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LAWRENCE BERKELEY LABORATORY - UNIVERSITY OF CALIFORNIA
ENGINEERING NOTE

BOOK NO. 620 | FILE NO. MT 289 | PAGE 1 of 9

SUBJECT: MAGNETIC UNDULATOR - MODELING & MEASUREMENTS OF END EFFECTS

NAME: Donald H. Nelson

DATE: June 9, 1980

Introduction

Klaus Halbach is designing an Undulator*. He believes that theoretical calculations are adequate for predicting internal field distributions produced by Samarium Cobalt Magnets that are regularly distributed and oriented above and below the plane of interest (Magnetic Midplane). However, end effects are more difficult to predict with high precision.

On January 20, 1980, Klaus Halbach, Michael I. Green, Bill Worthington and I met to discuss modeling the end effects due to a pair of Samarian Cobalt permanent magnets with various geometries of iron. The objective of building and measuring a model was to determine the magnitude of magnetic-induction integrals as functions of magnet position and orientation with a resolution of 25 Gauss cm.

Model for Testing Magnet End Effects

Figure 1 shows the model fabricated by Bill Worthington. The lower flat surface ($z = 0$) represents the plane of symmetry of the undulator so that for the model, magnets need be located only above this plane. (In this model, the magnets to be symmetrically located below the midplane are prepresented by "images" produced by the magnets above $z = 0$.) Two coordinate systems are shown in Figure 1 (The cartesian coordinate system for locating the magnet relative to the iron and the cylindrical-coordinate system showing the orientation of the magnet). The parameters that were varied during the course of the model tests (at the request of Klaus Halbach) are θ, angular orientation of the magnet pair, h, the height of the magnets above the midplane, and d, the distance between the field-clamp and the center line of the magnet pair i.e., the axis of rotation of the magnet pair.

Test Equipment

Figure 2 shows the equipment used for these tests. The integral-coil was designed by Michael I. Green and Ivan Wood and fabricated by Faye Witharm. Figure 3 is a full-scale copy of the positive used for fabricating the coil. The effective turns-width and the effective turns-area of the integral-coil were calculated by Kathy Schiff from the numerical-control coordinate-data used for fabricating the coil. The effective turns area was also determined by Michael I. Green in an NMR calibrated magnetic-field. The calculated and measured values are listed in Figure 3.

* A device for the production of synchrotron radiation in conjunction with high-energy electrons.

Test Procedures

Changes in flux-linkage in the integral-coil are proportional to changes in magnitudes of the integral of magnetic-induction over the length of the coil. Based on the effective turns-width of the coil, I selected values for the integrating resistor and capacitor that would produce a constant of proportionality of approximately 10^{-4} Volts/Gauss cm. The flux-standard produces a constant value of flux-linkage for determining the "operational RC time-constant" of the integrator.

Magnitudes of the integral ($-\int B_z dy$) were measured by repeatedly moving the integral-coil between a mu-metal shield and the model.

Test Results

Figures 4-6 represent the tests conducted by Ed Cyr and me. Figure 4 represents measurements of $\int Bdl$ vs. θ for three values of d (d = 1.27, 2.54 & 3.81 cm) with h = 3.61 cm. Figure 5 represents measurements of $\int Bdy$ vs. θ for extreme values of h (h = 1.96 cm and h = 3.61 cm) with d = 2.54 cm. Based on these preliminary results, Klaus Halbach requested that we collect the data represented in Figure 6 with d = 1.27 cm, h = 1.96, 2.49, 3.05, & 3.61 cm.

We experienced difficulty in reproducing measurements near the zero-cross-overs (i.e., the angular orientations, θ, that produced near-zero integrals). We made a series of measurements to determine the effect of magnetic-hysteresis. For the parameters h = 1.96 cm, d - 1.27 cm (see Fig. 6), we measured $\int B_z dy$ for θ = 150° and 330° with each of these magnet orientations being approached from θ = 60° (the maximum positive orientation) and θ = 240° (the maximum negative orientation). The results which are summerized in Table I show spreads near the zero-cross-overs of 5-6% of the peak values.

θ degrees	$-\int B_z dy$ [10^3 Gcm]	spread (% of peak integral)
60	+2.87	
150	-0.04	
240	-2.71	
150	-0.18	0.14/2.8 = 5%
240	-2.73	
330	-0.05	
60	+2.87	
330	+0.12	0.17/2.8 = 6%

Table I Hysteresis Checks - Measurements of $\int Bds$

h = 1.96 cm, d = 1.27 cm for selected values of θ

Discussion

On June 5, E. Hoyer, K. Halbach, I. Wood and I discussed plans for measurements of the operational undulator. Hoyer is preparing specifications for a pair of 1 m. long integral coils.

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E.C. Hartwig/L.J. Wagner/W.H. Deuser
E.H. Hoyer
I.E. Wood
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Magnetic Measurements Engineering (4)

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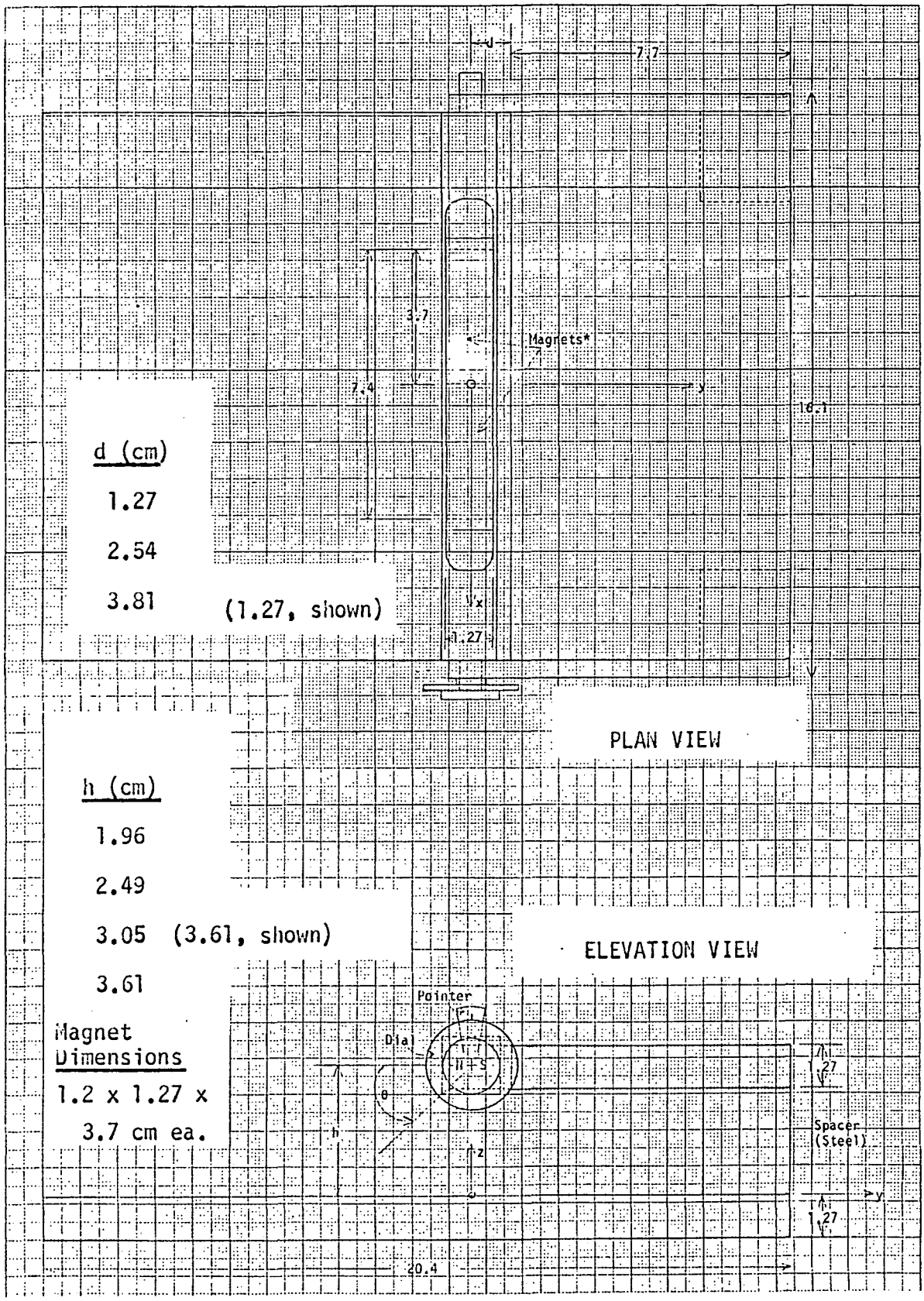

FIGURE 1 UNDULATOR MAGNET

* $SmCo_5$ Magnet Pair - Orientation shown $\theta = 0$

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		SERIAL NO.	NO. REQD.
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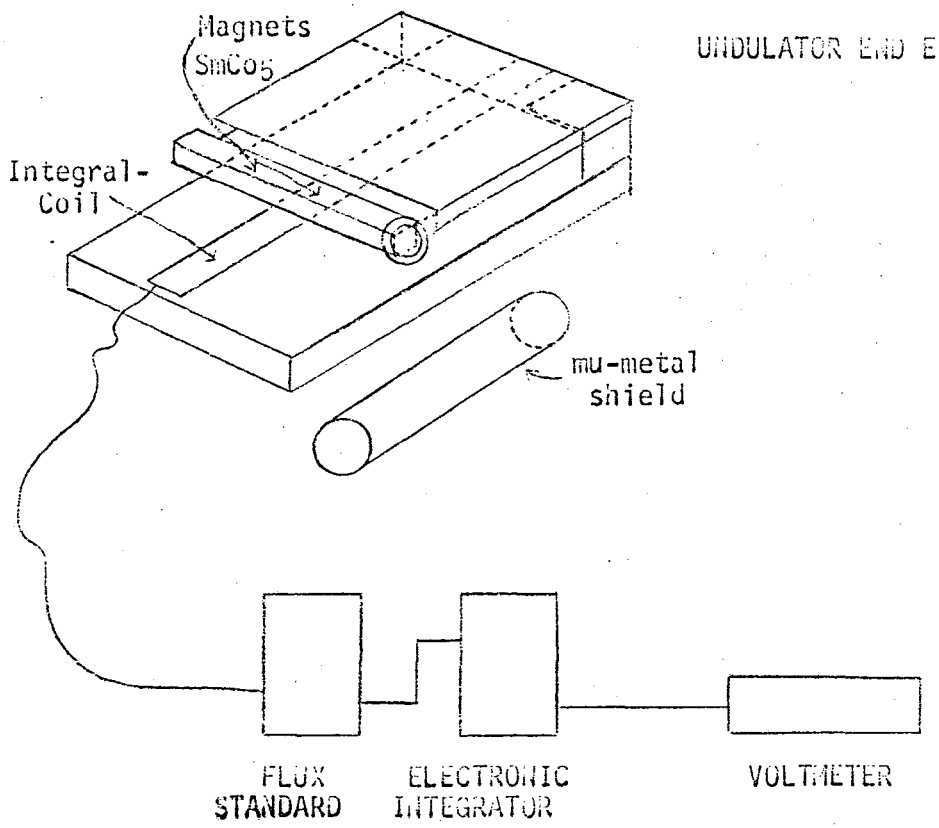
DATE 5/2/80 · BUILDING NO. · ROOM NO.	APPROVED BY · DATE	DELIVER TO	



DEVICE	IDENTIFICATION	NOTES
Model	LBL	
Magnets	$SmCo_5$	2 ea.
Coil	L-47	nw = 20.76 (cm)
Flux Standard	SLFS 40.01	Φ = 0.0105 (wb)
Integrator	Mod 71 S/N 2	R = 19.6 (kΩ) C = 0.1 (μF) Atten = 830
Voltmeter	Keitheley Mod 177	S/N = 10450

Figure 2 Test Equipment

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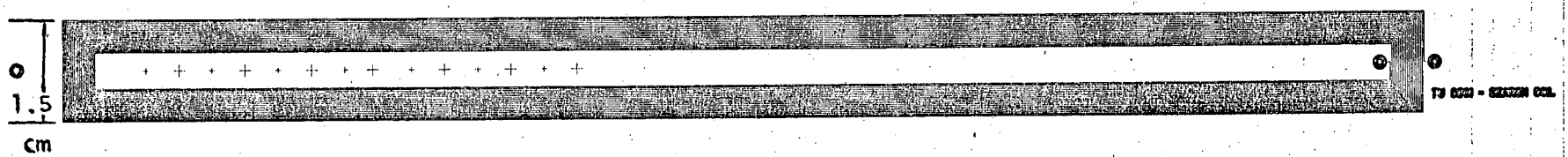

Figure 3 Artwork used for fabricating coil L-47

	Calculated based on design parameters	Measured
nA, turns area (cm^2)	417.75	413.0
nw, turns width (cm)	20.76	—

(number of turns: 20)

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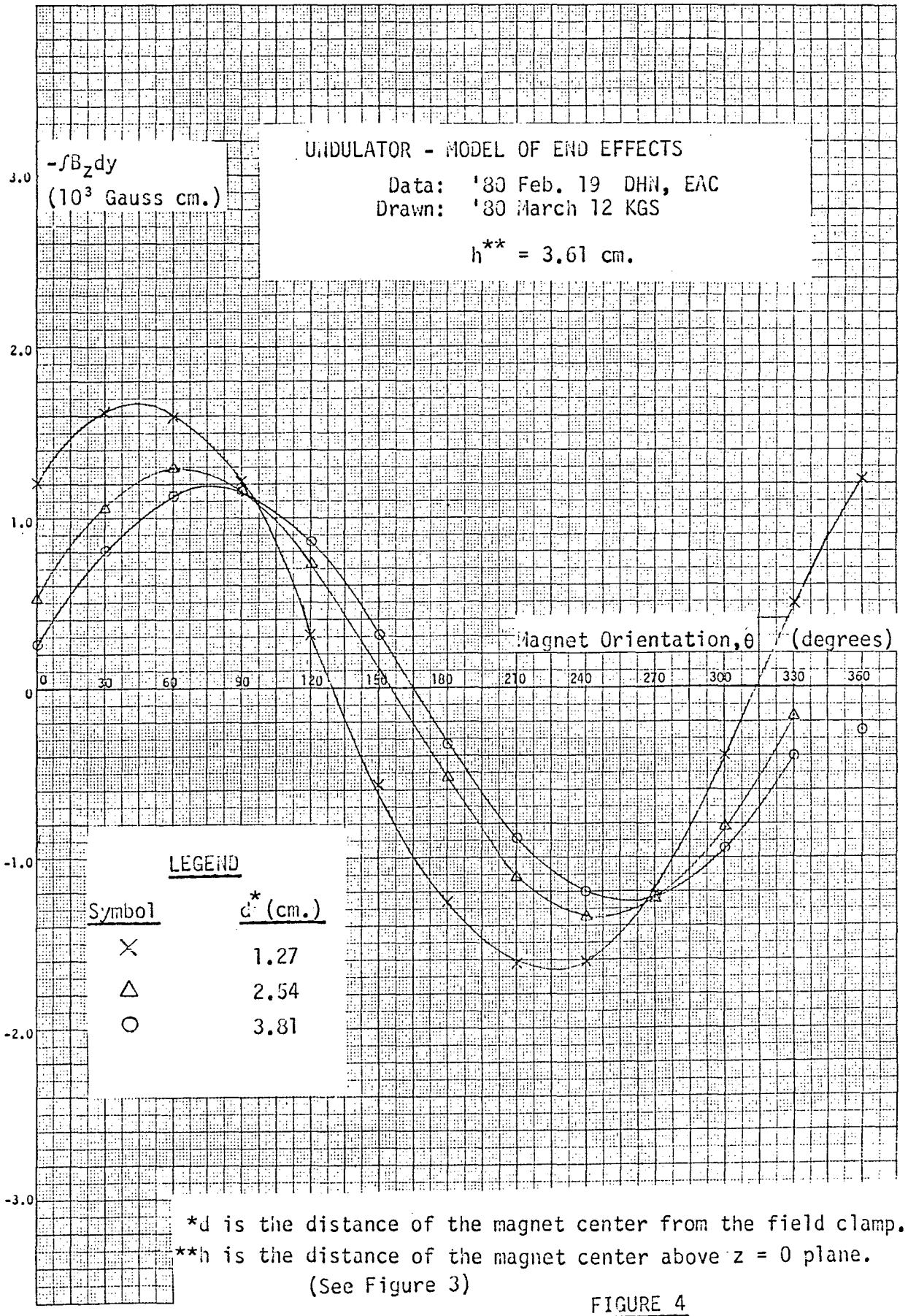
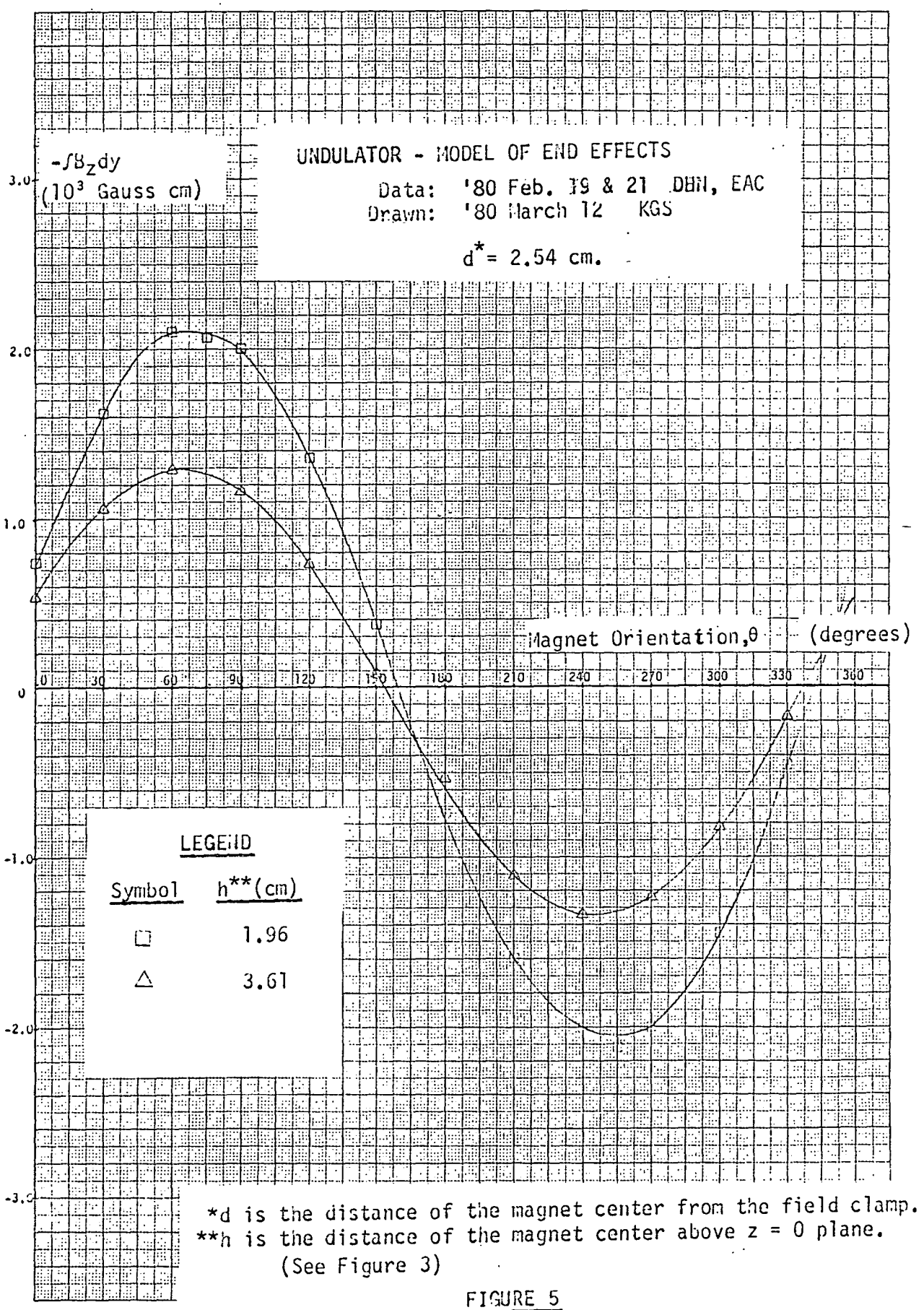


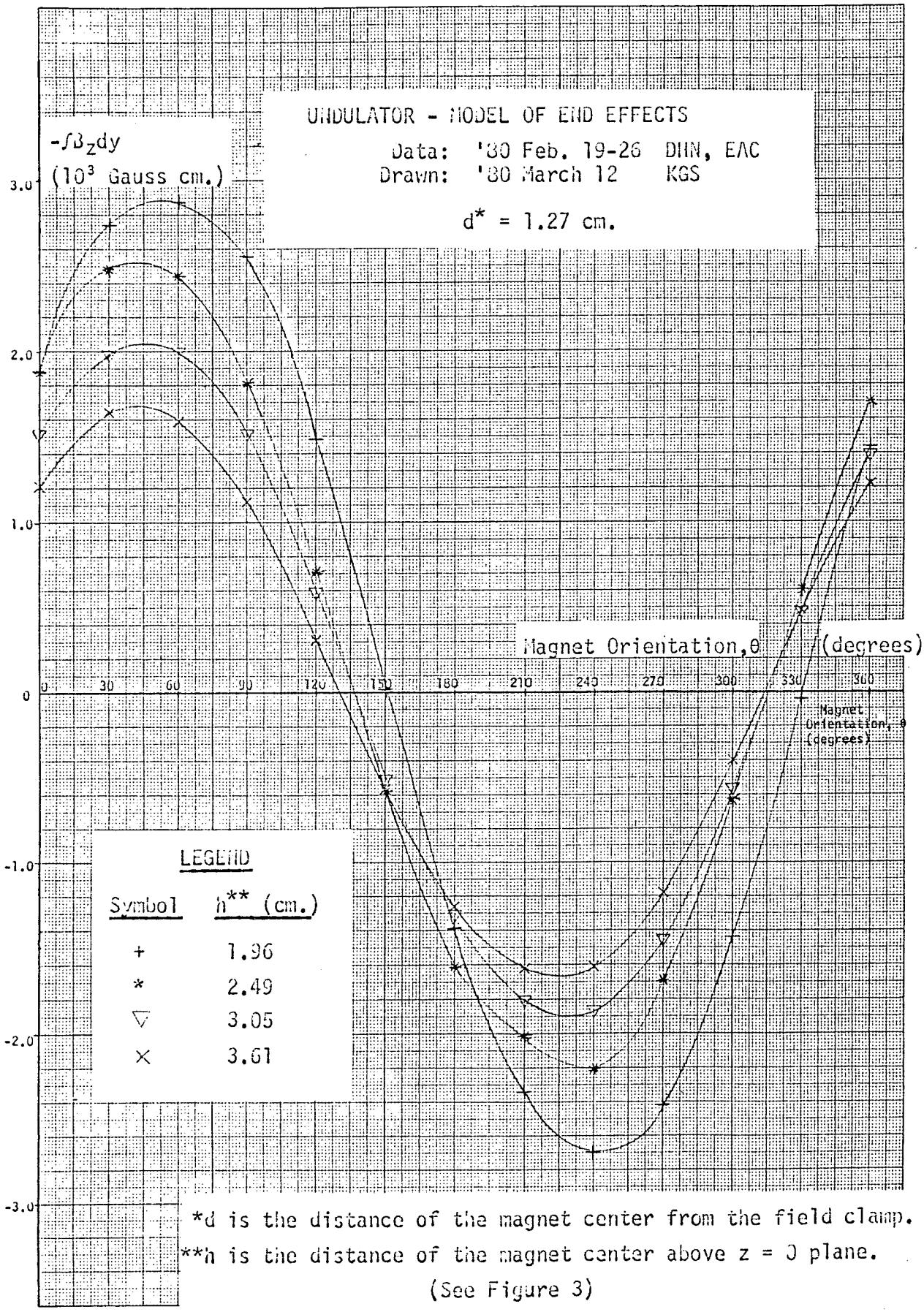
*d is the distance of the magnet center from the field clamp.
**h is the distance of the magnet center above z = 0 plane.
(See Figure 3)

FIGURE 4



*d is the distance of the magnet center from the field clamp.
**h is the distance of the magnet center above z = 0 plane.
(See Figure 3)

FIGURE 5



*d is the distance of the magnet center from the field clamp.

**h is the distance of the magnet center above z = 0 plane.

(See Figure 3)

FIGURE 6

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