SLAC-55
UC-28, Particle Accelerators and High-Voltage Machines
UC-34, Physics
TID-4500 (47 Ed.)

MAGNETIC CHARACTERISTICS OF THE ACCELERATOR QUADRUPOLE TRIPLETS

January 1966

J. K. Cobb and A. W. Burfine

Technical Report
Prepared Under
Contract AT(04-3)-515
for the USAEC
San Francisco Operations Office

Printed in USA. Price $2.00. Available from CFSTI, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia.

LIST OF FIGURES

I. INTRODUCTION

A number of the production quadrupole triplet assemblies (designed by H. Brechna) have recently been measured to determine their magnetic characteristics. The triplet assembly consists of three quadrupoles, one with an effective length of 8 inches and two of opposite polarity with an effective length of 4 inches. The three magnets are placed axially in the drift sections between the accelerating sectors of the accelerator. They operate as a spaced triplet so that a beam traverses one of the magnets with 4-inch length at one polarity, then the 8-inch magnet at opposite polarity, and finally the other 4-inch magnet with the same polarity as the first. The magnets are essentially identical in physical appearance except for the difference in length. The 4-inch magnets are designated as QA type and the 8-inch magnets are designated as QB type.

Figure 1 is a photograph of the exterior of a QA magnet. Figure 2 is a photograph of the same magnet showing its interior and the pole shape. The coils are potted in epoxy and are wound after the pole is bolted to the yoke plates. Figure 3 shows the stages in the fabrication of the coil on the pole piece. Figure 4 is a drawing showing the detail of the poles used in the magnet.

The 1.2-inch aperture magnets were designed to produce a gradient-length product of 10 kG for the QA and 20 kG for the QB when excited with a current of 6 amperes.

This report presents in a statistical fashion the results of the measurement of certain electrical and magnetic characteristics of 62 of the QA magnets and 31 of the QB magnets. Thus the magnets included in this report are the total of 31 quadrupole triplet assemblies.

II. DESCRIPTION OF TESTS AND MEASUREMENTS

The magnetic measurements which may be used to find the magnetic properties to first-order are given by A. Septier.[1] The coordinate system used is shown in Fig. 5. The various electrical tests are specified in SLAC Technical Specification PS 902-061. These include resistance measurements on the coils, high potential test for leakage between coil and poles, and a corona test to detect voids in the epoxy coil potting.

A. Electrical Tests

The corona threshold for all magnets was greater than 400 volts, which is 300 volts higher than the minimum specified threshold voltage.

The individual coil resistances and the total magnet resistances were measured with a Kelvin bridge. The measured total resistances of the magnets are shown in Fig. 6a for the QA magnets and Fig. 6b for the QB magnets.

B. Magnetic Tests

All magnetic tests were performed with either a Hall effect probe or with a rotating coil.

1. Point Field Measurements and Gradient

The transverse field B_Y as a function of X at $z = 0$ was measured using a Rawson-Lush Rotating Coil Model 820 gaussmeter with an accuracy of 0.1%. The displacement along X was made precisely by use of a machine cross slide. This measurement is also used to find the average gradient across the aperture. In Fig. 7 the gradient of each magnet at 6 amperes excitation is shown, and in Fig. 8 the percentile of magnets with specified percent gradient deviations at 6 amperes excitation is displayed.

2. Longitudinal Field Distributions

The longitudinal field distribution used to determine the effective length of each magnet was measured at $X = 0$, $Y = 0.25$ inch and at $x = 0$, $y = 0.25$ inch. These measurements were made with the magnet positioned on a machine lathe bed, with a Hall-effect gaussmeter fed into the y-coordinate of an x-y recorder. The machine bed position was used to drive the x-axis of the recorder. A sample graph is shown in Figs. 9a and 9b for QA and QB quadrupoles, respectively. The curves show the longitudinal field in the center of the magnet as well as in the fringe (leakage) fields. The effective length of each magnet is obtained from these curves by integrating the area under the curve and dividing by the field at $z = 0$. The effective length versus magnet number is shown in Figs. 10a and 10b for QA and QB quadrupoles. In Fig. 11 the percentile of magnets with specified effective lengths is shown.

3. Harmonic Analysis

The radial gradient as a function of excitation current and the distortions of the scalar magnetic potential were measured by the method of harmonic analysis.[2,3] The probe in this case consisted of an asymmetric loop coil rotating in the aperture of the quadrupole at a fixed frequency of 30 cycles per second. The output voltage waveform when the coil was radially centered was analyzed on a superhetrodyne wave analyzer which allowed one to separate the signal into its frequency components. Centering was accomplished by moving the coil until the 30 cycle component (corresponding to the dipole) induced voltage was minimized. The equipment arrangement used in this measurement is shown in Fig. 12. Each of these components, other than the first harmonic, corresponds to a distortion in the pure quadrupole field. The first harmonic (in this case 60 cycles per second) represents the quadrupole component of field. The harmonic content of each magnet was determined by this technique at a magnet excitation current of 7 amperes. If one records the amplitude of the first harmonic (quadrupole component) as the current is varied, the radial gradient as a function of excitation current can be obtained. This relationship can be normalized at a particular current to the average gradient found by point measurement with the Rawson rotating coil. The harmonic analysis coil used was 7/16-inch radius and one inch in longitudinal extent so that it was totally immersed in the non-fringing field of the magnets. It was rotated at the center of the magnet so that its z extent was between +0.5 inch and -0.5 inch. All higher-order poles except the dodecapole were insignificantly small. The dodecapole component was found to exist in some degree in all of the magnets and varied between one and three percent of the quadrupole component when normalized to the aperture radius. This corresponds to an actual measured percentage of less than one percent when the distortion due to dodecapole is considered at the expected beam radius of less than one centimeter. This result is caused by the fact that the dodecapole scales as $(r/a)^5$ where a is the aperture radius, whereas the quadrupole scales as $(r/a)^1$. A typical harmonic analysis spectrum is shown in Fig. 13. In Fig. 14 the percentile of magnets having specified dodecapole harmonic expressed as a percent of quadrupole is shown.

In Fig. 15 the gradient is displayed at $z = x = y = 0$ as a function of excitation current for a typical QA and QB magnet type.

III. SUMMARY

The design criteria for the magnets was to produce a magnet strength (gradient times length) of 10 kilogauss for the QA type and 20 kilogauss for the QB type at an excitation current of six amperes. As can be seen from Fig. 15, the respective strengths are attainable at 5.55 amperes for the QA type magnets and at 5.45 amperes for the QB type magnets. This difference in efficiency is probably caused by the fact that the pole body of the QB type has a considerably larger cross-sectional area than does the QA type. This advantage is approximately 1.3 and is no doubt enough to account for the higher efficiency of the QB type. In Fig. 16 the magnet strength of each magnet at six amperes is shown and in Fig. 17 the percentile of magnets having specified percent diviations in magnet strength is shown.

REFERENCES

1. A. Septier, Advances in Electronics and Electron Physics, Vol. XIV, p. 171 (Academic Press, New York, 1961).
2. J. Cobb and J. Muray, "Magnetic Field Measurement and Spectroscopy in Multipole Fields," SLAC Report No. 39, Stanford Linear Accelerator Center, Stanford, California (February 1965; revised November 1965).
3. J. Cobb and R. Cole, "Spectroscopy of Quadrupole Magnets," SLAC Pub - 133, Proceedings of the International Symposium on Magnet Technology, Stanford Linear Accelerator Center, Stanford, California, (September 8-10, 1965).

ACKNOWLEDGEMENTS

Our thanks are due to Mr. D. Malone and Mr. H. Lipinski for their diligence and conscientiousness in making these measurements.

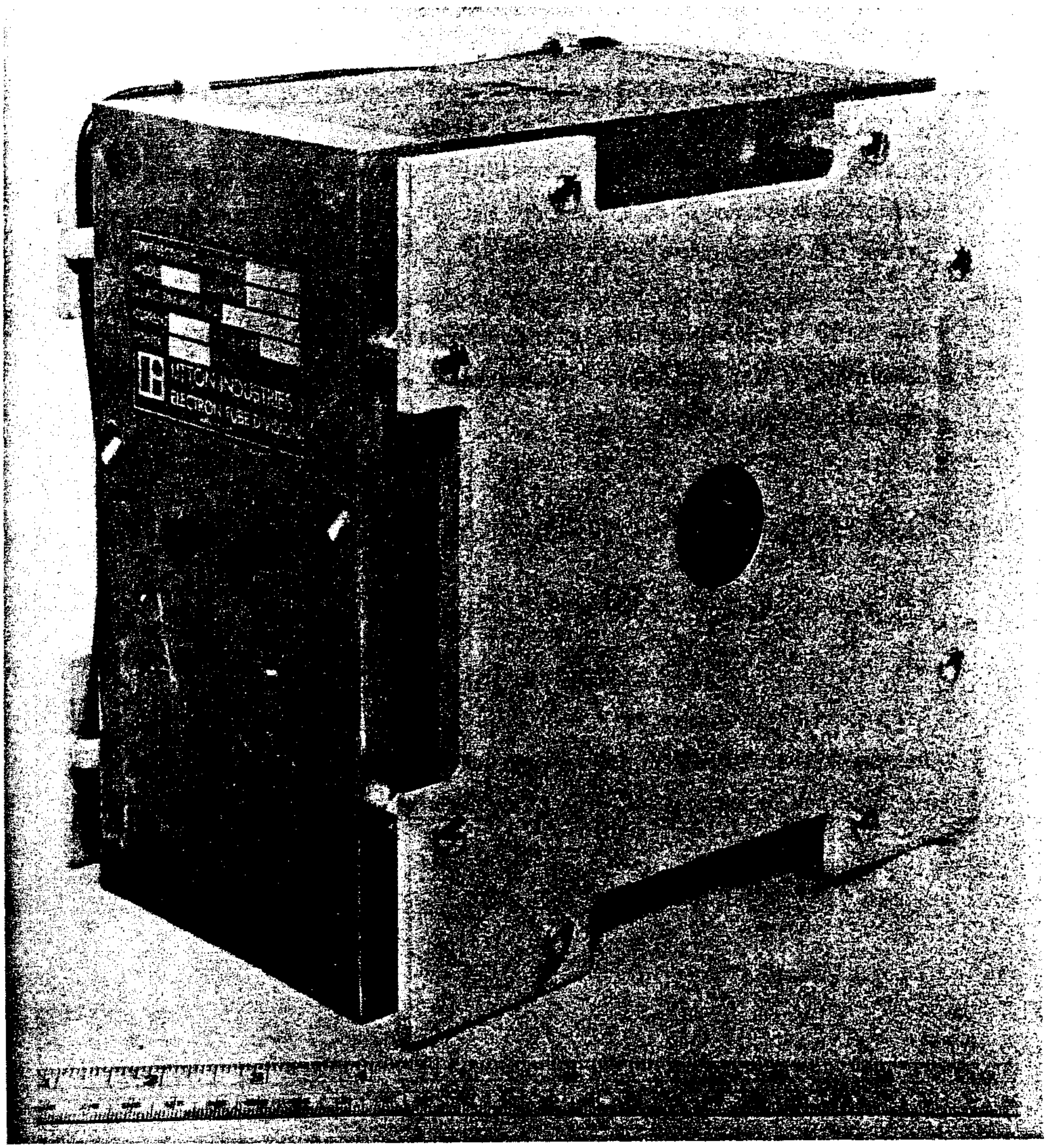


Fig. 1--QA quadrupole.

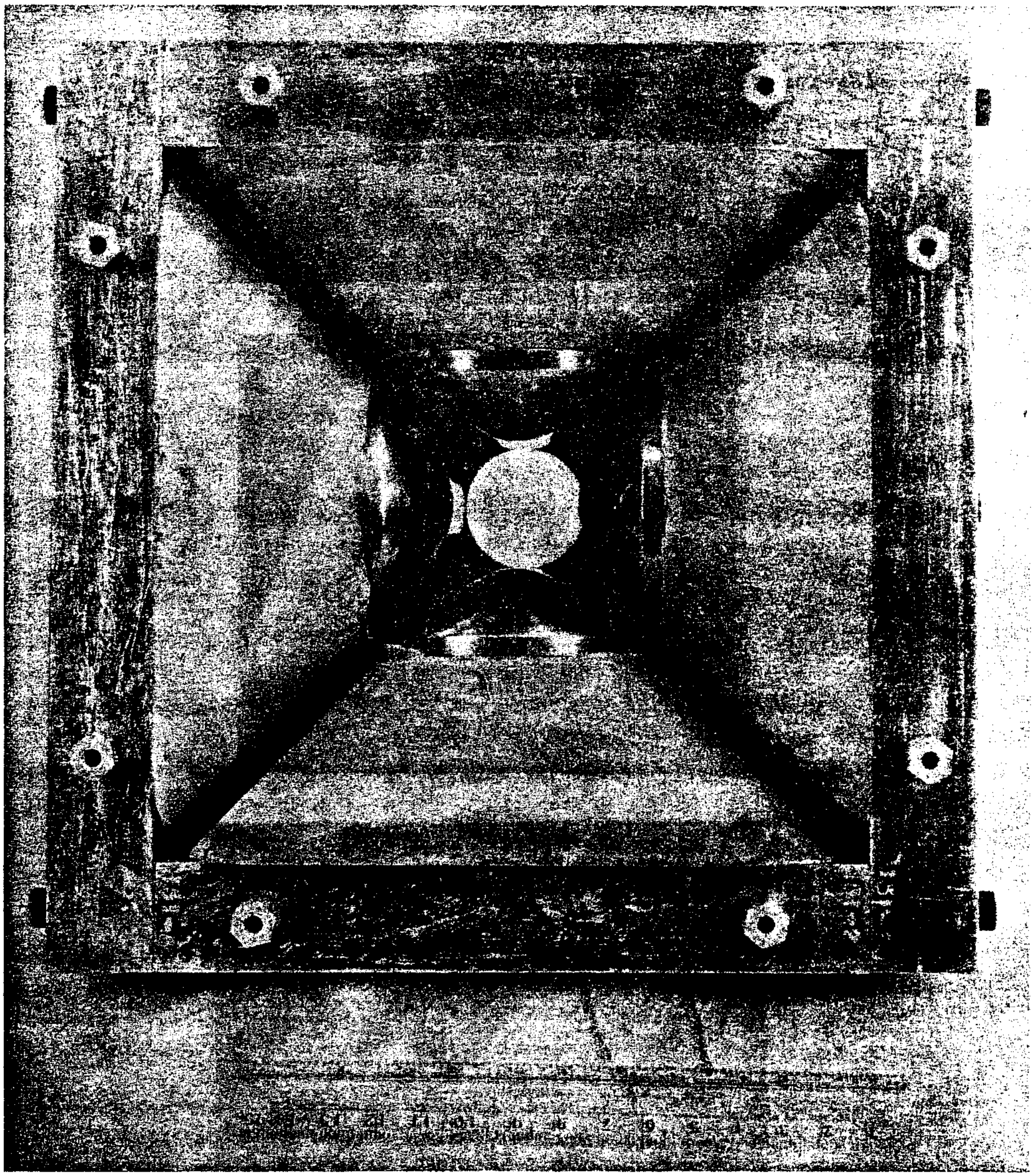
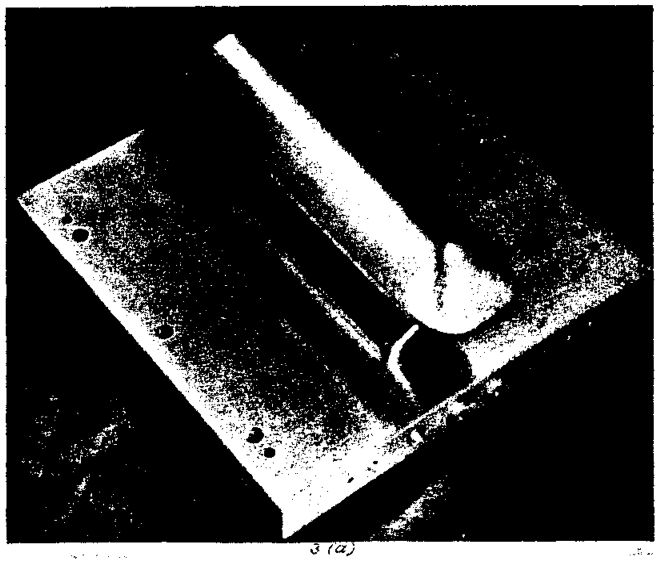
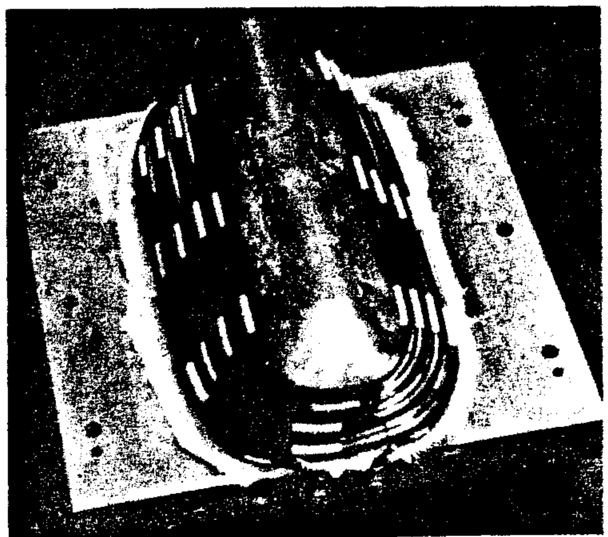


Fig. 2--QA quadrupole with magnetic mirror removed to show interior.



3 (a)



3 (b)

3 (c)

Fig. 3--Stages in the fabrication of a pole, yoke, coil assembly.

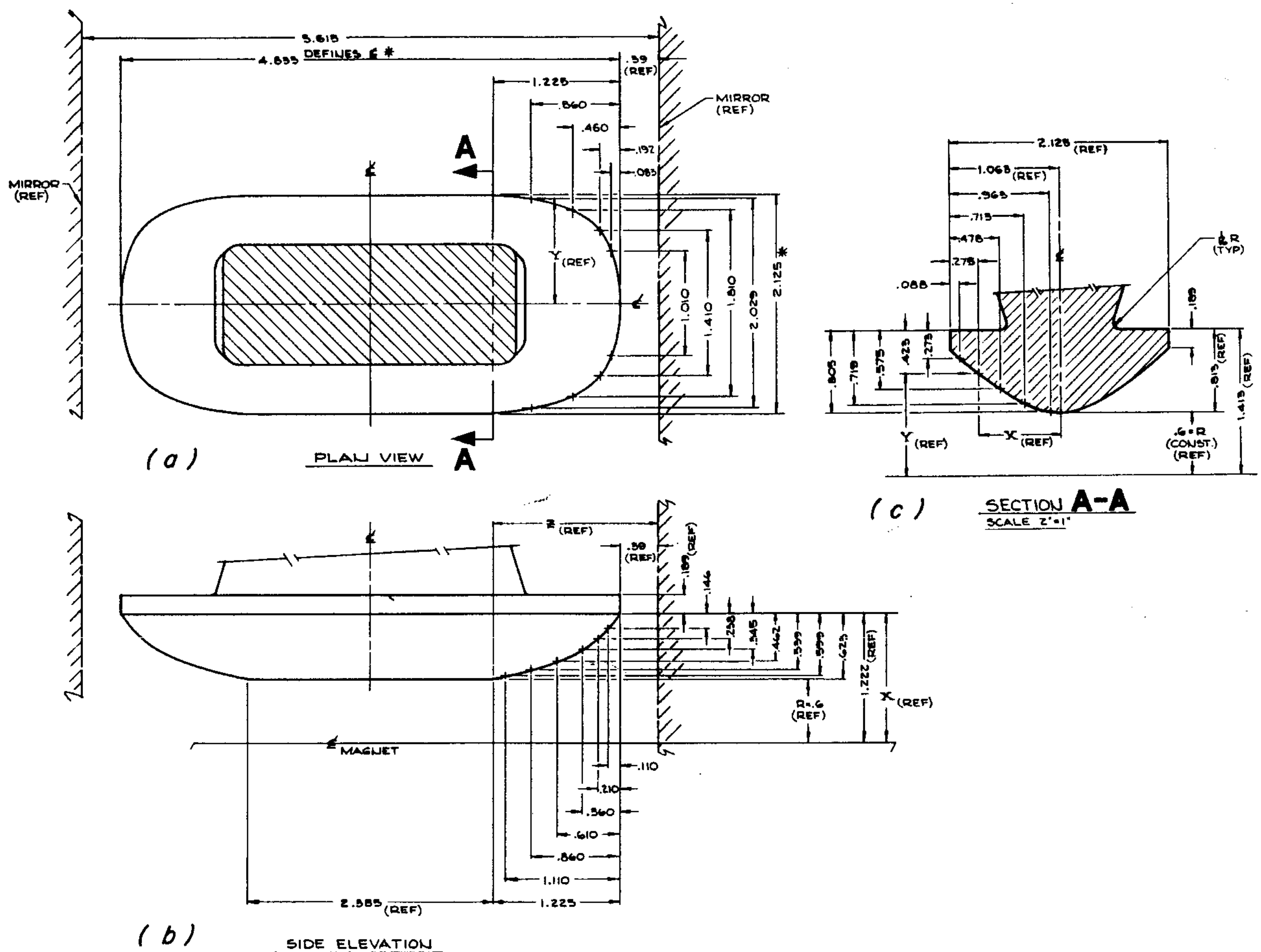


Fig. 4--Drawing of pole detail of QA magnet. (a) Top view (b) Side view (c) Cut at section A-A.

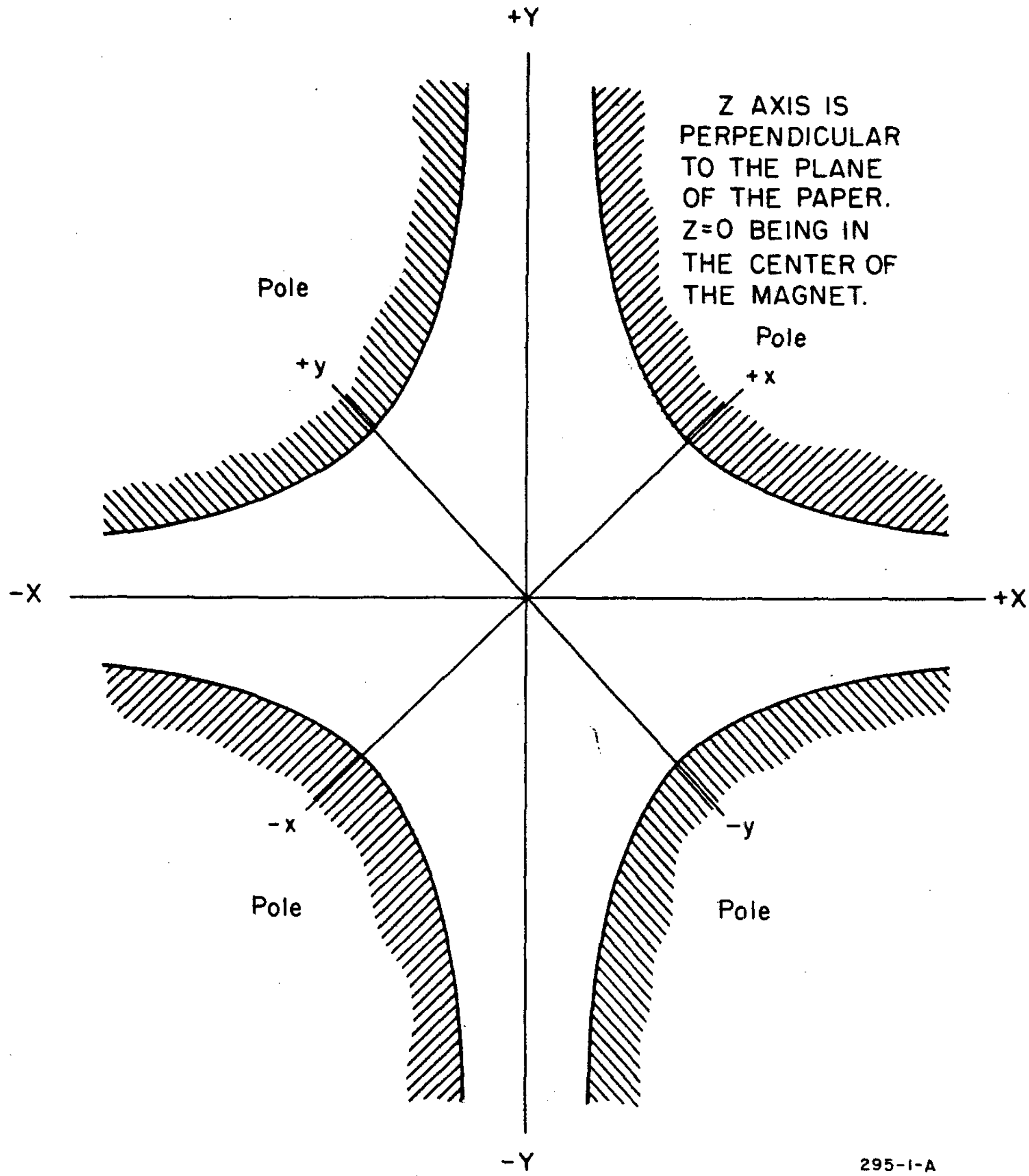


Fig. 5--The coordinate system used in measurements.

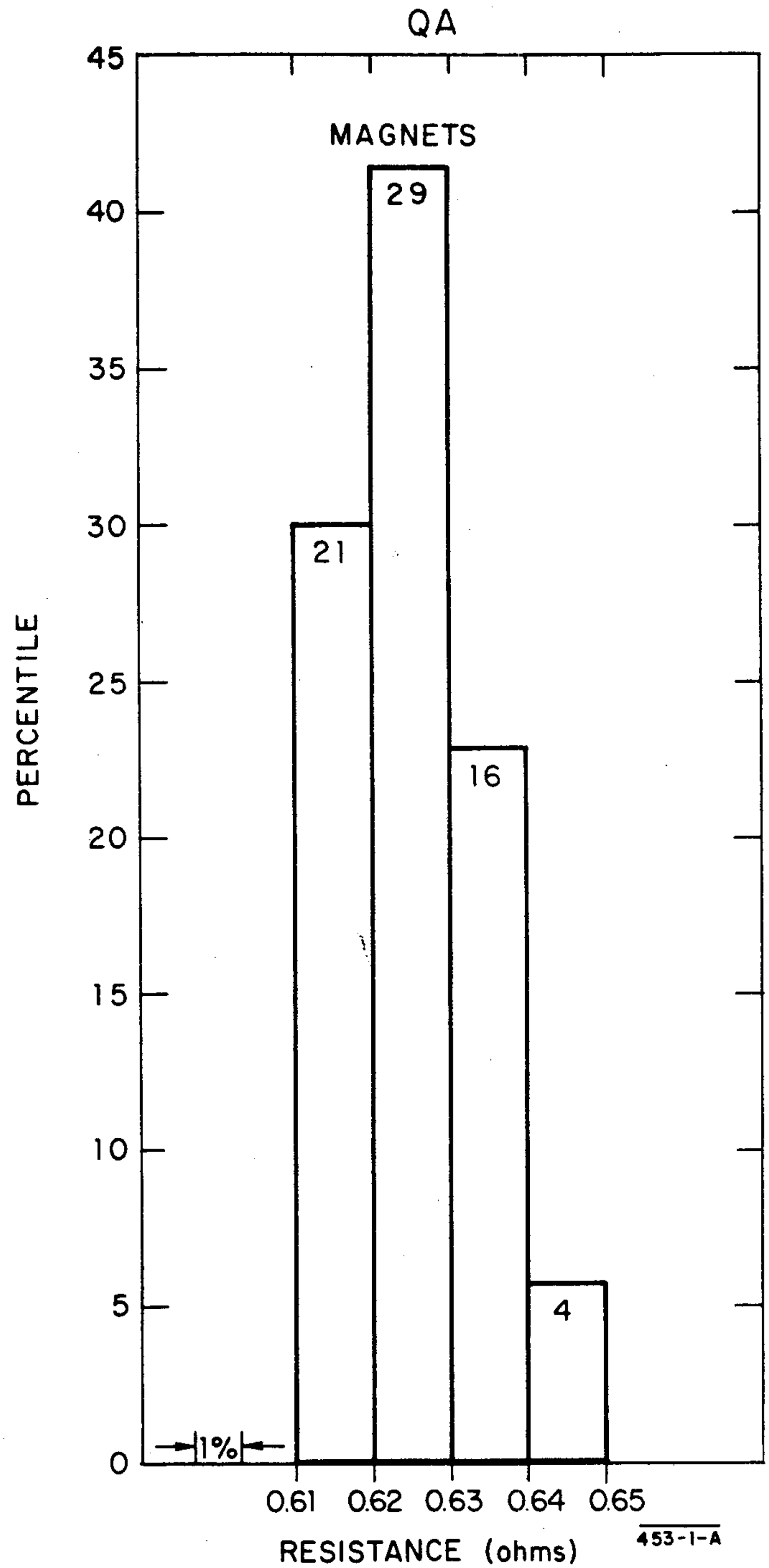


Fig. 6a--Percentile of magnets of specified total resistance for QA magnets.

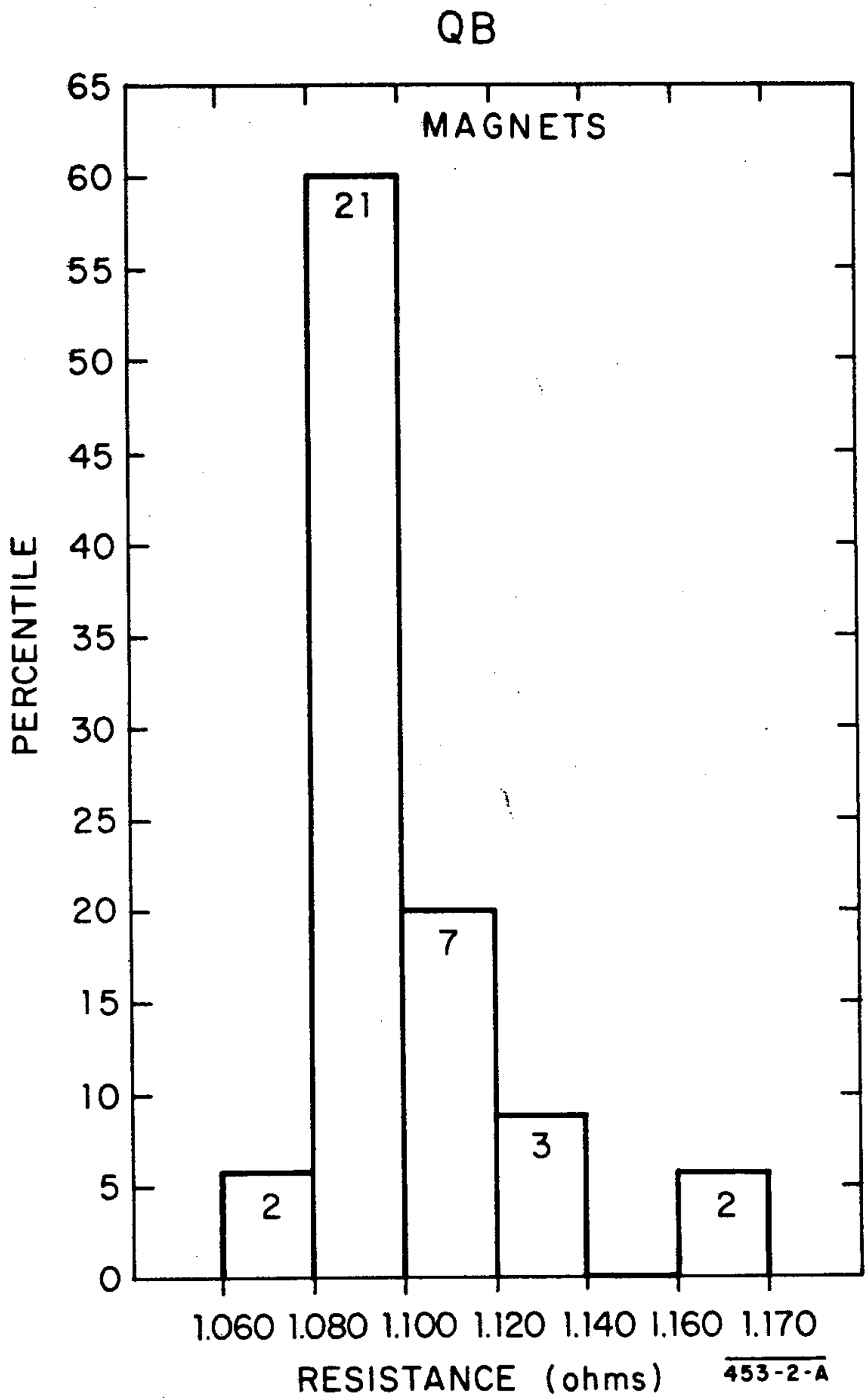


Fig. 6b--Percentile of magnets of specified total resistance for QB magnets.

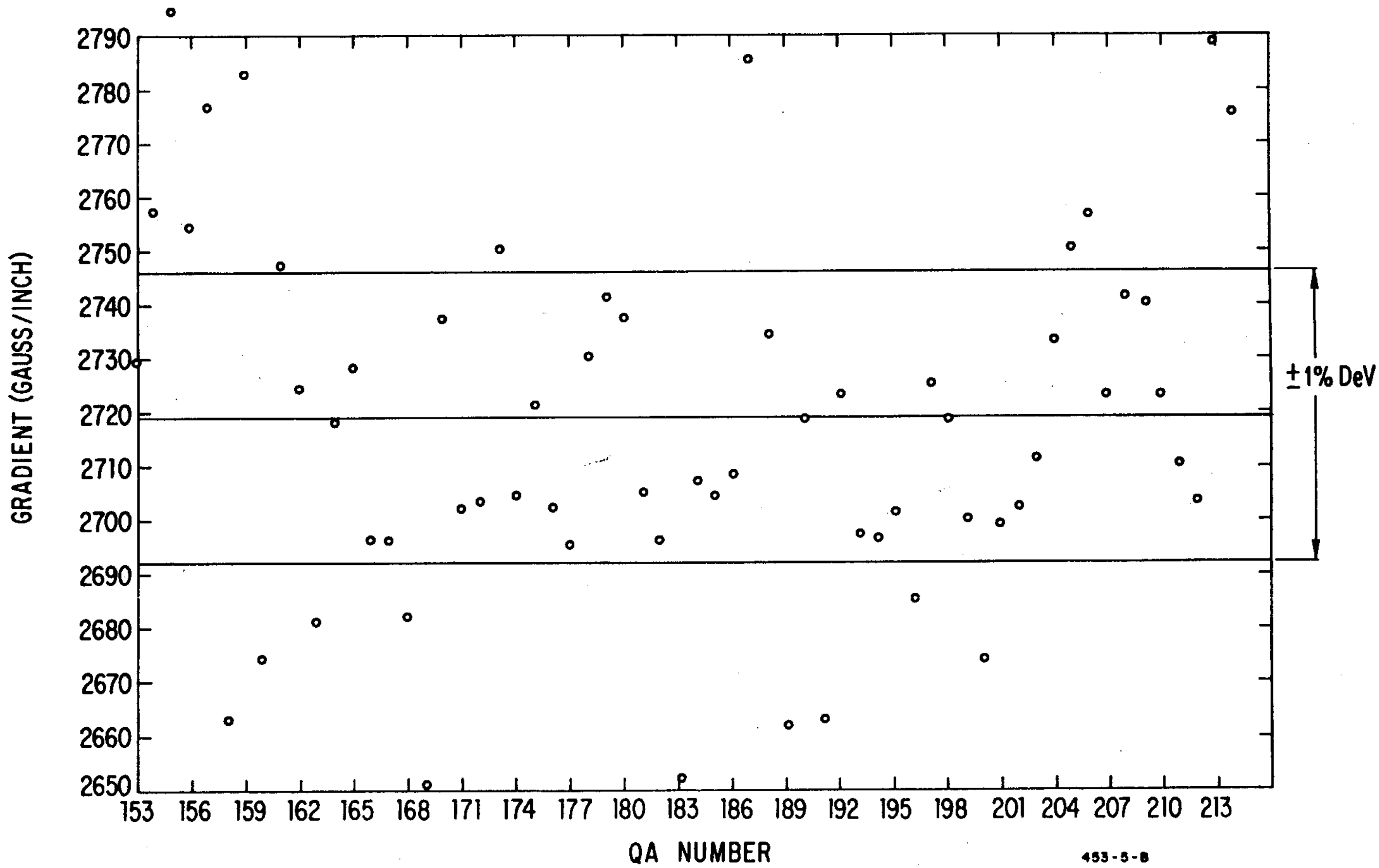


Fig. 7a--Percentile of magnets with specified percent gradient deviations at 7 amperes for QA magnets.

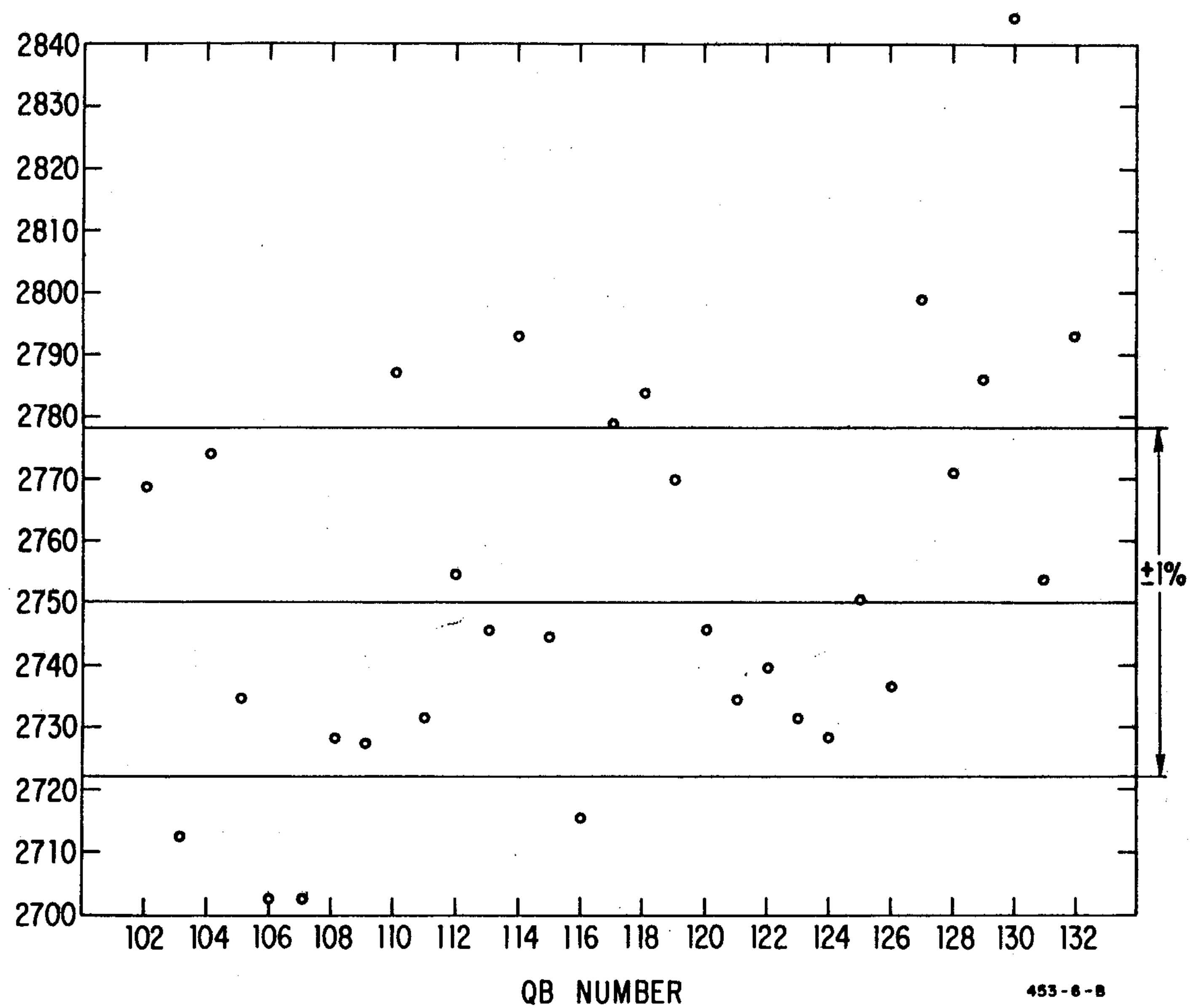


Fig. 7b--Percentile of magnets with specified percent gradient deviations at 7 amperes for QB magnets.

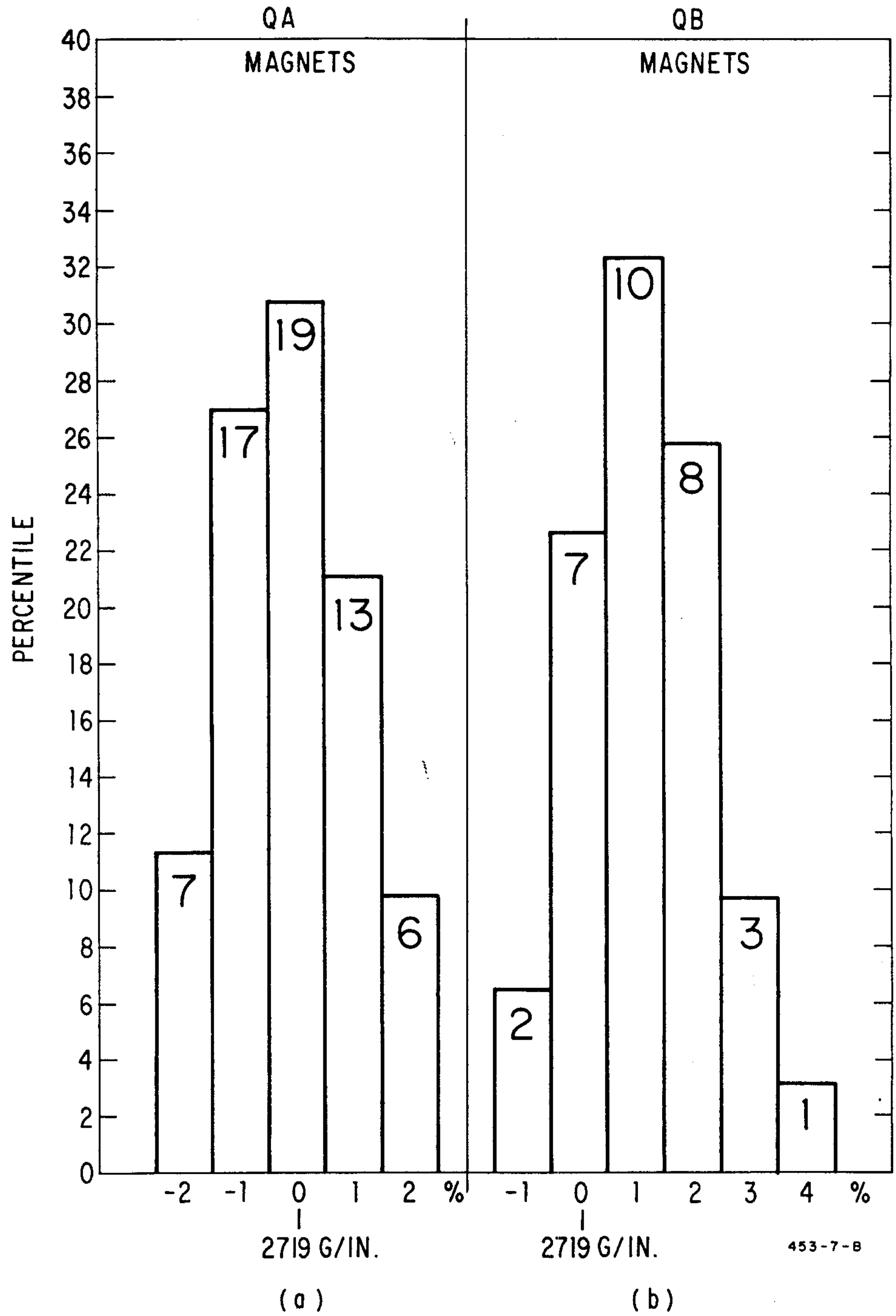


Fig. 8--Percentile of magnets with specified percent gradient deviations at 6 amperes. (a) QA magnets (b) QB magnets.

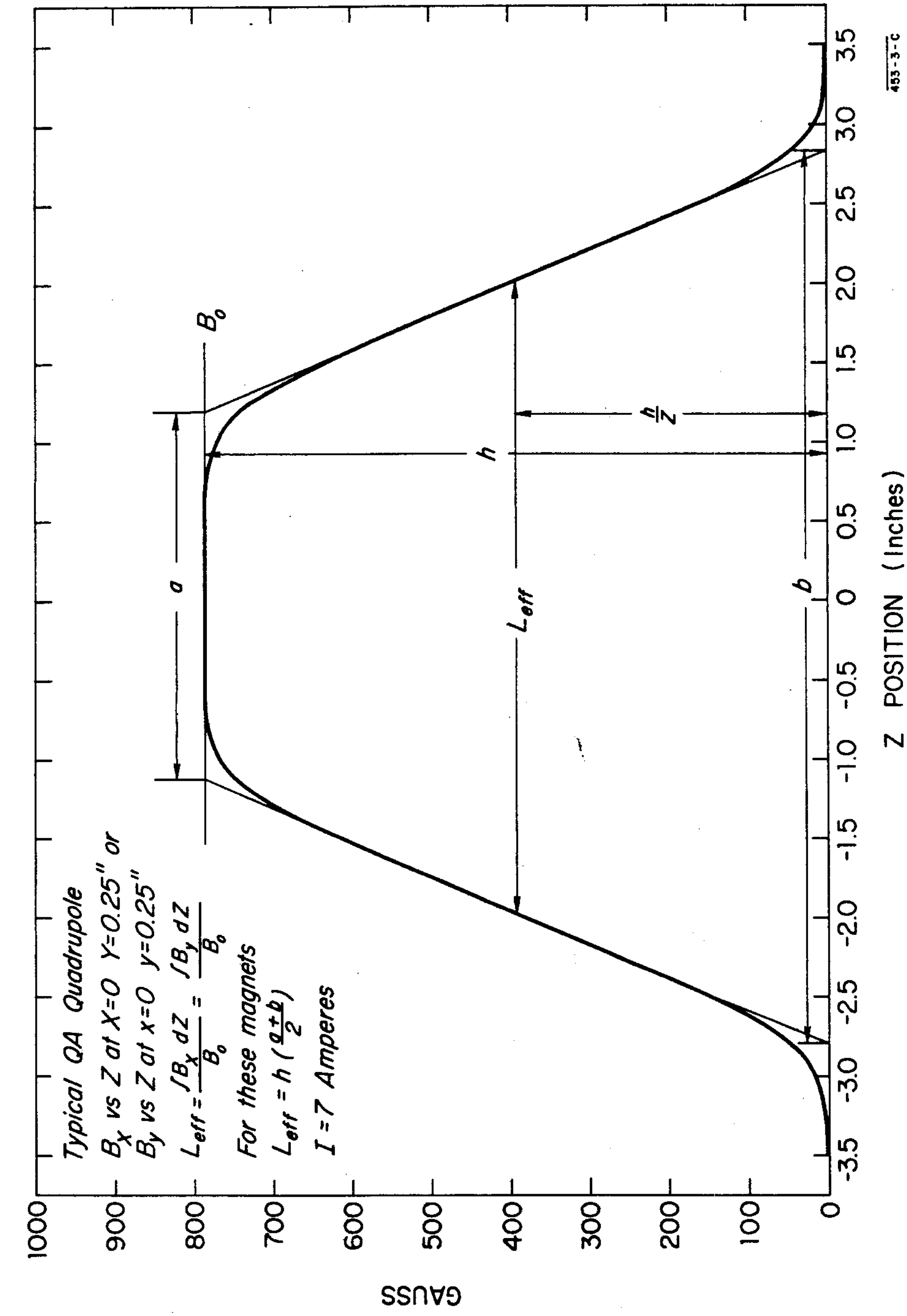


Fig. 9a--Longitudinal field distribution plot for QA magnets.

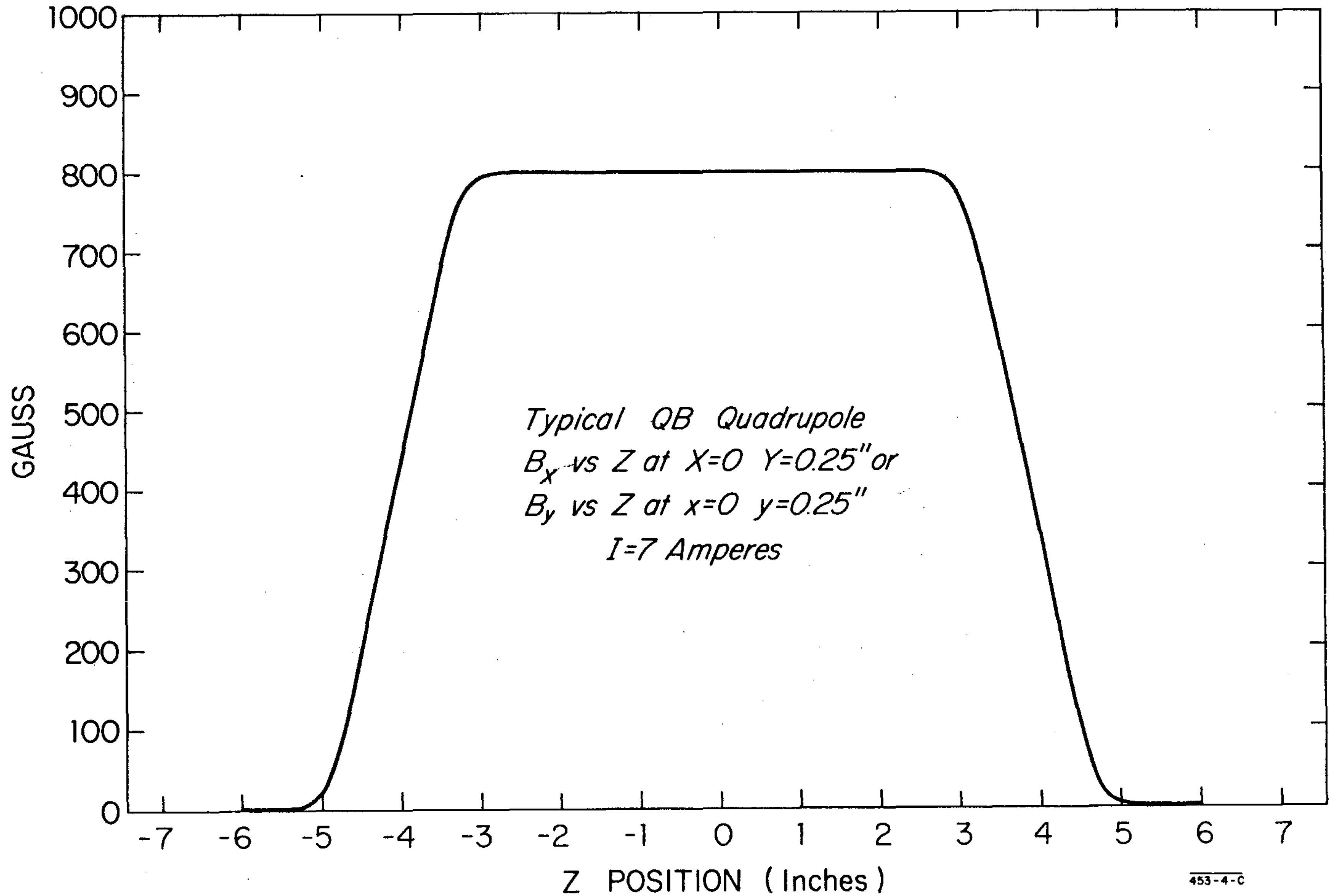


Fig. 9b--Longitudinal field distribution plot for QB magnets.

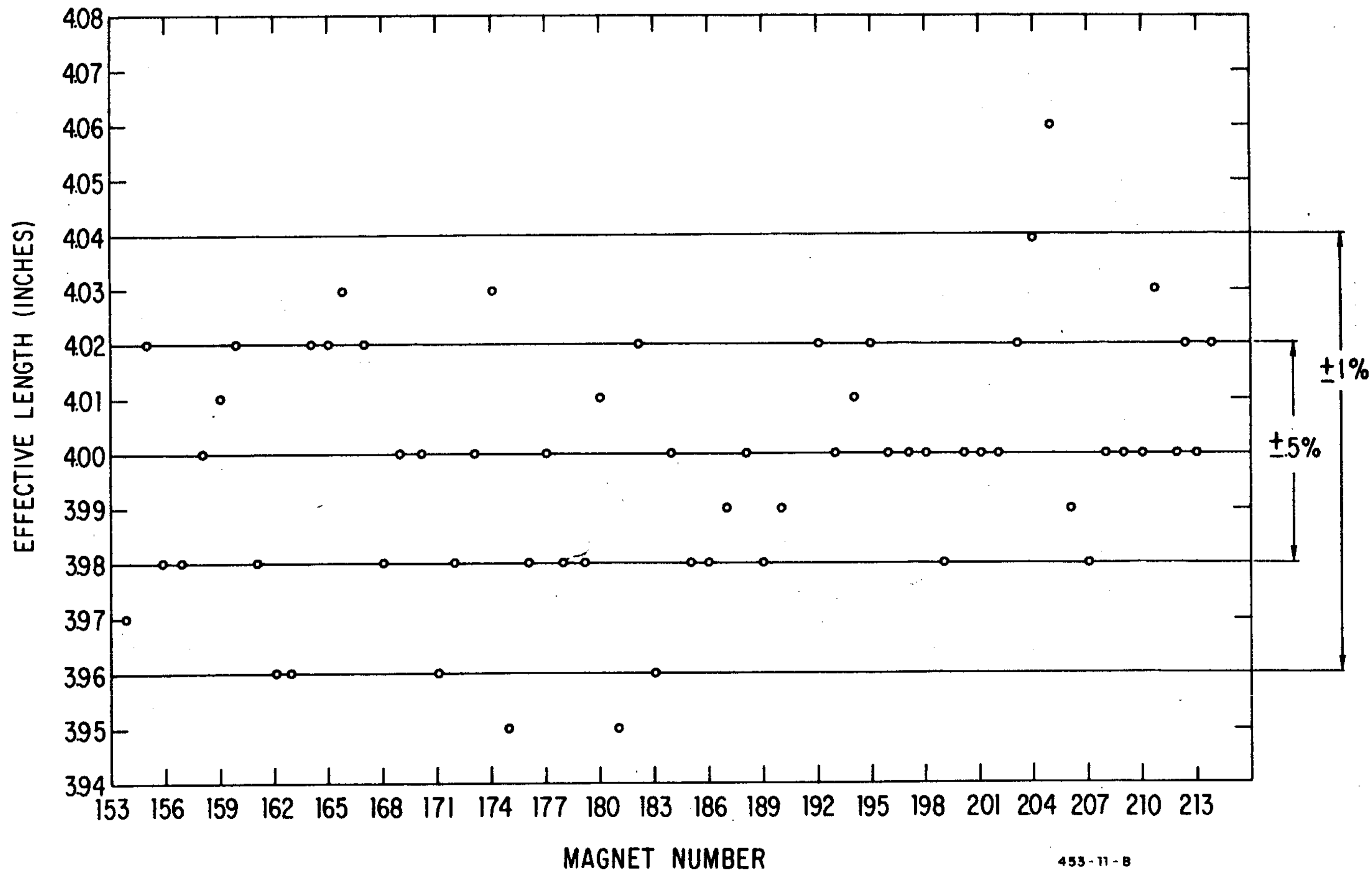


Fig. 10a--Effective length of each magnet for QA magnets.

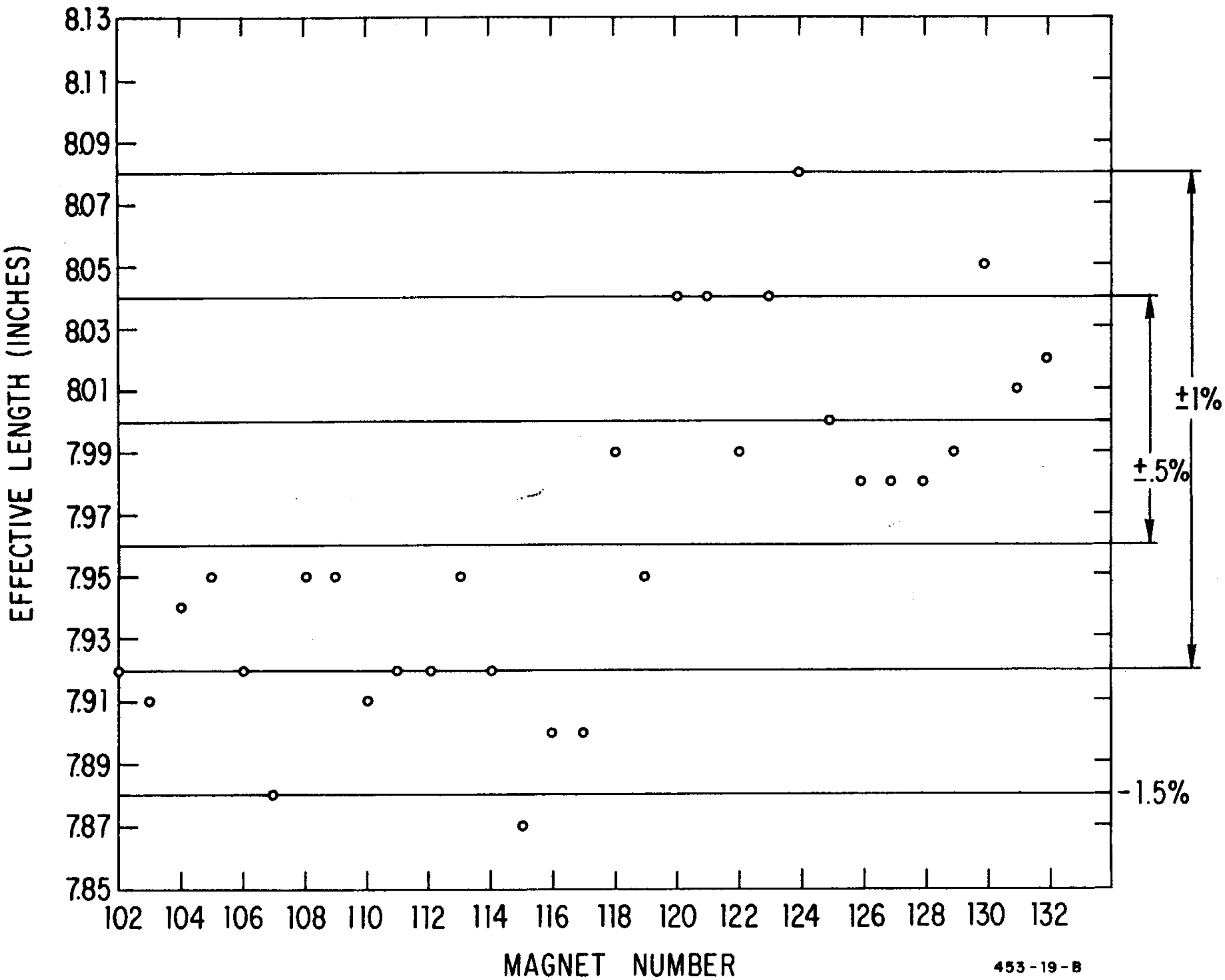


Fig. 10b--Effective length of each magnet for QB magnets.

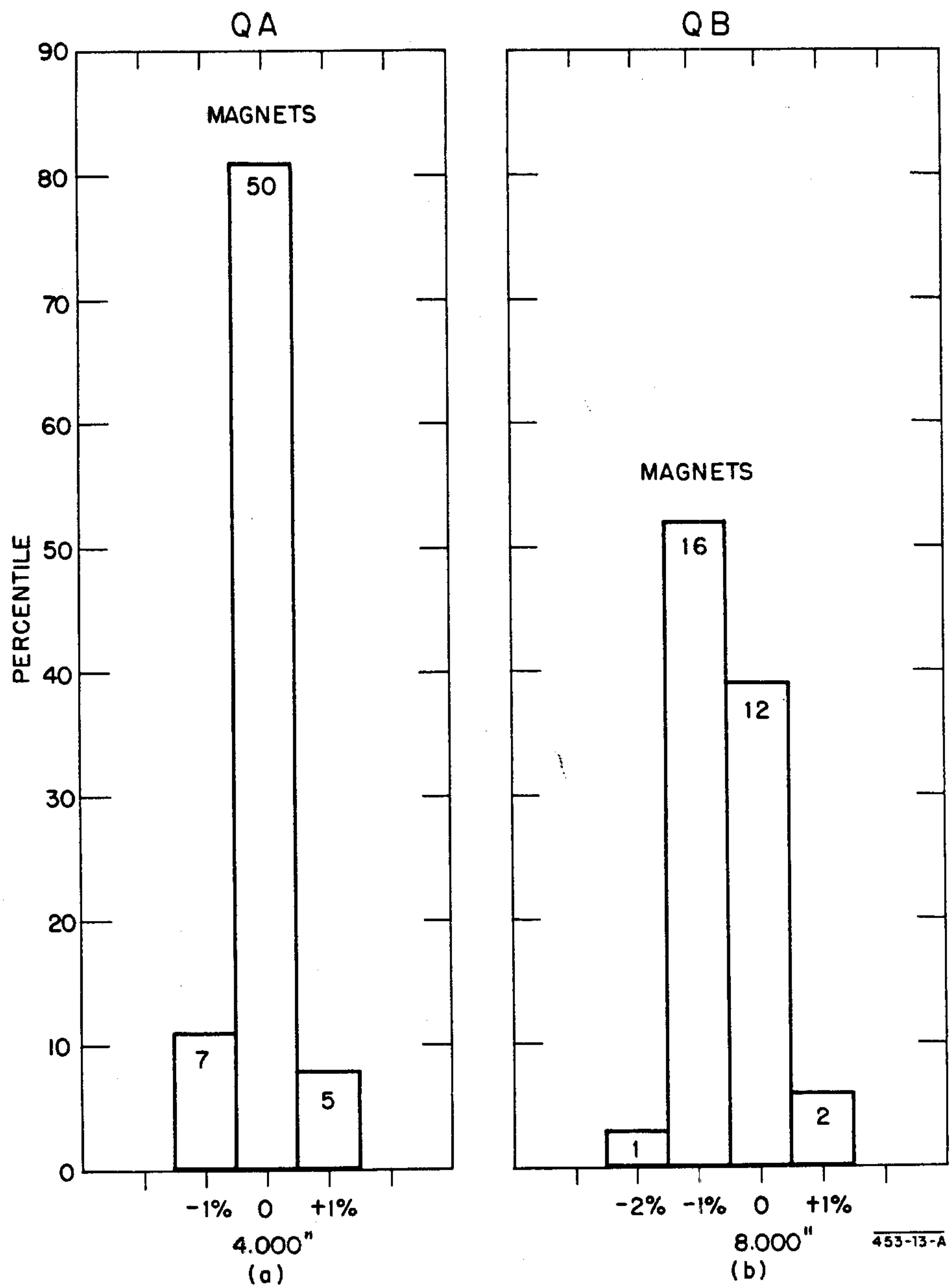


Fig. 11--Percentile of magnets with specified percent effective length deviations. (a) QA magnets (b) QB magnets.

Fig. 12--Equipment setup for harmonic analysis.

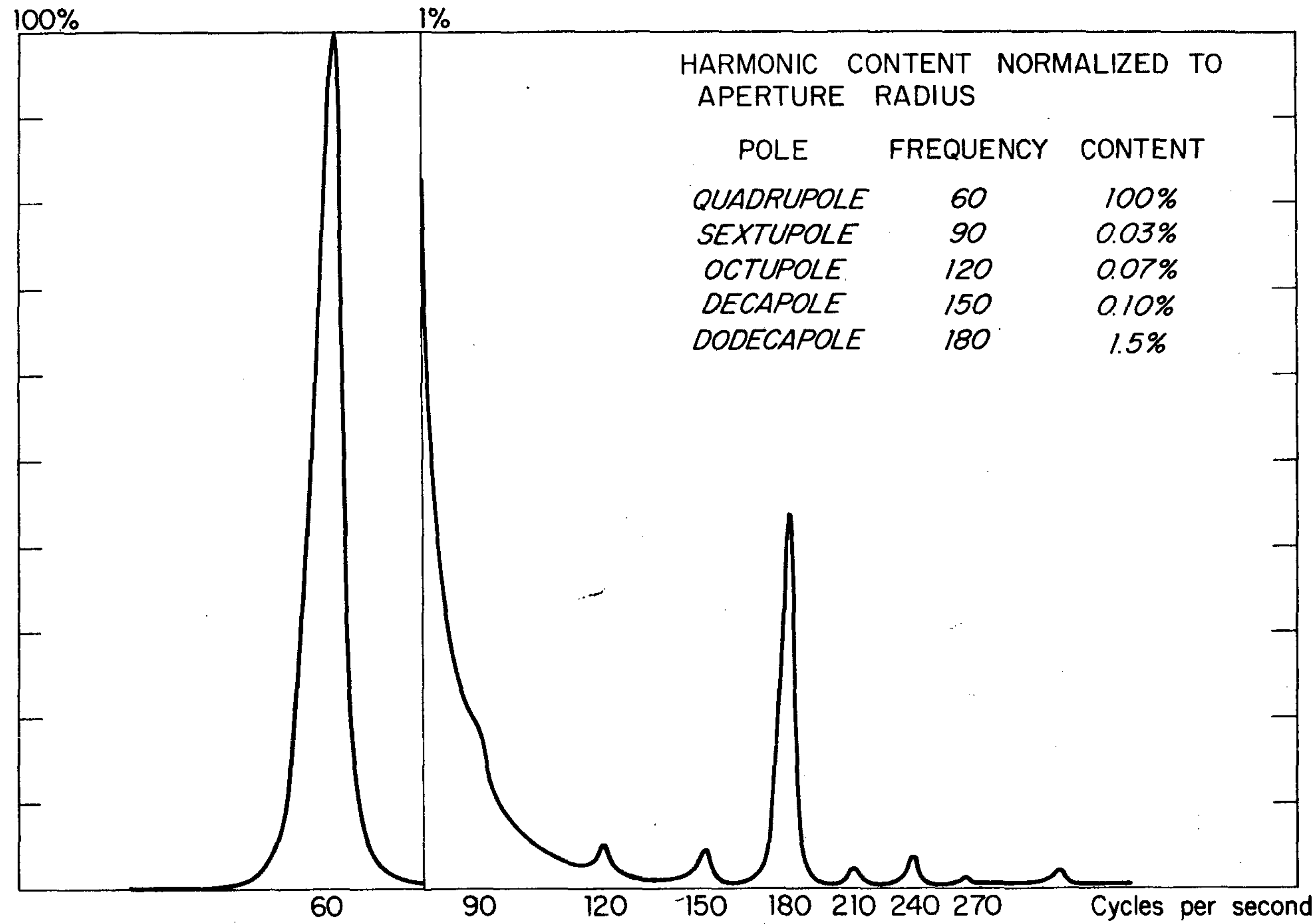


Fig. 13--Harmonic content of typical quadrupole (at 0.729 aperture radius).

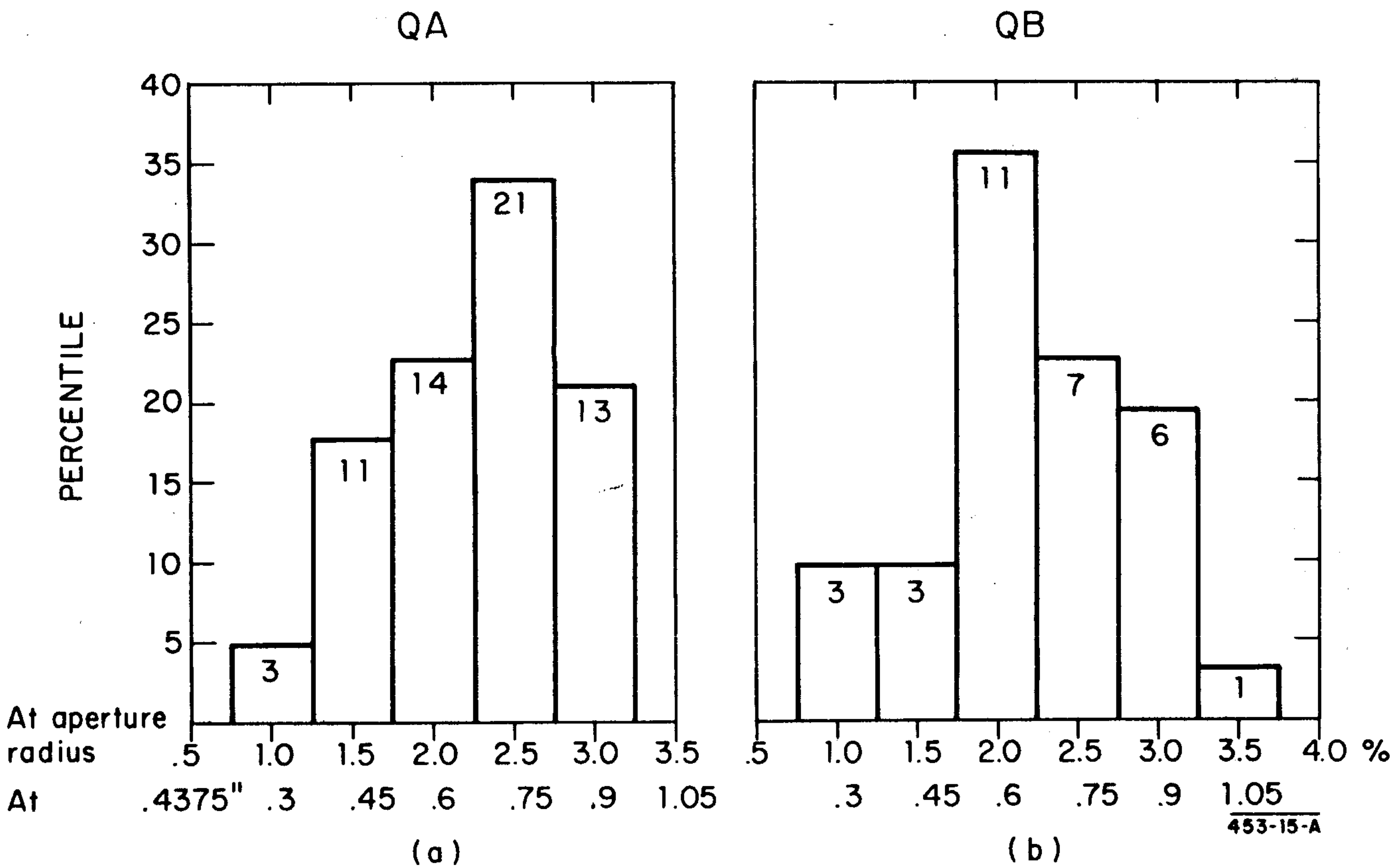


Fig. 14--Percentile of magnets with specified duodecapole field expressed as percentage of quadrupole field.
(a) QA magnets (b) QB magnets.

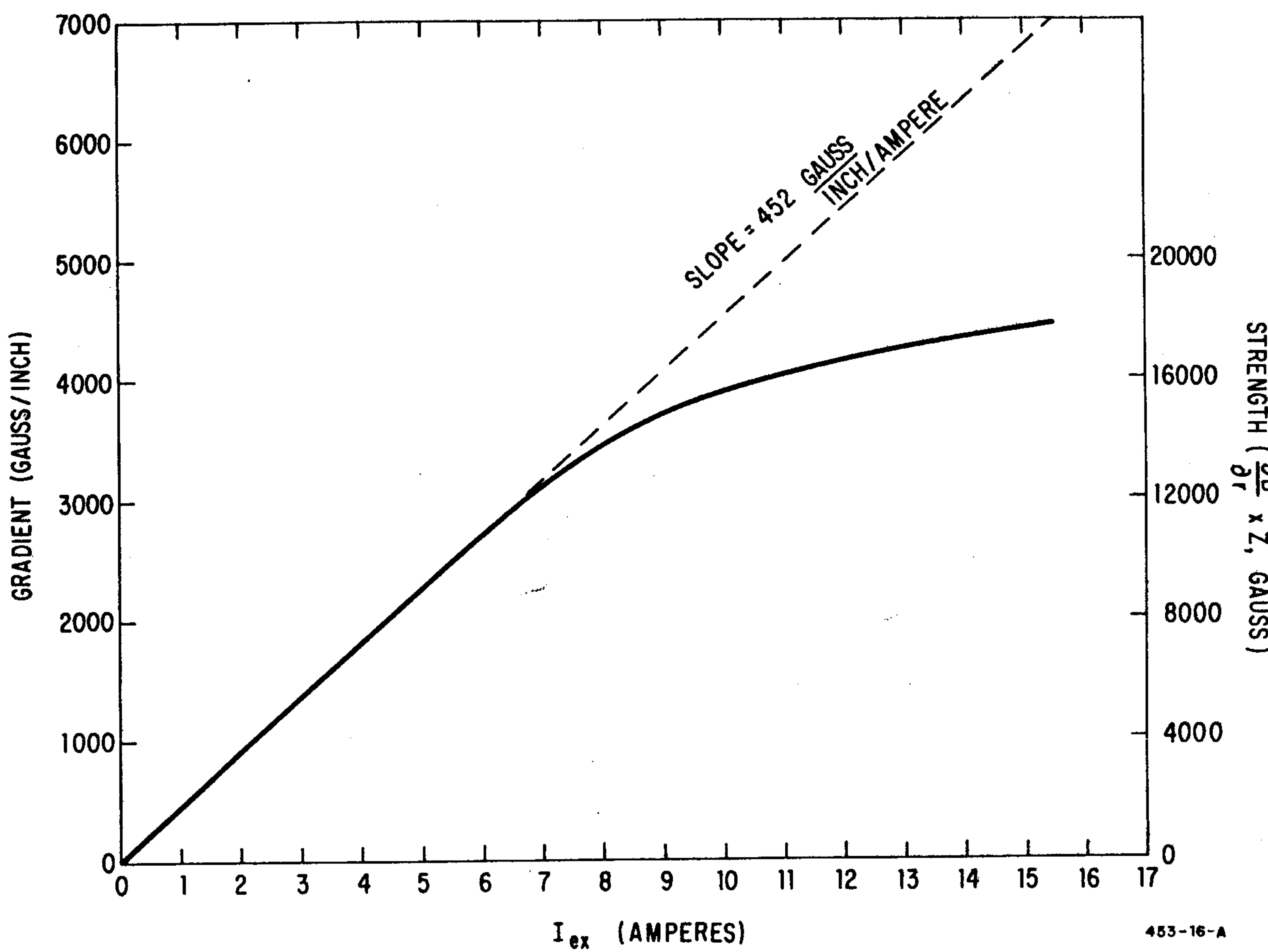


Fig. 15a--Gradient versus excitation current for QA magnets.

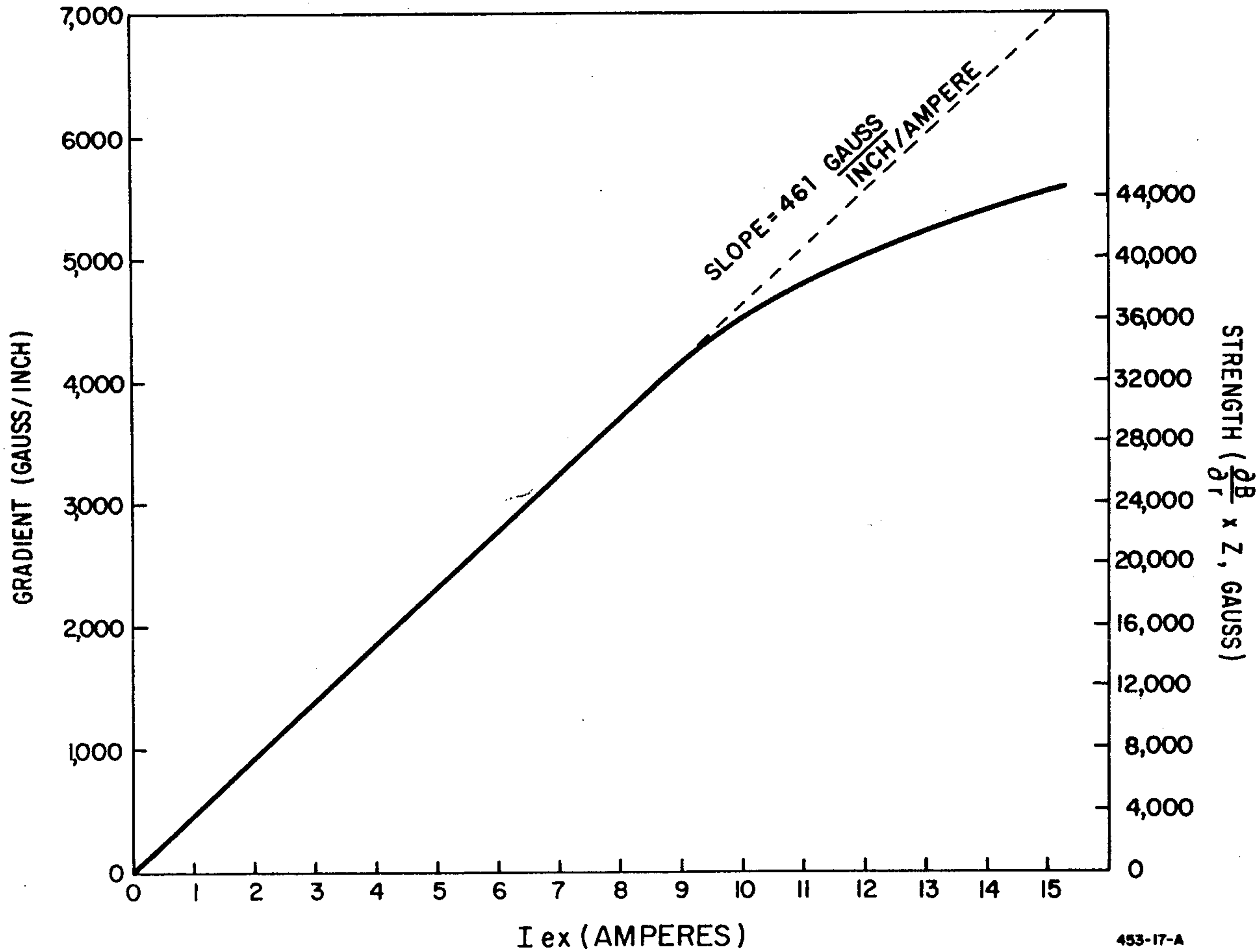


Fig. 15b--Gradient versus excitation current for QB magnets.

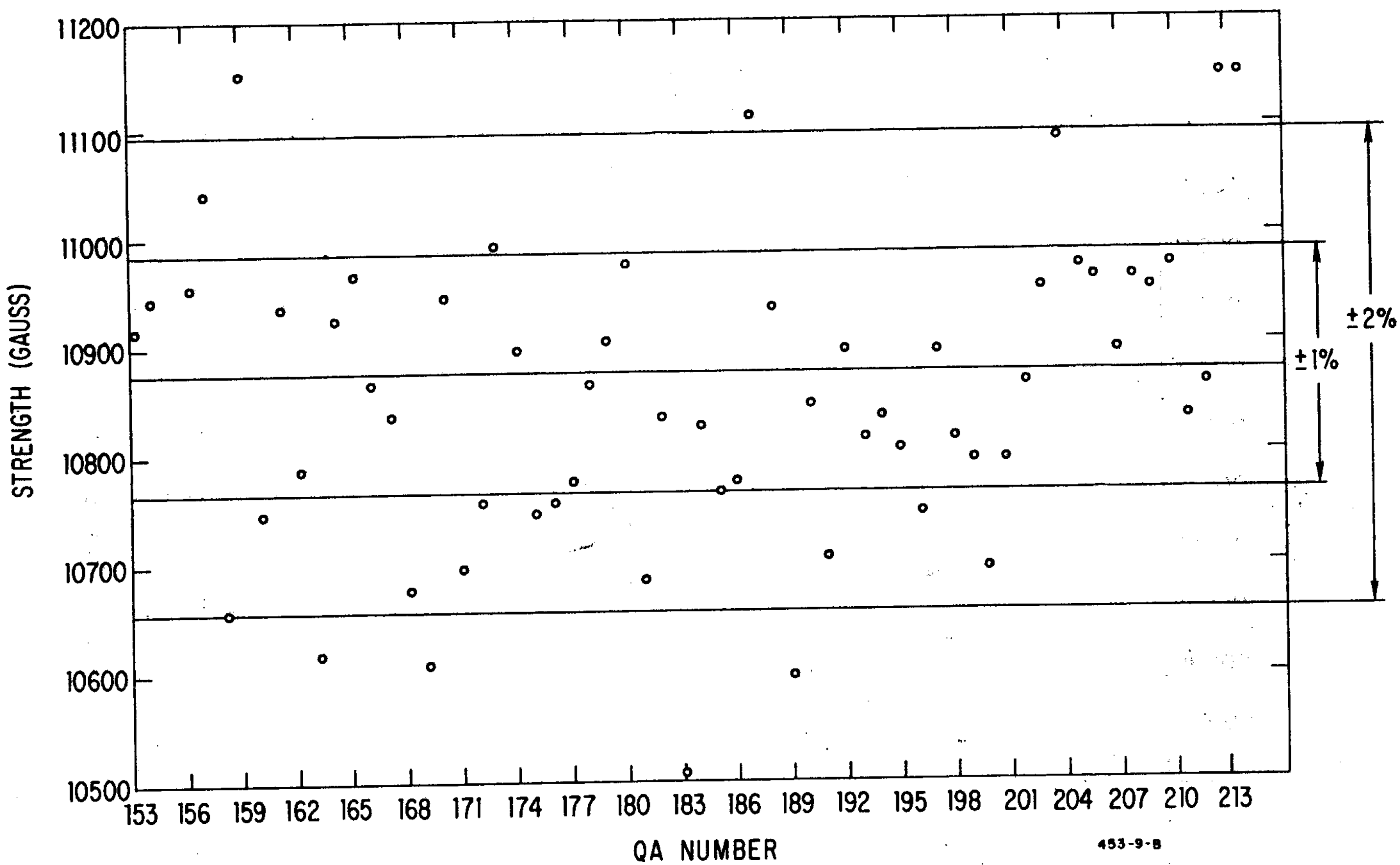


Fig. 16a--Magnet strength at 6 amperes for QA magnets.

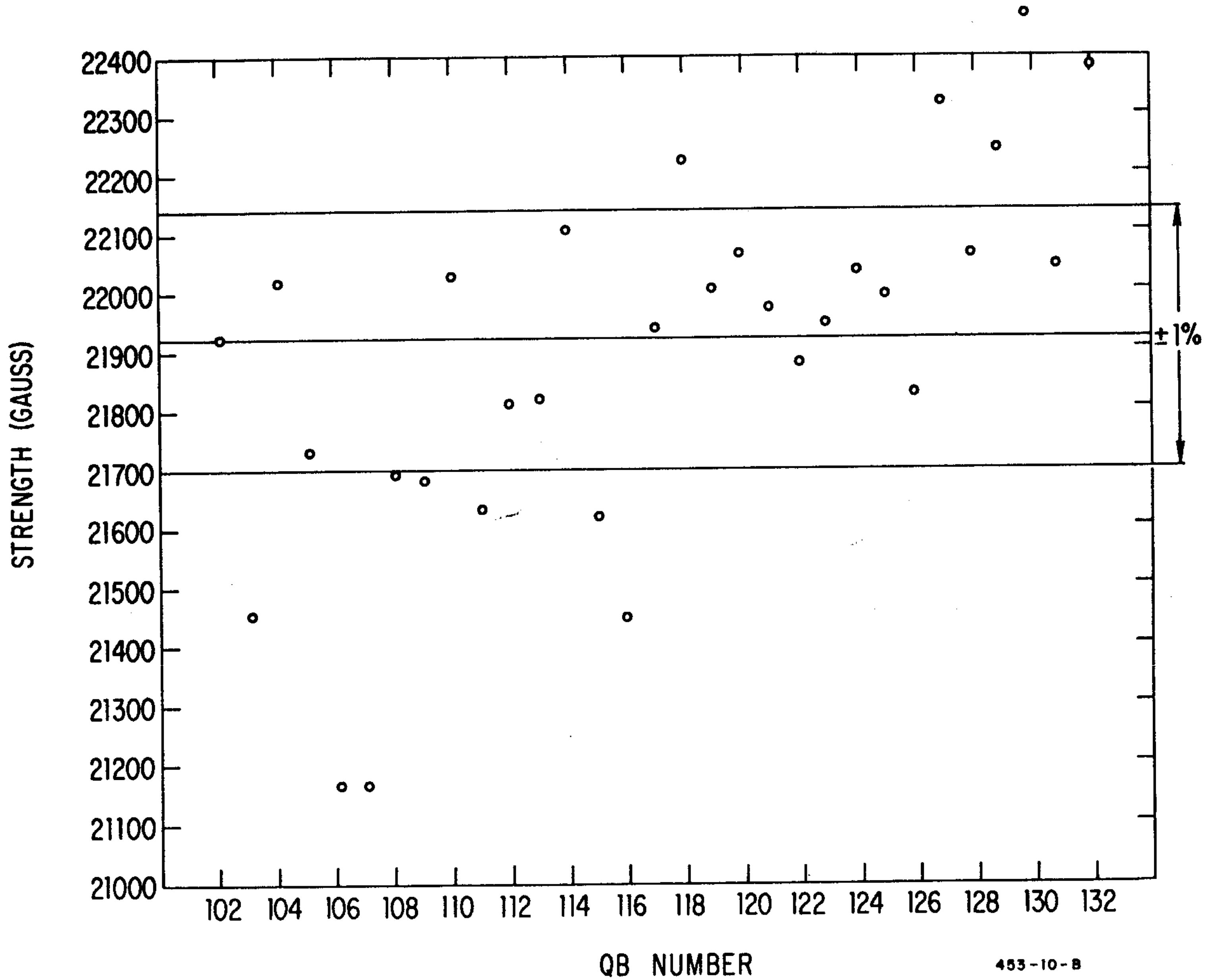


Fig. 16b--Magnet strength at 6 amperes for QB magnets.

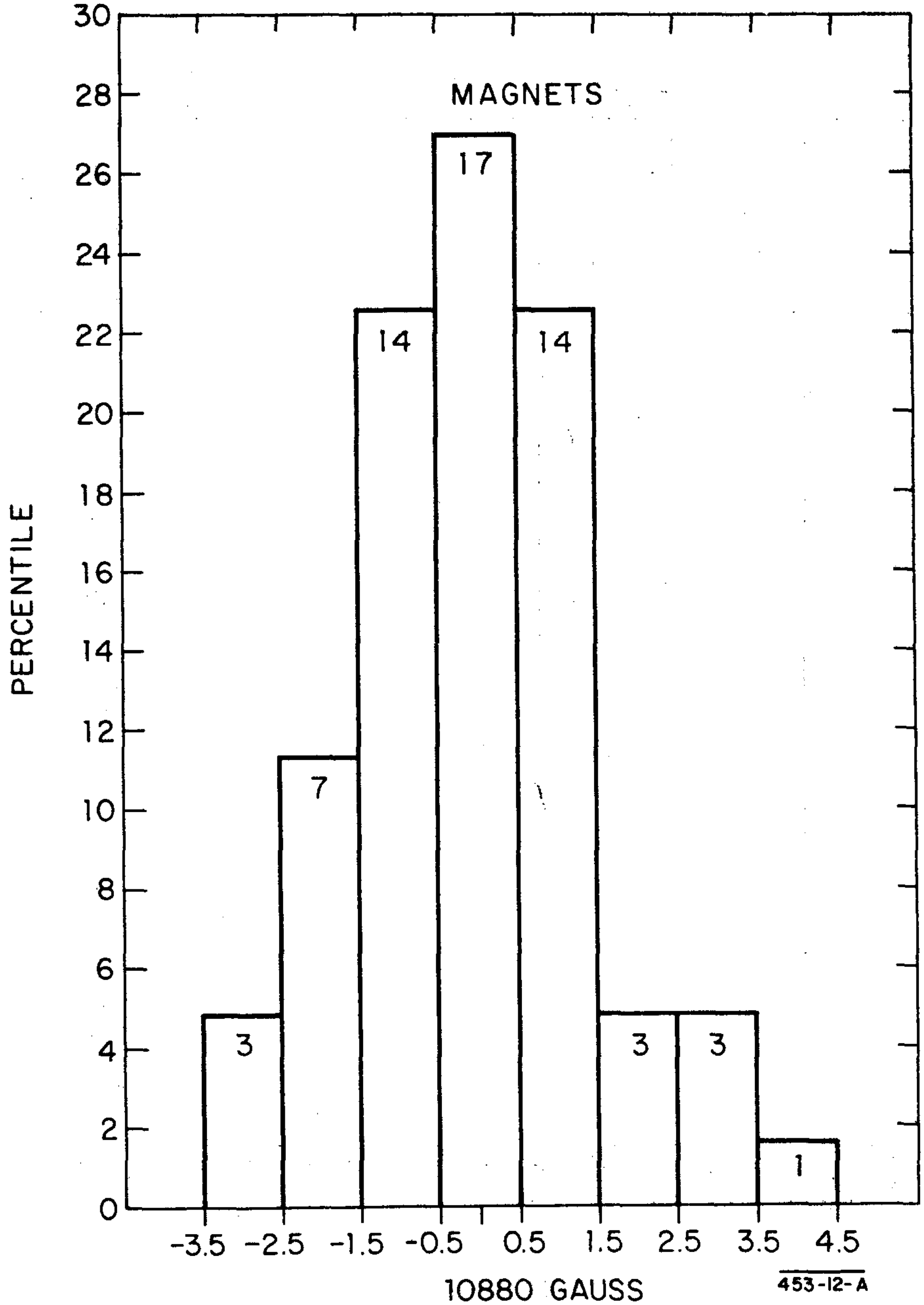


Fig. 17a--Percentile of magnets having specified percent deviation of magnet strength at 6 amperes for QB magnets.

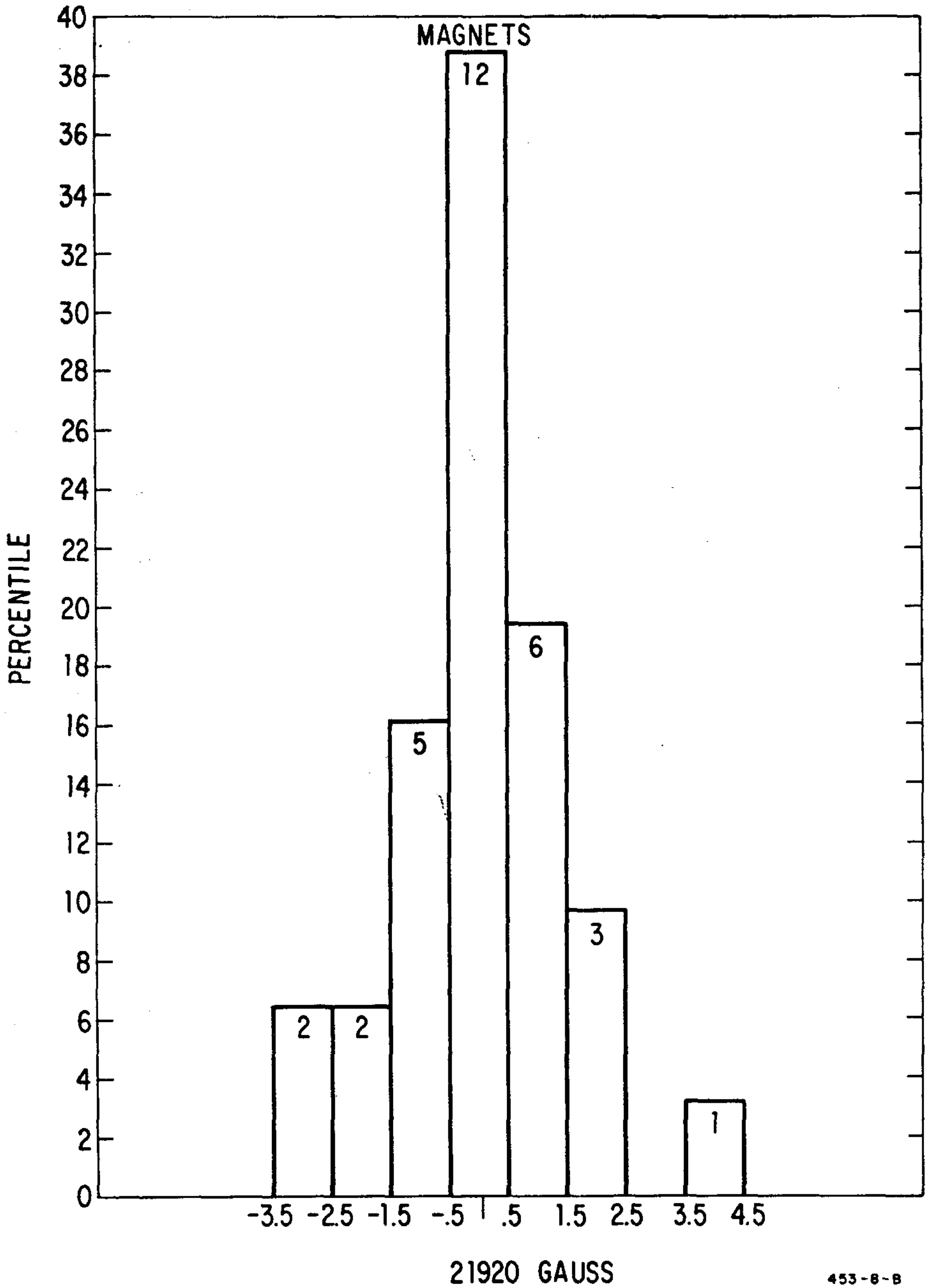


Fig. 17b--Percentile of magnets having specified percent deviation of magnet strength at 6 amperes for QB magnets.