTUPOLE MOMENT FROM DIPOLE -0.58829E-04-0.57567E-02
TEN POLE MOMENT FROM DIPOLE -0.21372E-02 0.19691E-01
5 5 2 4 -0.14572E-02 0.65249E-02
5 5 2 4 -0.10484E-02 0.43135E-02

****

DIAGNOSTICS FOR SPOOL# TS0047
MAGNET IS INDEED TYPE D

********** ANGLE AND CENTER CRITERIA APPLIED

POLE 4 UPSTREAM/DOWNSTREAM 2 HAS ANGLE = 1.06887 DEGREES
MAXIMUM PERMISSIBLE ANGLE = .57000 DEGREES

POLE 6 UPSTREAM/DOWNSTREAM 2 HAS ANGLE = 1.30723 DEGREES
MAXIMUM PERMISSIBLE ANGLE = 1.15000 DEGREES

Figure 5

********** HARMONIC CRITERIA APPLIED

********** HIGH VOLTAGE CRITERIA APPLIED

*** %COLD LIQUID HELIUM	%BUSS LEADS	+/GD	2.60 IS LOWER THAN THE LIMIT	3.00
*** %COLD LIQUID HELIUM	%UPSTREAM COIL	S/GD	1.30 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%DOWNSTREAM COIL	O/O	1.80 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%DOWNSTREAM COIL	O/GD	1.70 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%UPSTREAM/DOWNSTREAM	S/O	1.30 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%UPSTREAM/DOWNSTREAM	S/S	1.30 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%UPSTREAM/DOWNSTREAM	S/O	1.30 IS LOWER THAN THE LIMIT	2.00

****

DIAGNOSTICS FOR SPOOL# TS0048
MAGNET IS INDEED TYPE A

********** ANGLE AND CENTER CRITERIA APPLIED

********** HARMONIC CRITERIA APPLIED

********** HIGH VOLTAGE CRITERIA APPLIED

*** %PRETEST - 1 PHASE HELIUM AT AMBIENCE.	%BUSS LEADS	+/-	.70 IS LOWER THAN THE LIMIT	1.60
*** %PRETEST - 1 PHASE HELIUM AT AMBIENCE.	%BUSS LEADS	+/GD	.70 IS LOWER THAN THE LIMIT	1.50
*** %PRETEST - 1 PHASE HELIUM AT AMBIENCE.	%BUSS LEADS	-/GD	.70 IS LOWER THAN THE LIMIT	1.50
*** %COLD LIQUID HELIUM	%BUSS LEADS	+/-	1.00 IS LOWER THAN THE LIMIT	3.00
*** %COLD LIQUID HELIUM	%BUSS LEADS	+/GD	1.10 IS LOWER THAN THE LIMIT	3.00
*** %COLD LIQUID HELIUM	%BUSS LEADS	-/GD	1.10 IS LOWER THAN THE LIMIT	3.00
*** %POST TEST IN NITROGEN AT AMBIENCE.	%BUSS LEADS	+/-	1.80 IS LOWER THAN THE LIMIT	2.00
*** %POST TEST IN NITROGEN AT AMBIENCE.	%BUSS LEADS	+/GD	2.10 IS LOWER THAN THE LIMIT	3.00
*** %POST TEST IN NITROGEN AT AMBIENCE.	%BUSS LEADS	-/GD	2.40 IS LOWER THAN THE LIMIT	3.00

INVALID DATA D-GRD=INFI LINE NUMBER 30 SPOOL# TSC050
INVALID DATA E-GRD=INFI LINE NUMBER 31 SPOOL# TSC050

****

DIAGNOSTICS FOR SPOOL# TSC050
MAGNET IS INDEED TYPE C

********** ANGLE AND CENTER CRITERIA APPLIED

POLE 4 UPSTREAM/DOWNSTREAM 2 HAS ANGLE = -.82601 DEGREES
MAXIMUM PERMISSIBLE ANGLE = .57000 DEGREES

POLE 6 UPSTREAM/DOWNSTREAM 2 HAS ANGLE = -1.38778 DEGREES
MAXIMUM PERMISSIBLE ANGLE = 1.15000 DEGREES

********** HARMONIC CRITERIA APPLIED

********** HIGH VOLTAGE CRITERIA APPLIED

*** %COLD LIQUID HELIUM	%UPSTREAM COIL	S/GD	1.70 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%DOWNSTREAM COIL	O/S	1.90 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%DOWNSTREAM COIL	O/GD	1.90 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%DOWNSTREAM COIL	O/GD	1.80 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%UPSTREAM/DOWNSTREAM	S/O	1.40 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%UPSTREAM/DOWNSTREAM	S/S	1.80 IS LOWER THAN THE LIMIT	2.00
*** %COLD LIQUID HELIUM	%UPSTREAM/DOWNSTREAM	O/S	1.70 IS LOWER THAN THE LIMIT	2.00

****

DIAGNOSTICS FOR SPOOL# TS0051
MAGNET IS INDEED TYPE D

********** ANGLE AND CENTER CRITERIA APPLIED

********** HARMONIC CRITERIA APPLIED

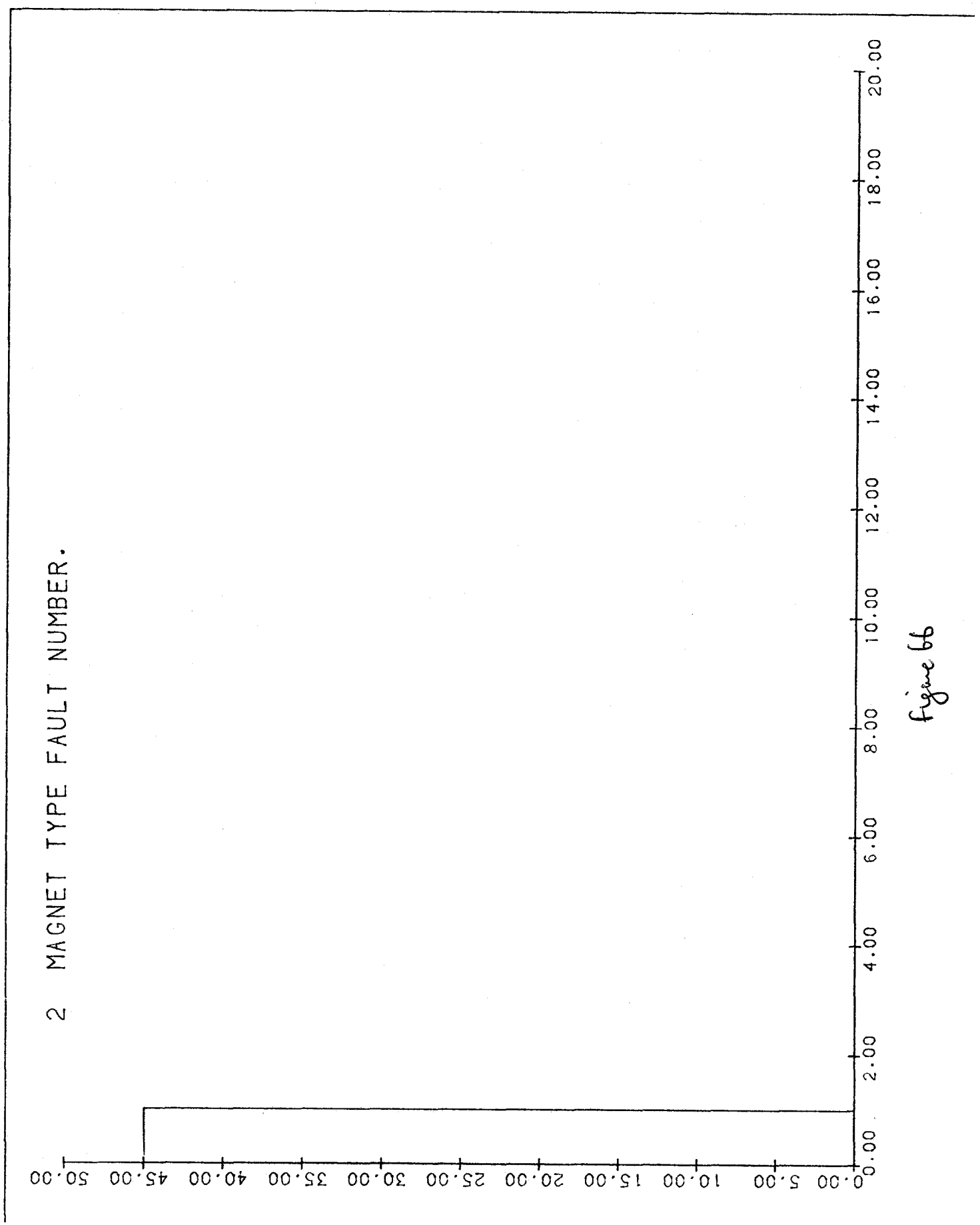
2 MAGNET TYPE FAULT NUMBER.
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00 50.00

Figure 66

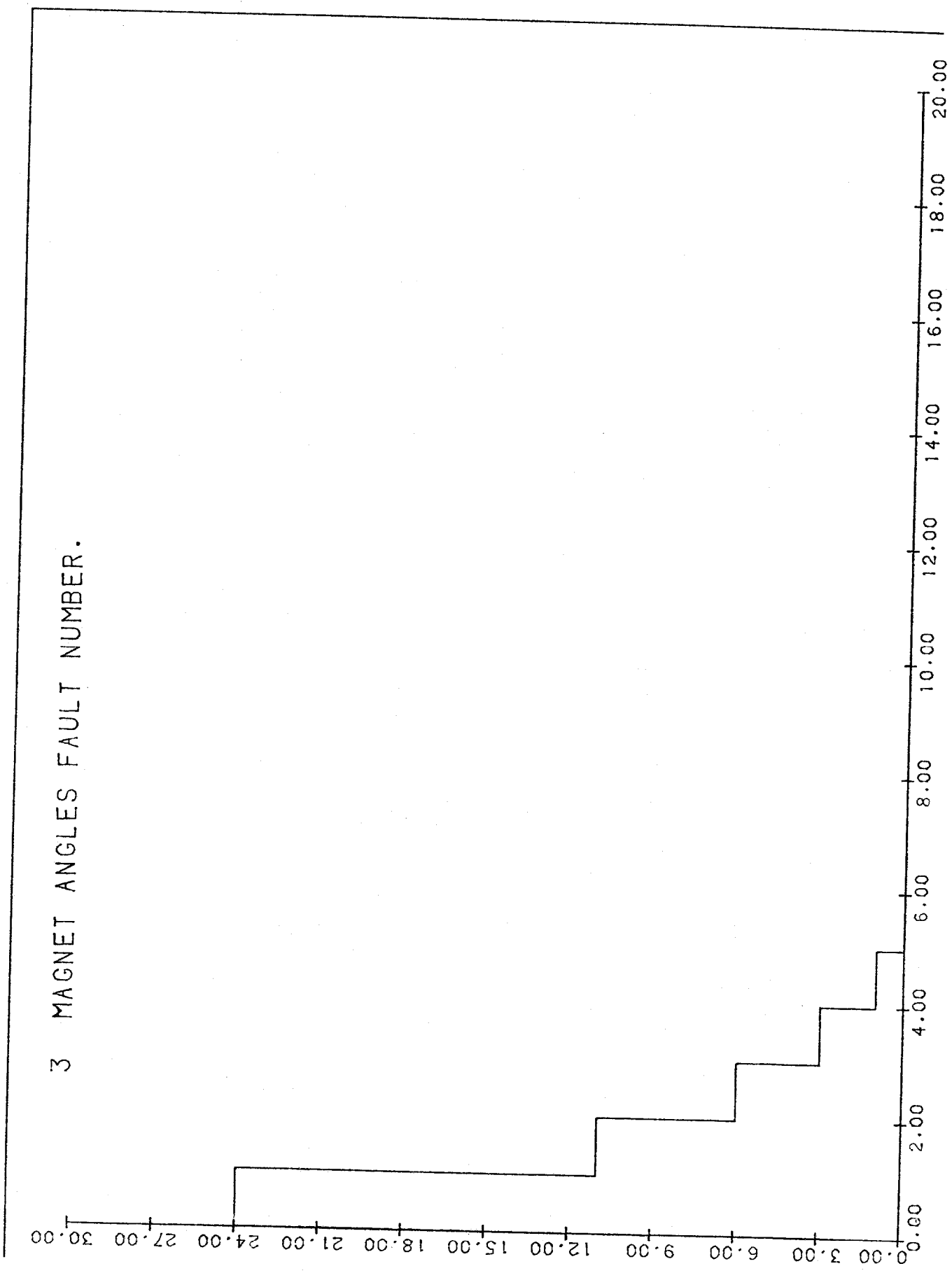
3 MAGNET ANGLES FAULT NUMBER.
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
3.00
6.00
9.00
12.00
15.00
18.00
21.00
24.00
27.00
30.00

Figure 67

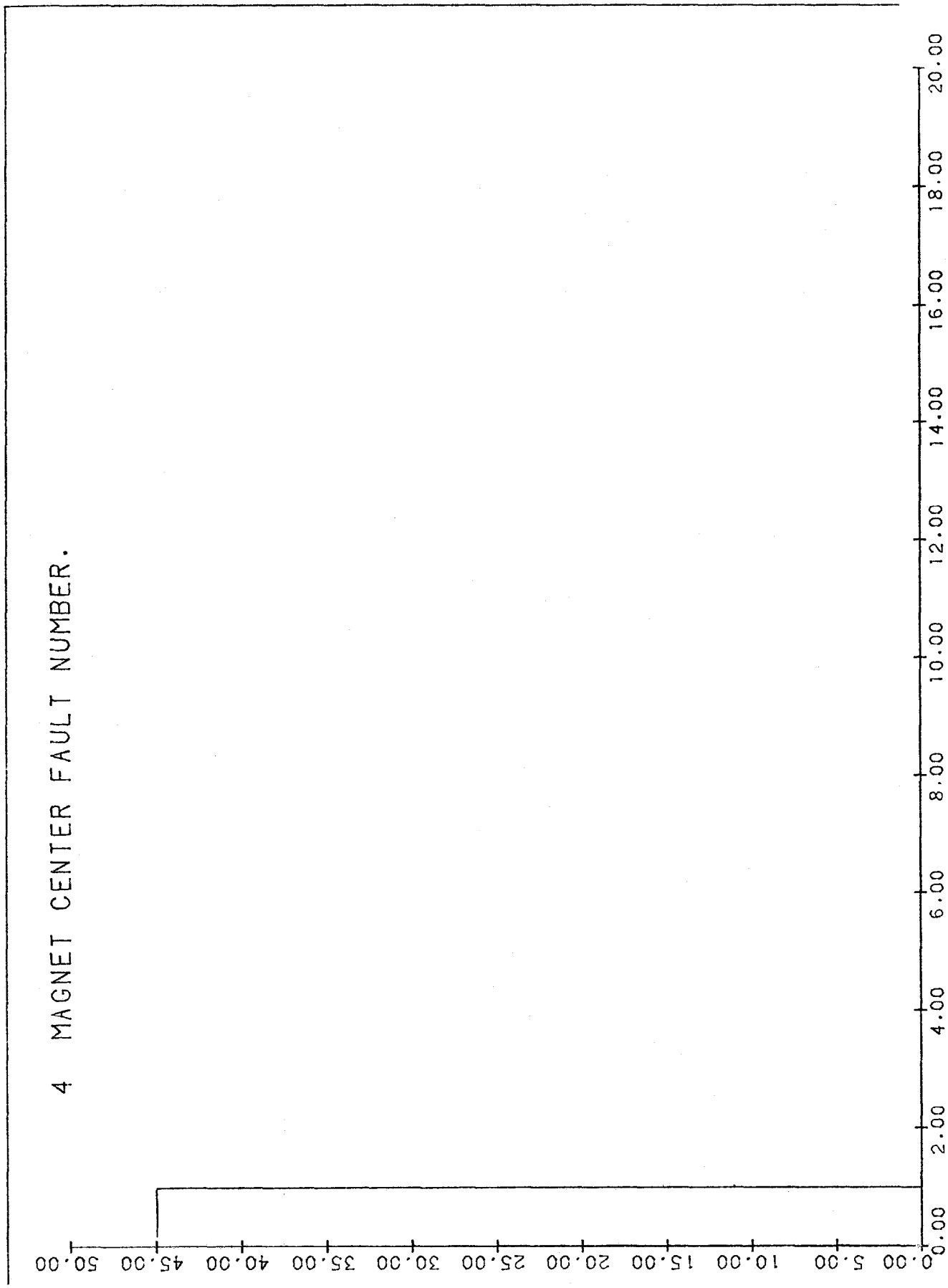
4 MAGNET CENTER FAULT NUMBER.
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00 40.00 45.00 50.00

Figure 68

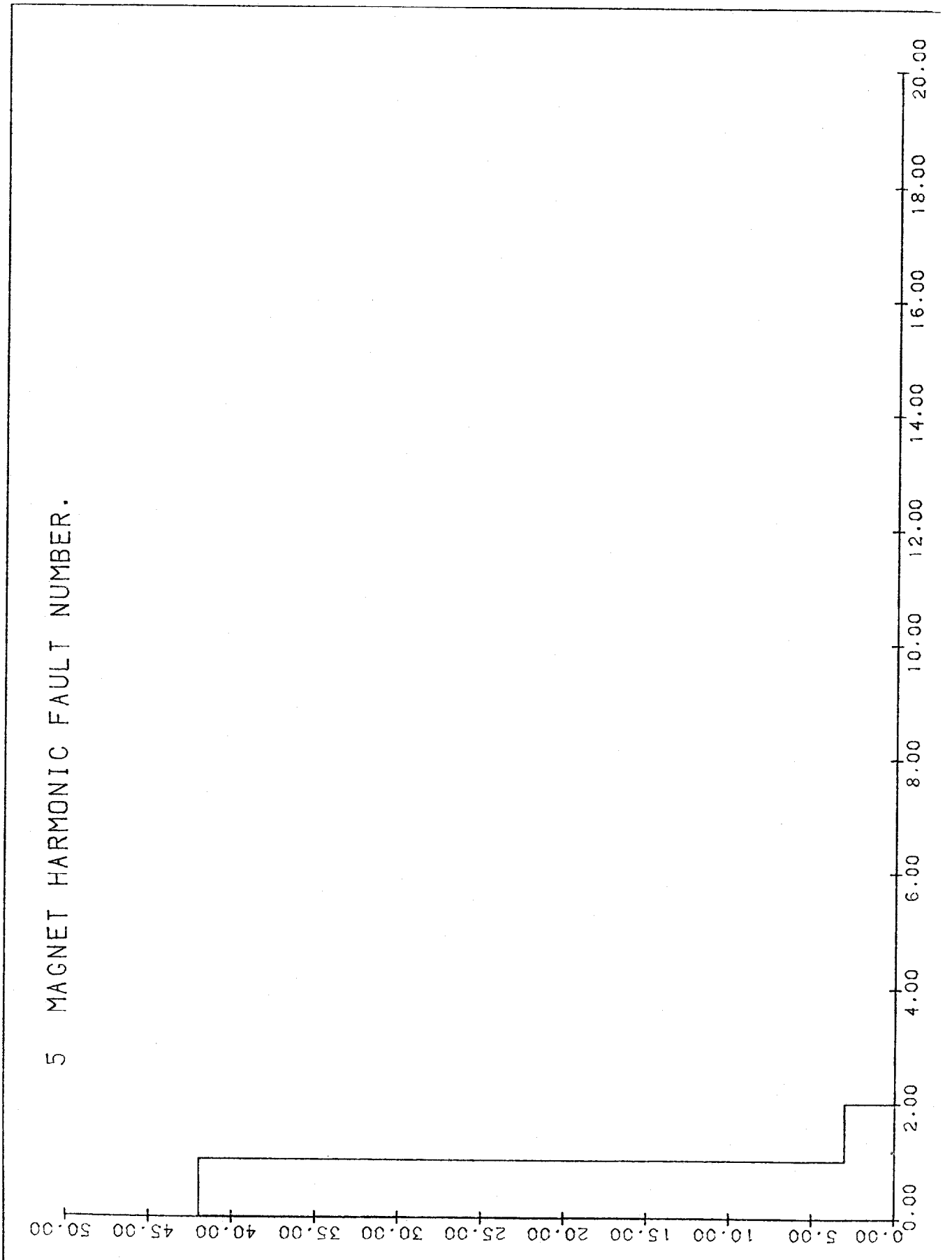
5 MAGNET HARMONIC FAULT NUMBER.
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00
0.00
5.00
10.00
15.00
20.00
25.00
30.00
35.00
40.00
45.00
50.00

figure 69

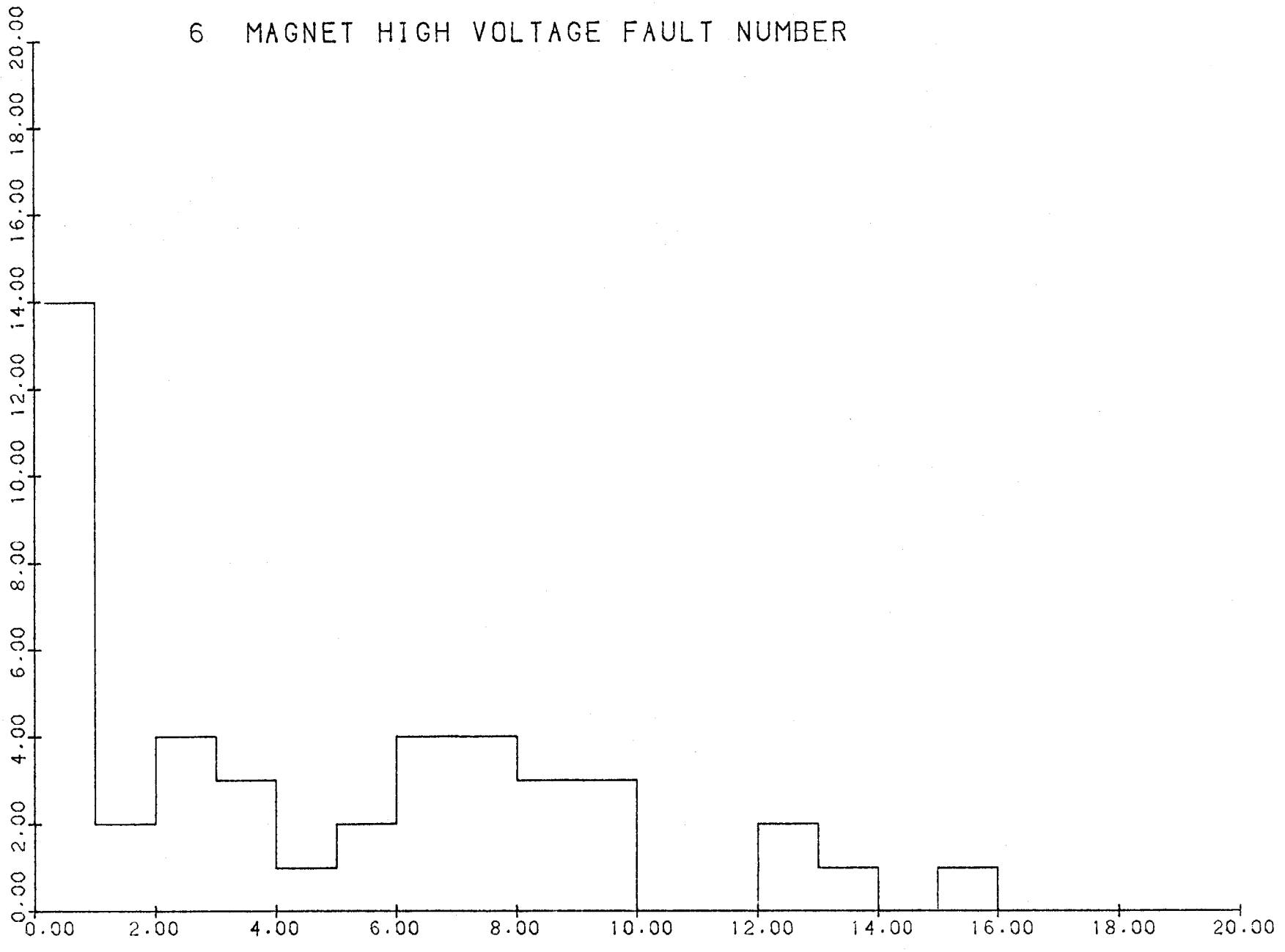
6 MAGNET HIGH VOLTAGE FAULT NUMBER
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 70

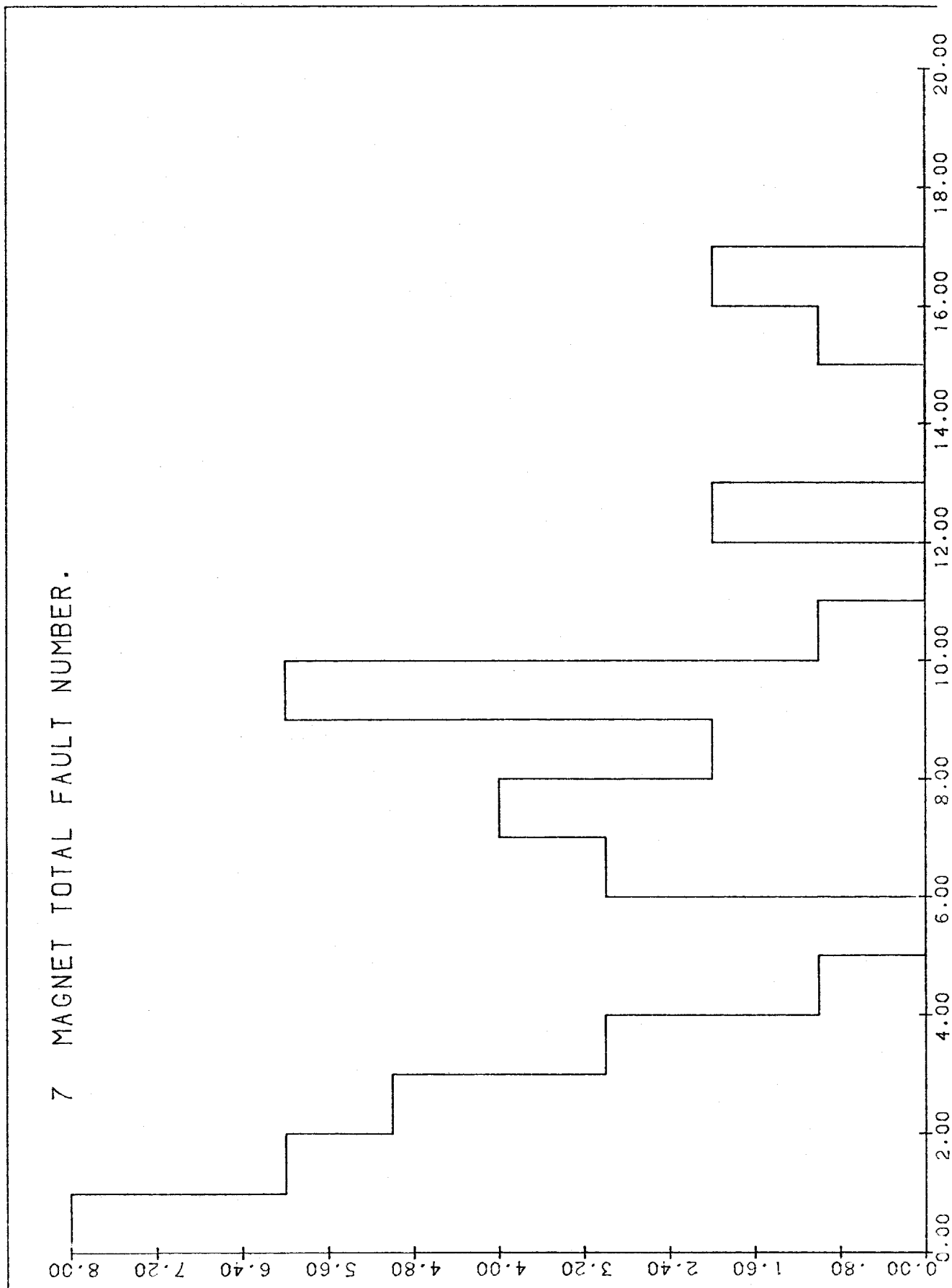
7 MAGNET TOTAL FAULT NUMBER.
0.00
.80
1.60
2.40
3.20
4.00
4.80
5.60
6.40
7.20
8.00
0.00
2.00
4.00
6.00
8.00
10.00
12.00
14.00
16.00
18.00
20.00

Figure 71