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MEASUREMENTS OF COARSE CONTROL ARM DROP CHARACTERISTICS IN THE MATERIALS TESTING REACTOR HIFAR

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AAEC

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ABSTRACT

Measurements were made of the angular position/time characteristics of a coarse control arm in the AAEC's materials testing reactor HIFAR, following a trip. The method of measurement is described and the results are presented. It is clear that all of the measured transients may be reasonably fitted by a single differential equation.

The following descriptors have been selected from the INIS Thesaurus to describe the subject content of this report for information retrieval purposes. For further details please refer to IAEA-INIS-12 (INIS: Manual for Indexing) and IAEA-INIS-13 (INIS: Thesaurus) published in Vienna by the International Atomic Energy Agency.

CONTROL ELEMENTS; DIFFERENTIAL EQUATIONS; HIFAR REACTOR; MEASURING METHODS; REACTOR SHUTDOWN

CONTENTS

1. INTRODUCTION

The position/time characteristics of the coarse control arms (CCAs) in the AAEC's materials testing reactor HIFAR during a reactor trip are required in safety studies to determine the rate of shutdown. Such characteristics were measured in the prototype DIDO reactor at Harwell, England and this information, together with that derived from the HIFAR CCA timing system, was used for HIFAR safety studies, with appropriate safety factors. The CCA timing system measures the instants of drop initiation, magnet release, and arms in the fully down position. As a matter of safety philosophy, it was decided that direct measurement should also be made of the detailed characteristics of the CCA position versus time during CCA drop.

2. METHOD OF MEASUREMENT

2.1 General Concept

It is neither permissible nor feasible to attach a transducer directly to a coarse control arm in the reactor for reasons of safety and because of space and access considerations. A scheme was devised therefore to measure the distance between the holding magnet in the head unit and the armature, which is attached via a linkage to the CCA. A sketch of the general arrangement of the CCA is given in Figure 1. Note that all items were manufactured to Imperial measurements; these have been retained here, SI measurements being stated in parenthesis.

The armature position was measured with a linear potentiometer, which was installed in the connecting rod guide, behind the electromagnet; details are shown in Figure 2. The potentiometer body was fixed to the connecting rod guide and the potentiometer spindle spring-loaded to the fully-out position. When the head unit is connected to the CCA, the armature position is picked up automatically since the armature guide rod bears onto the cup at the end of the potentiometer spindle. During a CCA drop, the spring keeps the cup in contact with the guide rod, so that at any time the CCA angle may be determined from the change in potentiometer ratio. This is directly related to the separation distance of the magnet and armature faces.

2.2 Relation Between Measurement and CCA Angle

The basic geometry of the CCA drive and linkage is shown in Figure 3. The magnet/armature system is in the line AC, the line AQ is the motor quadrant lever and the line PC is the length of the control arm between the hinge pin at P and operating-arm attachment point at C. The dimensions with magnet engaged are given in Figure 3 together with an analysis of the relationship between the lengths and angles. Note that the CCA datum level from which the CCA angle φ is conventionally measured is 56° down from the horizontal. This diagram, analysis, dimensions and angle relationships were taken from the manufacturer's design specifications [H.M. Hobson Ltd, no date].

When the magnet is released, the length L, joining A to C increases, but point A stays fixed in space. To find the relationship between the CCA angle and the spacing between magnet and armature the equation

$$L^2 = (E + R \sin\theta - R \sin\alpha)^2 + (R \cos\alpha + R \cos\theta - 2D)^2 \qquad (1)$$

must be solved, with θ fixed at the initial value and the angle φ as a variable. Note that there is a direct relationship between φ and α of α = φ -29°. Results from this analysis (Figure 4) show that the relationship is nearly linear; to clarify this relationship, the error in an assumption of linearity, i.e. the difference between a straight line joining the two end points and the actual characteristics, is shown in Figure 5. This difference is never greater than 0.7°, so the method is useful for measuring the CCA angle to high accuracy with only simple processing of the signal.

2.3 Transducer

The potentiometer had to be linearly actuated and able to fit into the space available within the connecting rod guide. Computer Instruments Corporation (USA) provided a suitable unit having a body cross-section of 0.5" x 0.315" (12.7 x 8 mm), a stroke length of 3" (76.2 mm) and a resistance of 2 kΩ with ±0.5 per cent linearity. To ensure that the armature spigot was followed adequately, a small brass cup was fitted to the end of the spindle together with springs to hold the spindle fully extended. The spring rate was about 150 N m^{-1} and, when unloaded, the spring force produced a full scale travel time of 48 ms. This test was done with the transducer installed in the guide. The spring was compressed by a light rod, then released to allow free

movement.

The electrical circuit for the potentiometer is shown in Figure 6. The ultra-violet recorder has a low input impedance, so it was necessary to incorporate a buffer amplifier system to avoid undue load on the potentiometer. This system reduced the maximum systematic error due to loading to 0.2 per cent. The recorder had a maximum systematic departure from linearity of 0.6 per cent for the deflections used. Tests on the recorder showed that the time marker was accurate to within 0.3 per cent.

2.4 Preliminary Tests

Although analysis of the system indicated close approximation to a linear relationship, it was necessary to confirm this characteristic and to ensure that the system was operating correctly. To do this the CCA angle needed to be measured accurately and a device was used which consisted basically of a rotary potentiometer with the body attached to the CCA hinge pin and the spindle actuated by an arm attached to the CCA.

Because the CCAs are highly radioactive this equipment could not be used in the reactor; fitting had to be done either in a hot cell or under water in the active handling bay cropping pond. Furthermore it was not possible to fit the potentiometer to the hinge pin in the hot cell because of spatial limitations in the handling flask used to transport the CCA between the hot cell and pond. Consequently, in the hot cell a holder for the potentiometer body was fitted to the hinge pin and a location member for the potentiometer actuation arm was attached to the CCA. The CCA was then transferred to the pond where the potentiometer, in a waterproof enclosure, was fitted by spring clips with dowel location onto the holder. The operating arm was also fitted to the control arm location member by a spring clip. The rotary potentiometer was specified to have 0.1 per cent linearity and calibrated before use. The r.m.s. error from linearity was equivalent to about 0.05° over the range utilised, so no correction was applied during angle measurements.

In the pond a rope was fastened around the far end of the control arm to control its position, and the relationship between the CCA angle, as indicated from the rotary potentiometer ratio, and the signal from the armature position transducer was measured for different initial CCA withdrawal angles. Results are shown in Figure 7 and the measured error in an assumption of linearity is given in Figure 8 for an initial angle of 56°.

In Figures 7 and 8 it is taken that the straight line joins the measured fully-down point (0°) to a point 0.5° below the measured raised value for the initial withdrawal angle. This allowance was made because resilience in the linkages permitted the blades to be raised further by about this amount after the magnet/armature faces were in contact. The measured results plotted in Figure 8 follow a very similar path to the theoretical curve, so in all analyses of CCA movement the theoretical characteristics are assumed to apply and the results interpreted accordingly.

Drop tests were also carried out in the pond so that the dynamic performance of the transducer signal could be compared with that derived from the rotary potentiometer fixed directly onto the CCA. A typical recorder chart for an initial withdrawal angle of 36°, showing the two angle measurements and the signal from the CCA drop timer, is given in Figure 9.

The timer signal is produced from the magnet power supply, and from microswitches which indicate the armature position in the head unit. The results were processed from manual measurements of the chart traces to give the characteristics shown in Figure 10; those from tests with initial angles of 56° and 20° are also included. Note that the transducer signal leads the direct measurement by about 0.5° in all cases. This effect is probably due to resilience or backlash in the linkage between armature and CCA. The armature drops a distance equivalent to 0.5° before the arm moves appreciably. This means that the transducer indicates that the arm is falling faster than is the actual case. To avoid such an error when measuring the drop characteristics, it was decided to assume that there is no movement until 0.5° movement is indicated by the transducer and then to subtract this value from all indicated movement, i.e. to add 0.5° to the indicated angle from datum. The general agreement between the shape of the transducer-derived transient and that measured directly by the rotary potentiometer gives confidence in the overall analysis of the system and in the assumed characteristics.

The transducer was installed in the head unit for CCA B and was tested in the pond on CCA A.

3. REACTOR MEASUREMENTS

3.1 Measured Results

The reactor tests were carried out on 24 July 1979, during a scheduled shutdown. The head unit for CCA B, with transducer installed, was fitted to CCA E in position 6 (Figure 11). A list of the tests is given in Table 1 together with the results produced by the CCA drop timer. Plots of the drop characteristics from a range of positions are given in Figure 12; these begin at the instant of magnet release to allow comparison with the curves used previously for calculating reactor shutdown in HIFAR safety studies.

Measured transients for different pump combinations are given in Figure 13; these are plotted for the total time from indicated trip initiation up to first reaching the zero angle position. Additional results for 'maintenance angles' are given in Figure 14; these are the initial positions required for drop tests in the maintenance schedules. Values on the times between trip initiation and indicated magnet release, the magnet release (delay) times, are plotted in Figure 15 and those between indicated magnet release and indicated CCA down, the CCA drop times, are given in Figure 16. Figures 15 and 16 contain all the results from the tests on HIFAR in July 1979, from the tests in the pond, and also from preliminary tests made on HIFAR during a shutdown in May 1977, using the same CCA. The plotted lines are in no way intended to indicate correlations of the results but merely to indicate trends and groupings.

From these results, it appears that for the CCA tested, pump combinations have only minor effect on either magnet release or drop times. There is evidence that at the higher angles the drop times are slightly shorter if no pumps are running. The CCA drop times measured in the pond were shorter, although the magnet release times were longer. In these tests both the CCA and the magnet energising system were different from those used in the reactor; also the pool is filled with light water whereas heavy water is used in the reactor.

It is interesting that the tests made in 1977 gave very similar CCA drop times to those measured in 1979, but that the magnet release times were longer for the former and were similar to those measured in the 1979 pond tests.

The preliminary tests in 1977 indicated no difference between dropping CCAs individually and dropping them as a group, so such tests were not included in the 1979 program.

3.2 CCA Characteristics

This study is not intended to provide recommended characteristics for use in safety studies. This would involve an analysis of the spread in performance of all the CCAs in the reactor over a specified period, and then a judgement of the margins to be applied to ensure that, within a given probability, the CCAs would fall within the chosen characteristic. However, it may be helpful to compare the measured results against a theoretical prediction. The differential equation used by Meister and Kalker (1964) for the fall of CCAs in the FRJ-2 DIDO-type reactor at Jülich in the Federal Republic of Germany, based on the analysis of a pivoted arm falling through a turbulent fluid, was

$$\ddot{\psi} + \omega^2 \sin\psi - A\dot{\psi}^2 = 0 \quad , \tag{2}$$

where ψ is the angle from the downward vertical, ω is the pendulum frequency, and A is a drag coefficient. A value for ω^2 of 9.5 was derived in that work for a CCA immersed in heavy water.

Equation 2 was used to predict the results of the present experiment and was solved numerically using the subroutine DC02AD of Hopper [1978]. Figure 17 compares the solutions with some of the experimental results. The value for A which gave the closest fit for the CCA tested was 5, so the equation plotted is

$$\ddot{\psi} + 9.5 \sin\psi - 5\dot{\psi}^2 = 0 \quad , \tag{3}$$

where $\psi = 34 + \phi$ (see Figure 3). The solutions are in good agreement over the whole range of initial CCA angles for the case considered although there is a tendency for the calculation to give larger angles than those measured when the CCAs are nearly fully down.

4. CONCLUSIONS

The detailed characteristics of CCA angle versus time, following a CCA trip, have been measured on one CCA in position 6 in the materials testing reactor HIFAR during a shutdown period. The measured characteristics may be closely fitted by a simple analysis used in previous work on the FRJ-2 reactor.

The method of measurement appears to be satisfactory although there is an uncertainty of about 0.5° due to resilience or backlash in the linkages. The correction applied for this effect gives confidence that the actual CCA movement is not significantly underestimated.

5. ACKNOWLEDGEMENTS

Acknowledgement is made of the efforts of W.E. Carr who calibrated the equipment, and of N.C. Chalson, K.R.E. Butcher and the Reactor Operations staff for considerable assistance in performing the experiments.

6. REFERENCES

H.M. Hobson Ltd [no date] - Design Summary No.3 for Control System, Nuclear Reactor E443. Coarse Control.

Hopper, M.J. [1978] - Harwell Subroutine Library. AERE-R-9185.

Meister, G. and Kalker, K. [1964] - Analyse denkbarer Grobsteverarm - Unfalle am Reaktor FRJ-2. Jul-146-RE.

TABLE 1

CCA DROP TESTS IN HIFAR ON 24 JULY 1979

Test No.	Angle (degrees)	Pumps	Water Temp. (°C)	*Magnet Release Time (ms)	*CCA Down Time (ms)
1	50	1 and 3	42.5	23	766
2	40	1 and 3	42.8	29	663
3	30	1 and 3	42.8	33	549
4	20	1 and 3	42.8	38	424
5	10	1 and 3	42.6	44	296
6	40	all	42.5	28	666
7	30	all	43.1	32	559
8	20	all	43.8	36	418
9	40	none	40.5	28	629
10	30	none	40.1	30	521
11	20	none	40.5	36	416
12	40	1 and 2	41.5	30	677
13	30	1 and 2	43.9	31	549
14	20	1 and 2	46.0	35	427
15	36	1 and 2	46.0	29	616
16	28	1 and 2	45.6	32	517
17	12	1 and 2	45.5	46	320
18	4	1 and 2	45.4	55	190
19	36	none	45.1	28	576
20	28	none	44.3	28	491
21	12	none	44.0	58	334
22	4	none	43.6	61	198

*measured from drop initiation indication
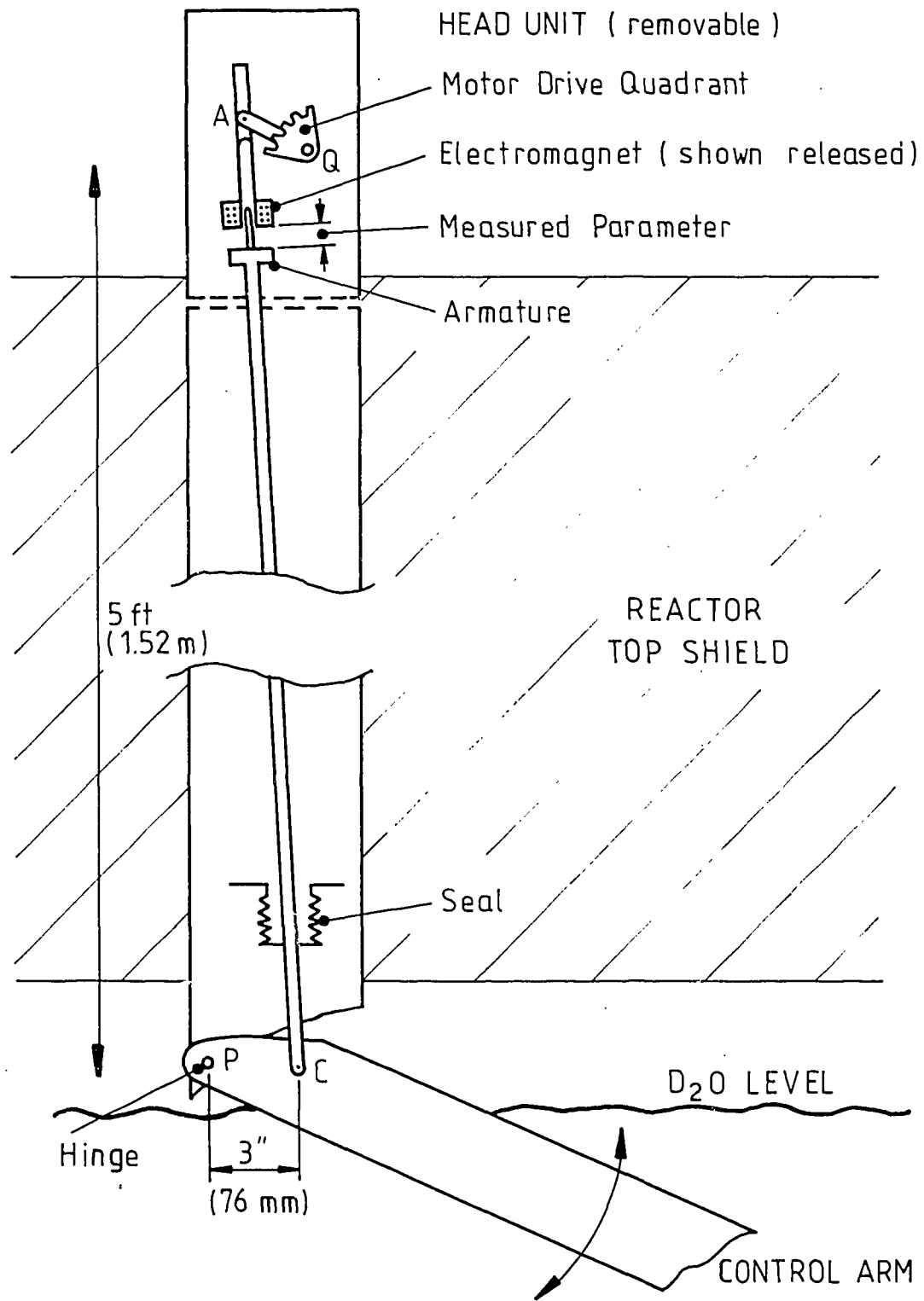
FIGURE 1. HIFAR CCA ARRANGEMENT

12

Linear Potentiometer
(body fixed)

Motor Drive Arm

Connecting Rod
Guide

Spring Actuated
Potentiometer Spindle

Cup

Fully Raised (56°)

2.8″
(71 mm)

Electromagnet

Fully Down (0°)

Armature Guide Rod

Armature

Linkage to Control Arm
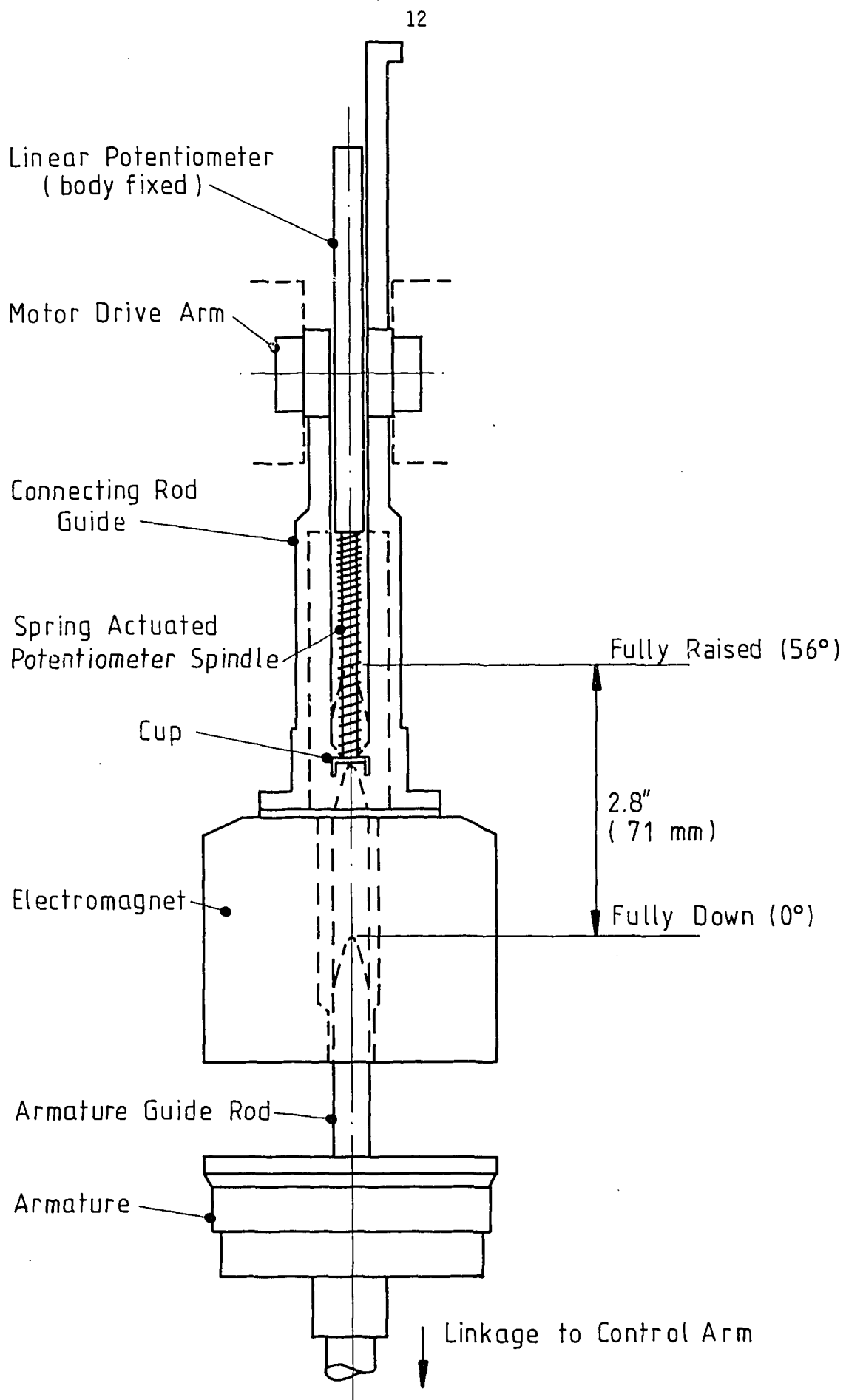
FIGURE 2. TRANSDUCER ARRANGEMENT

2D

A

R

θ

Q

In triangle ABC
  AB = E + R sin θ − R sin α
  BC = R cos α + R cos θ − 2D

Thus
  $L^2 = (AC)^2 = (AB)^2 + (BC)^2$

Angles α and θ
  measured + ve above
  horizontal,− ve below

CCA angle φ taken + ve
  anticlockwise from datum

E

L

B

C

R

27°

α

Horizontal P

56°

CCA position

CCA angle
φ

CCA datum

	mm
R = 3″	(76.2)
D = 2.125″	(54)
L = 62.64″	(1591)
E = 62.6945″	(1592.4)
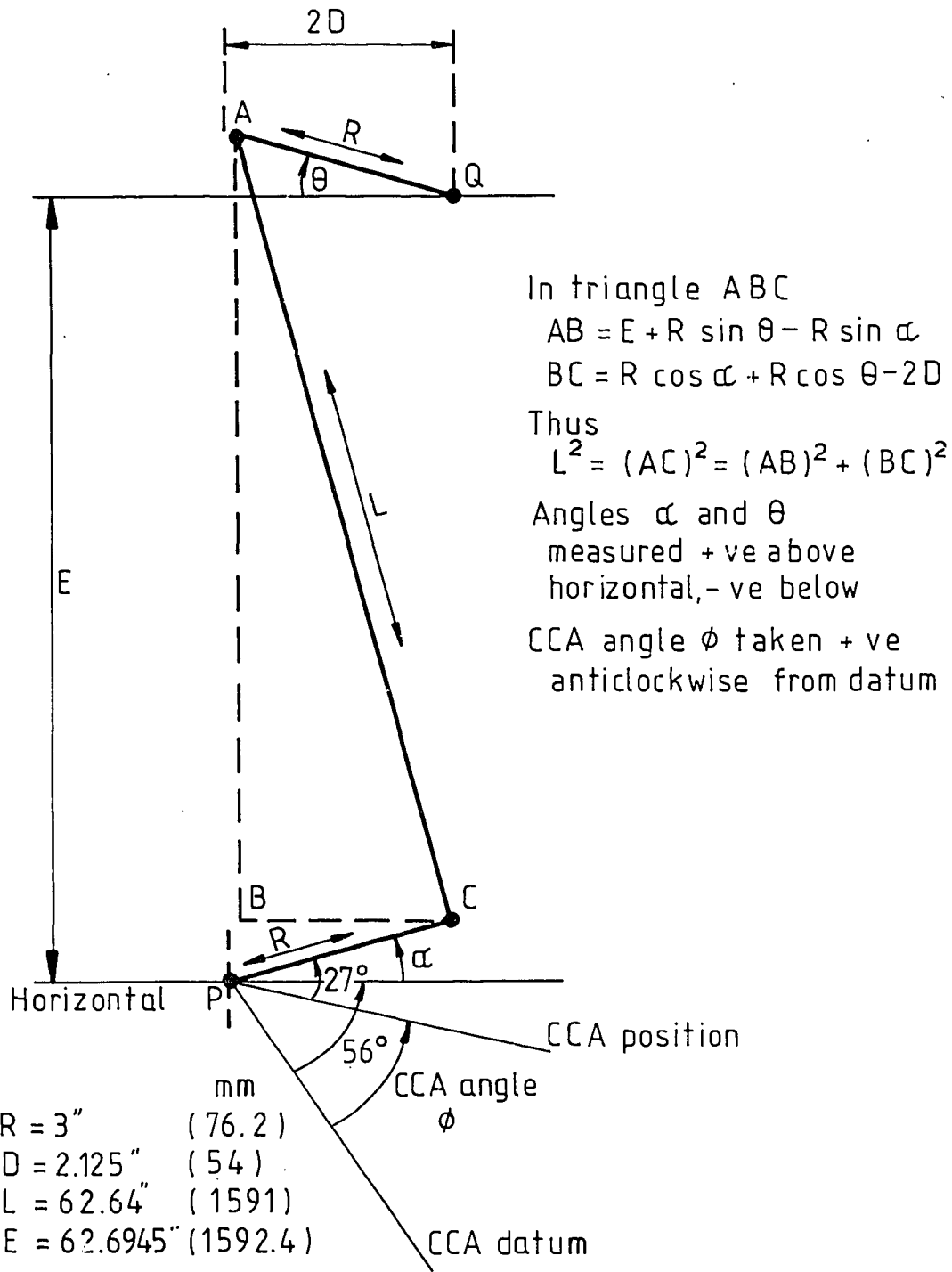
φ	α	θ	
0	−29	−30.367	fully lowered
10	−19	−20.425	
20	−9	−10.483	
30	1	−0.5083	
40	11	9.517	
56	27	25.642	fully raised

FIGURE 3. CCA LINKAGE
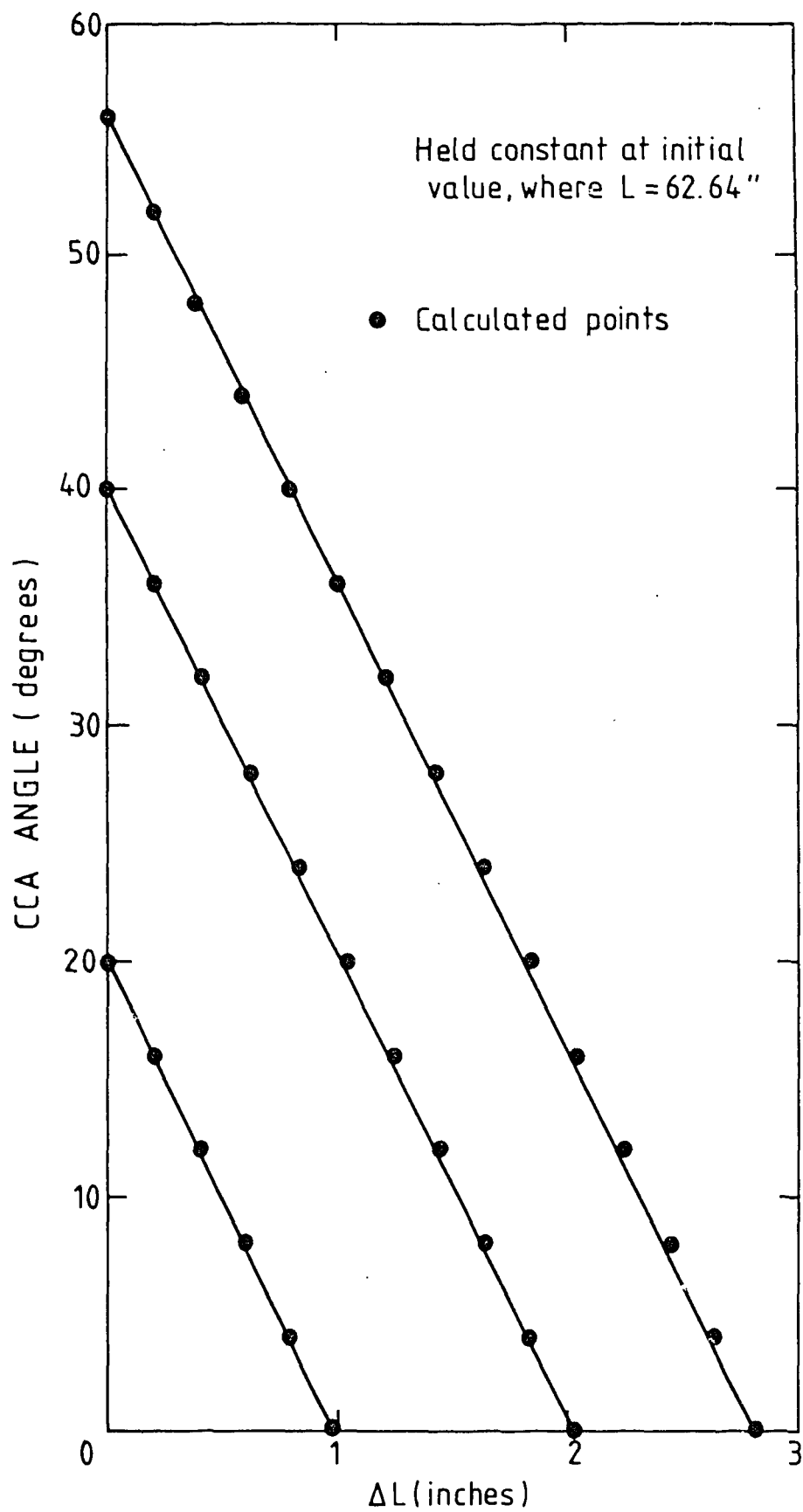
FIGURE 4. CALCULATED MAGNET SEPARATION ON CCA ANGLE
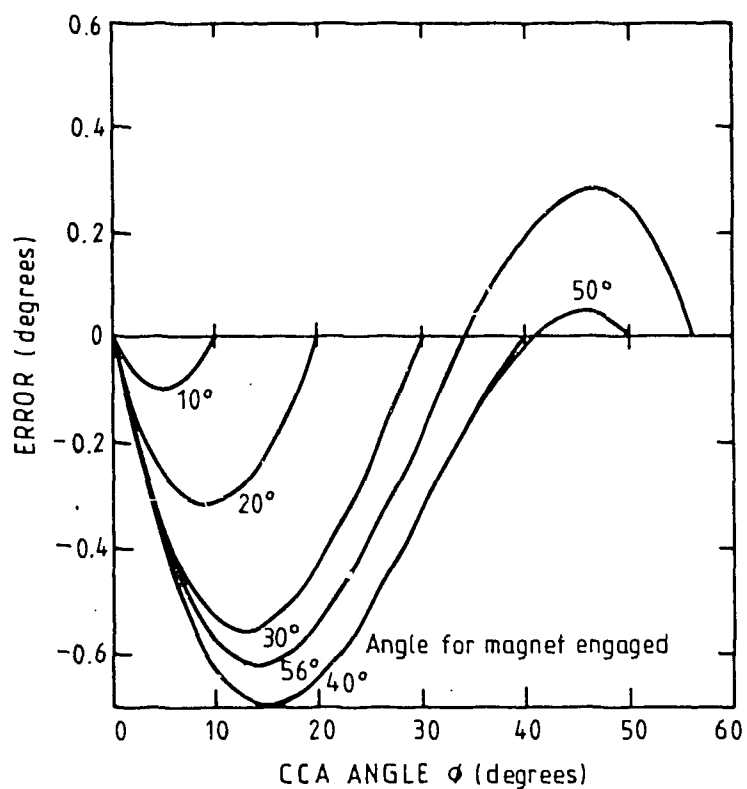
FIGURE 5. ERROR IN LINEARITY ASSUMPTION
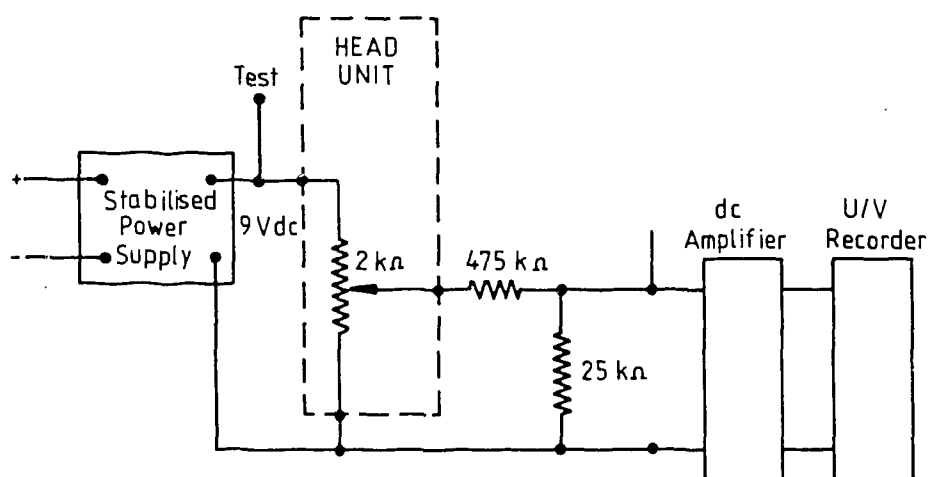
FIGURE 6. TRANSDUCER CIRCUIT
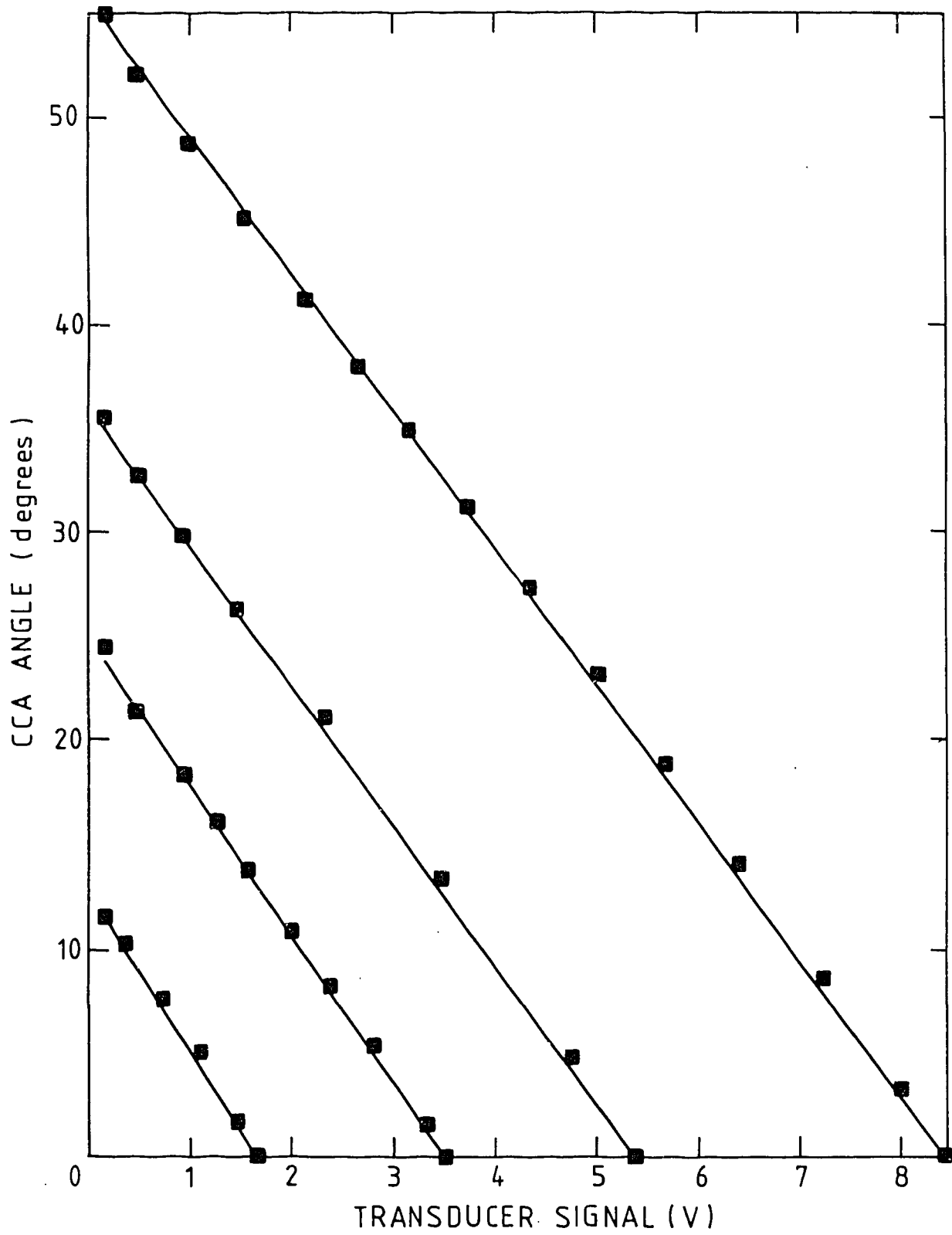
FIGURE 7. MEASURED TRANSDUCER CHARACTERISTICS
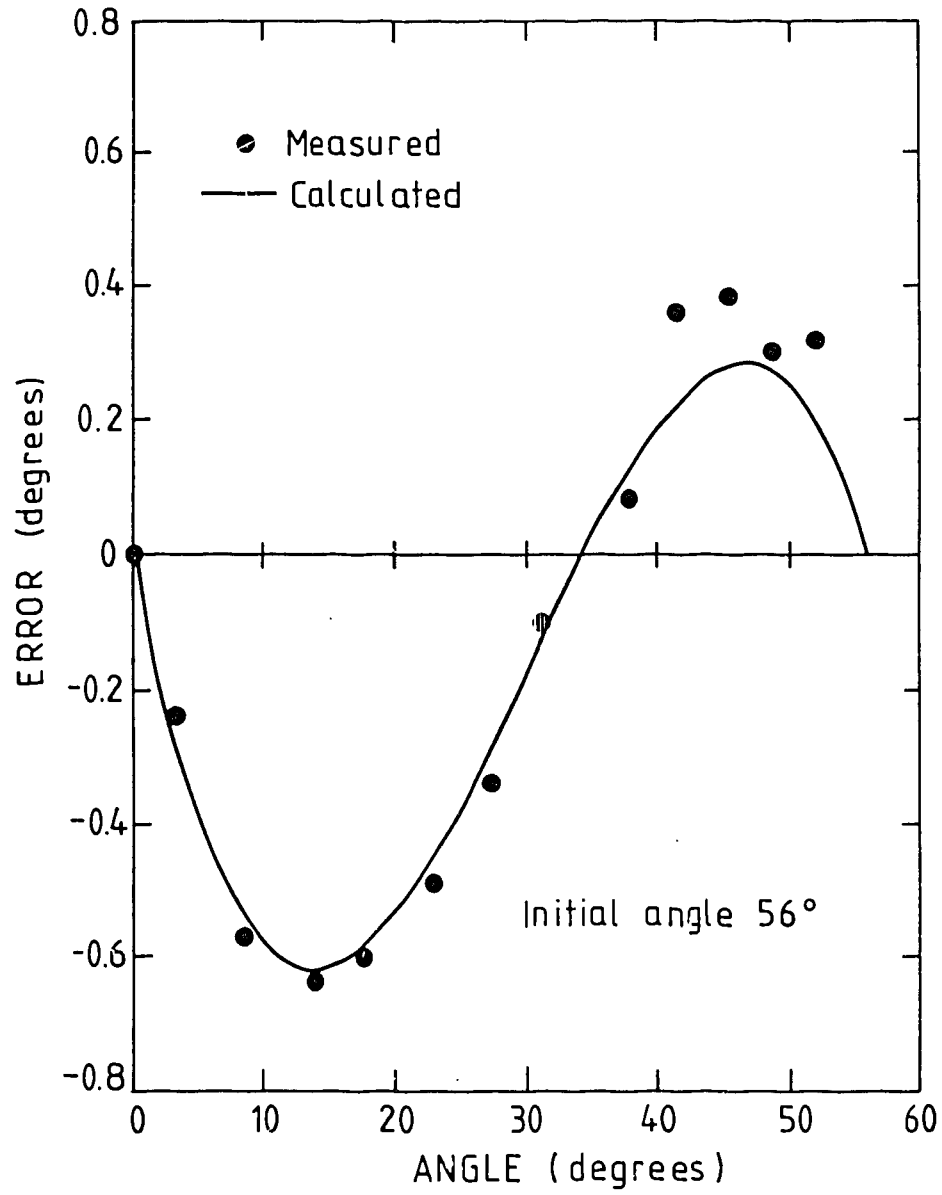
FIGURE 8. MEASURED ERROR IN LINEARITY ASSUMPTION
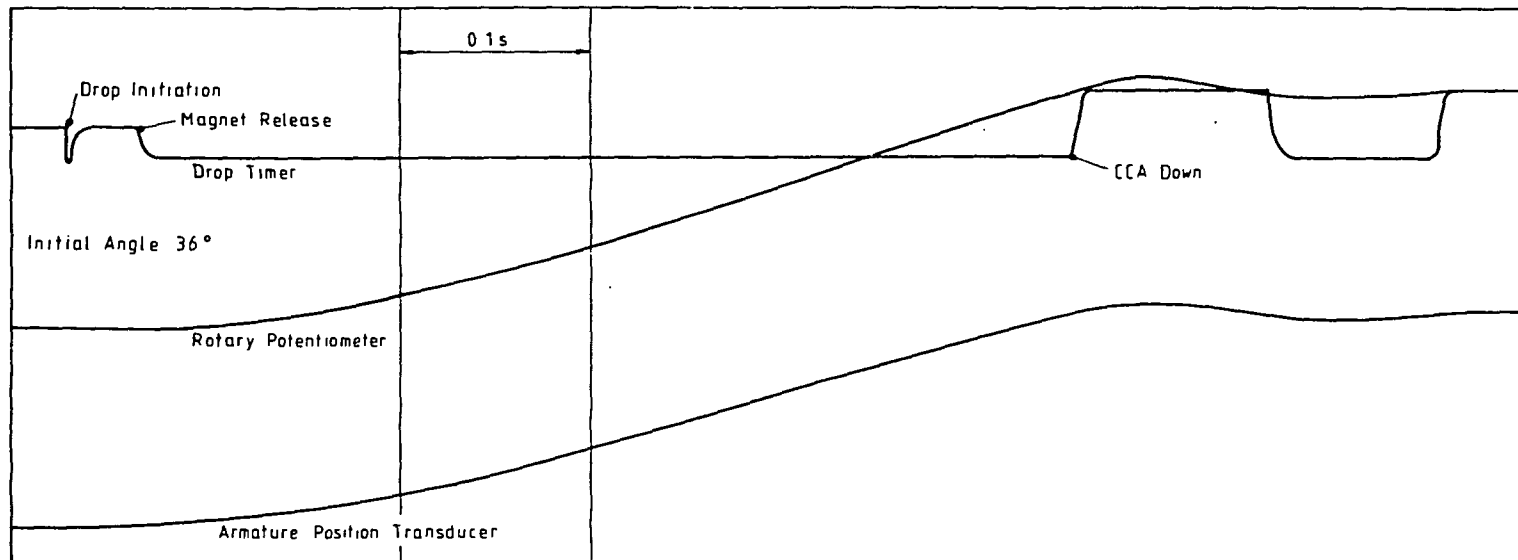
FIGURE 9. TYPICAL RECORDER TRACE: DROP TEST IN POND
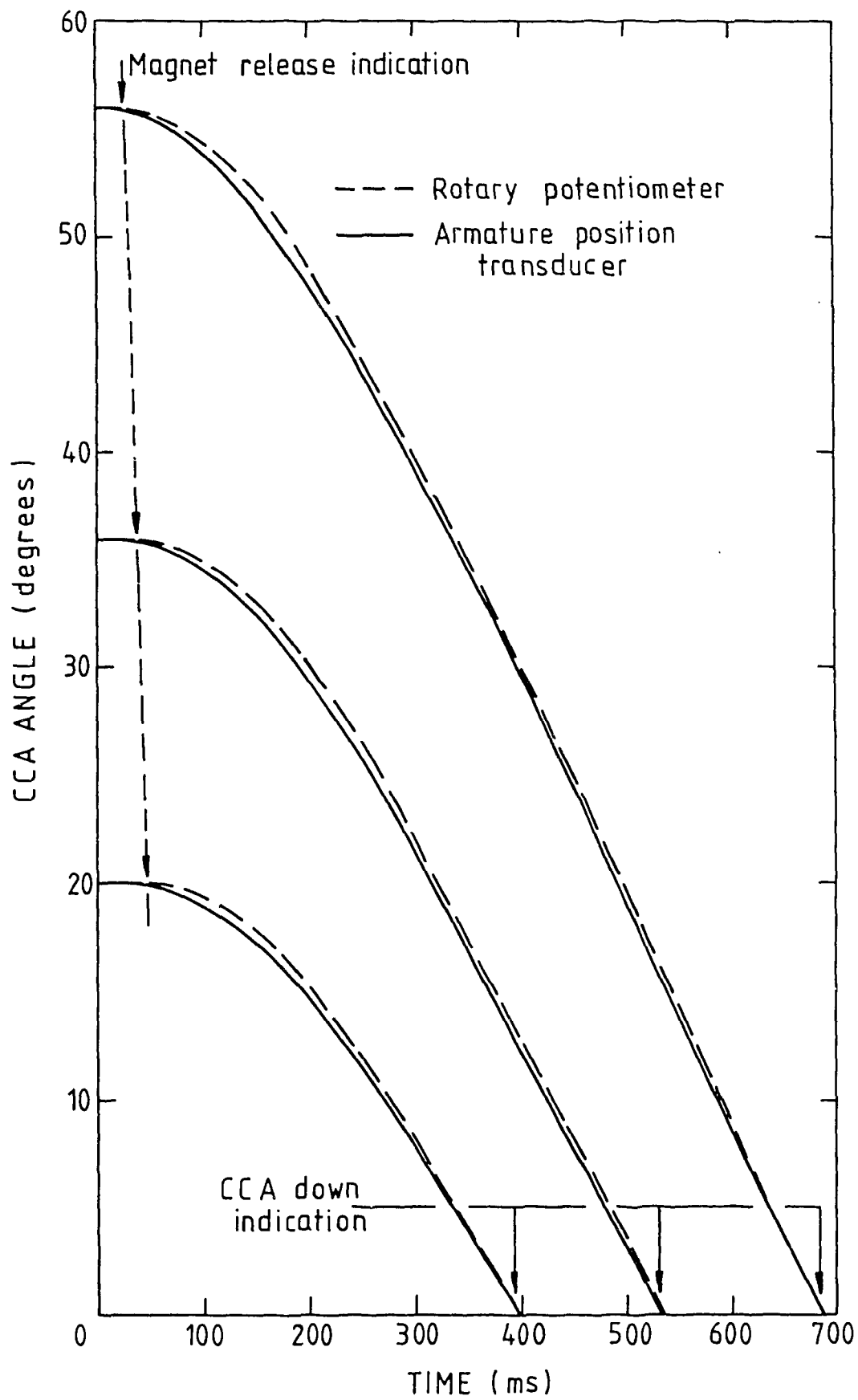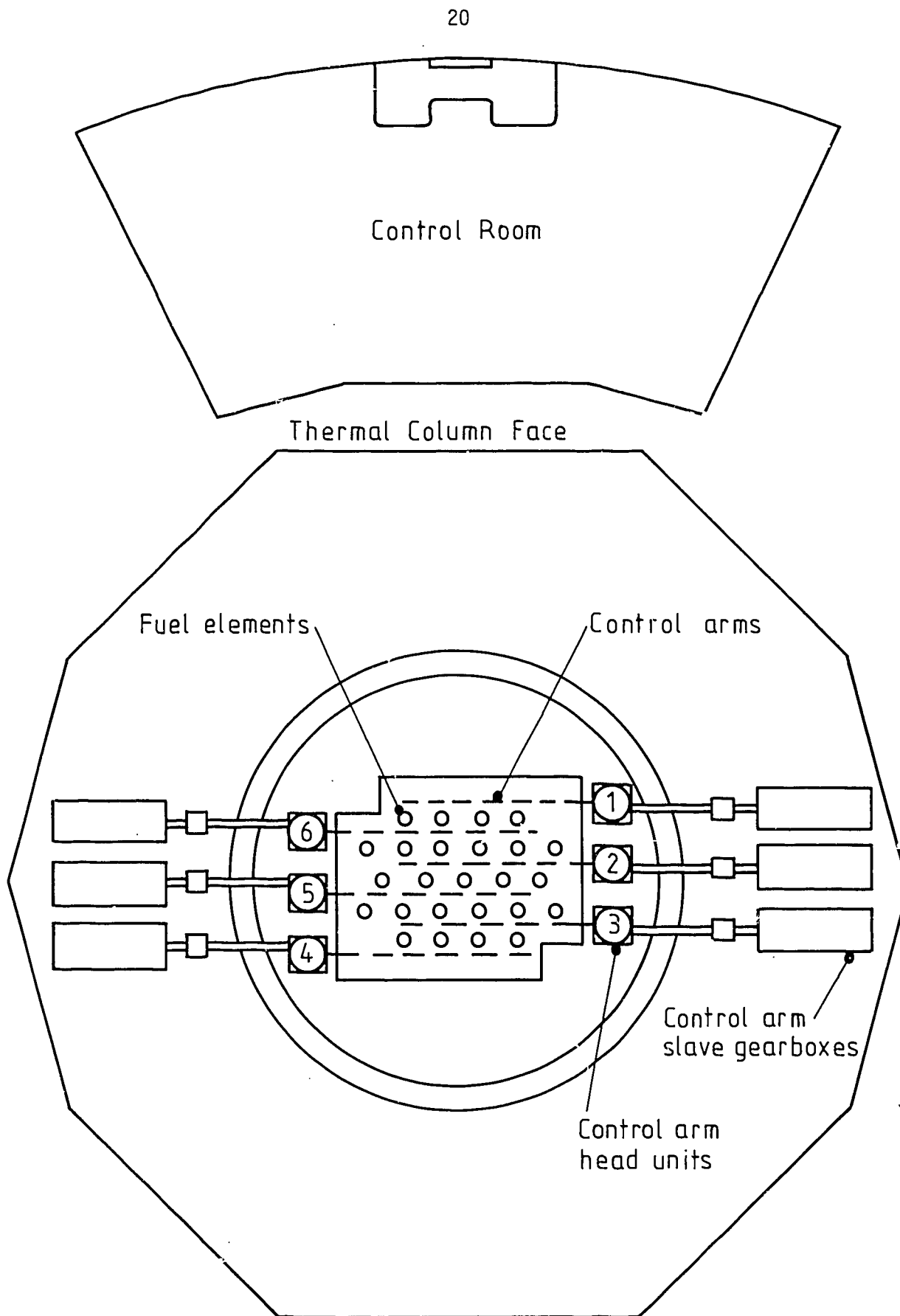
FIGURE 10. CCA DROP TESTS IN POND

Control Room

Thermal Column Face

Fuel elements

Control arms

6

5

4

1

2

3

Control arm
slave gearboxes

Control arm
head units

FIGURE 11. LAYOUT OF CONTROL ARMS IN HIFAR
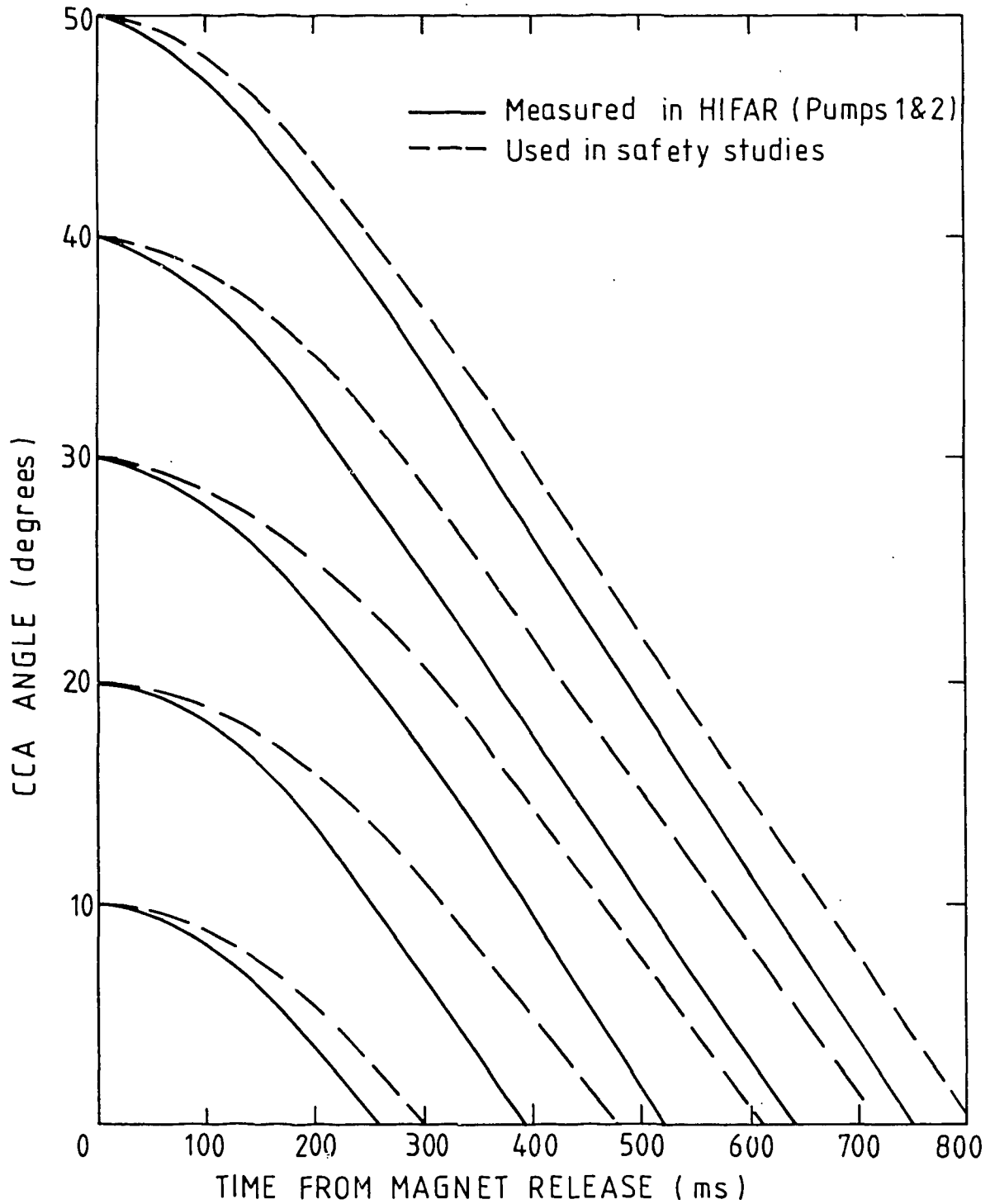
FIGURE 12. CCA DROP TESTS: EFFECT OF INITIAL ANGLE
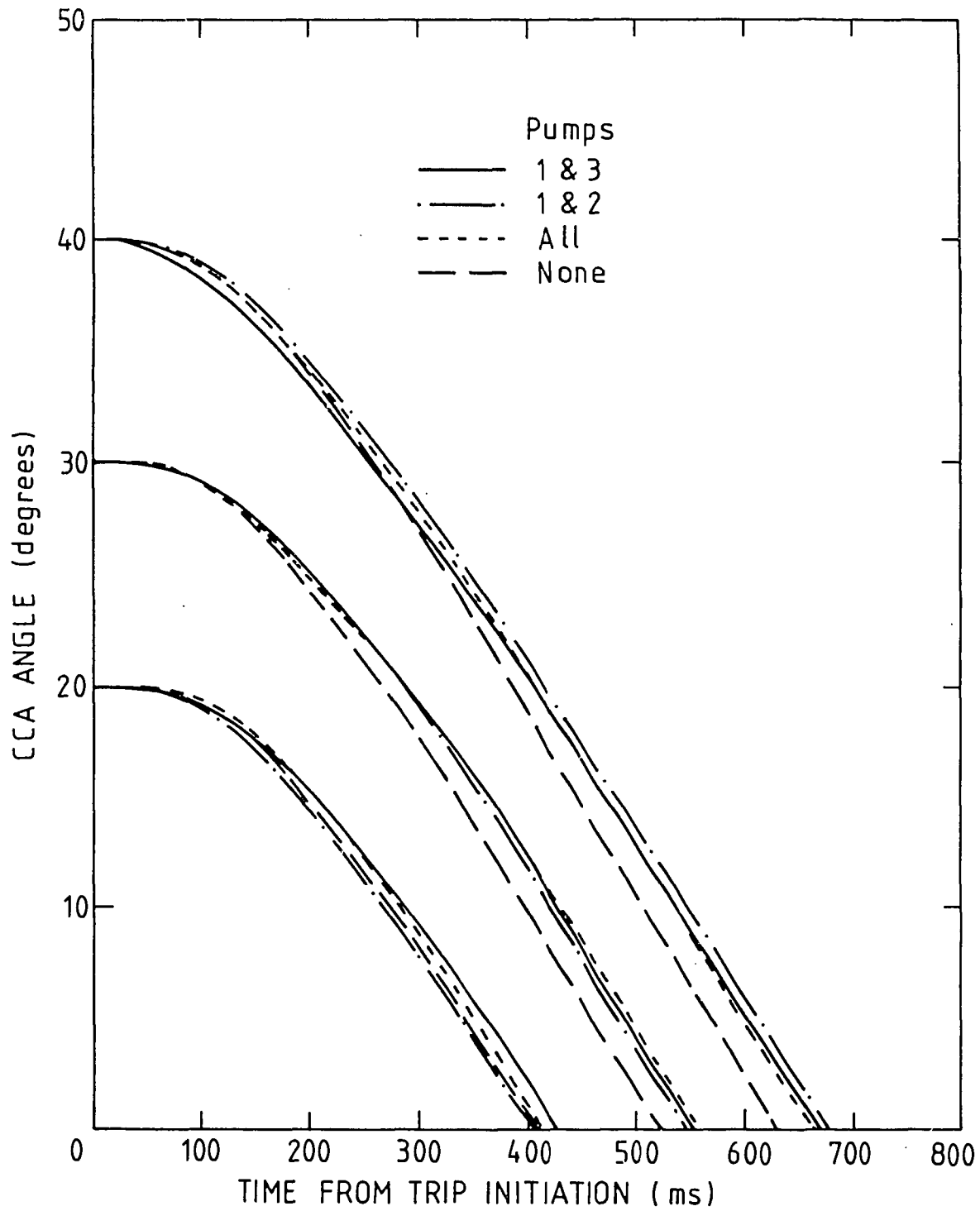
FIGURE 13. CCA DROP TESTS: EFFECT OF PUMPS
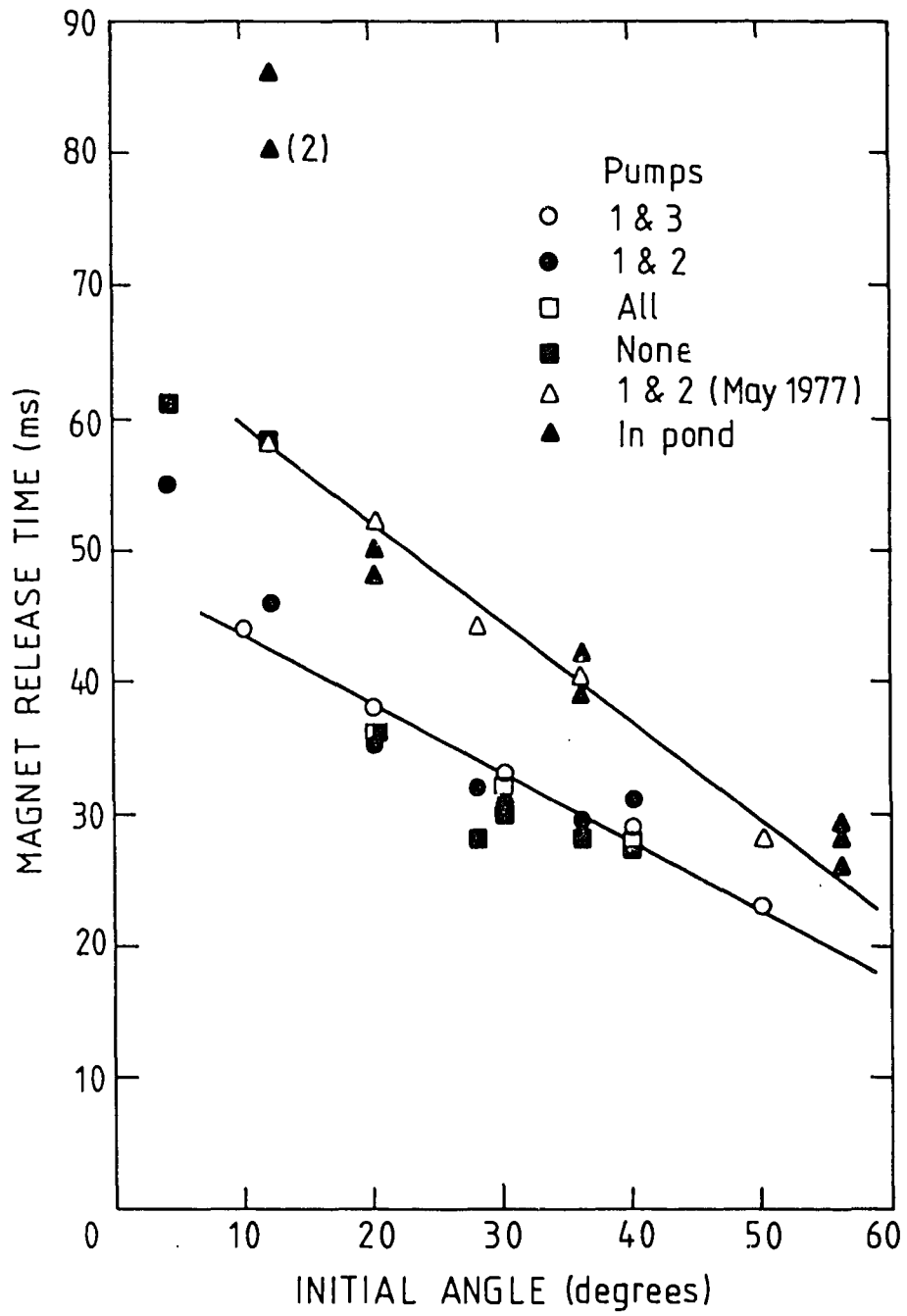
23
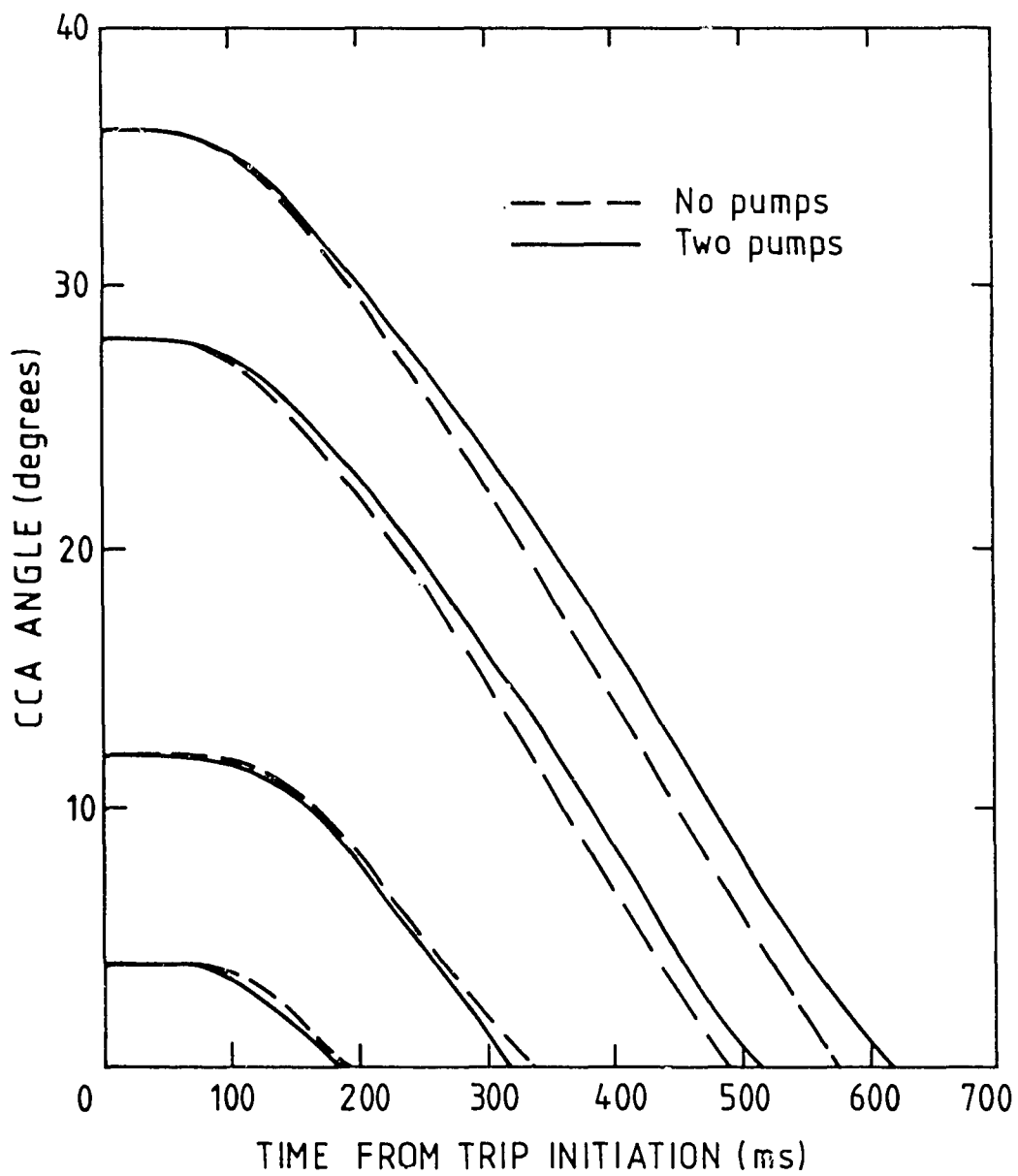
FIGURE 14. CCA DROP TESTS: MAINTENANCE ANGLES
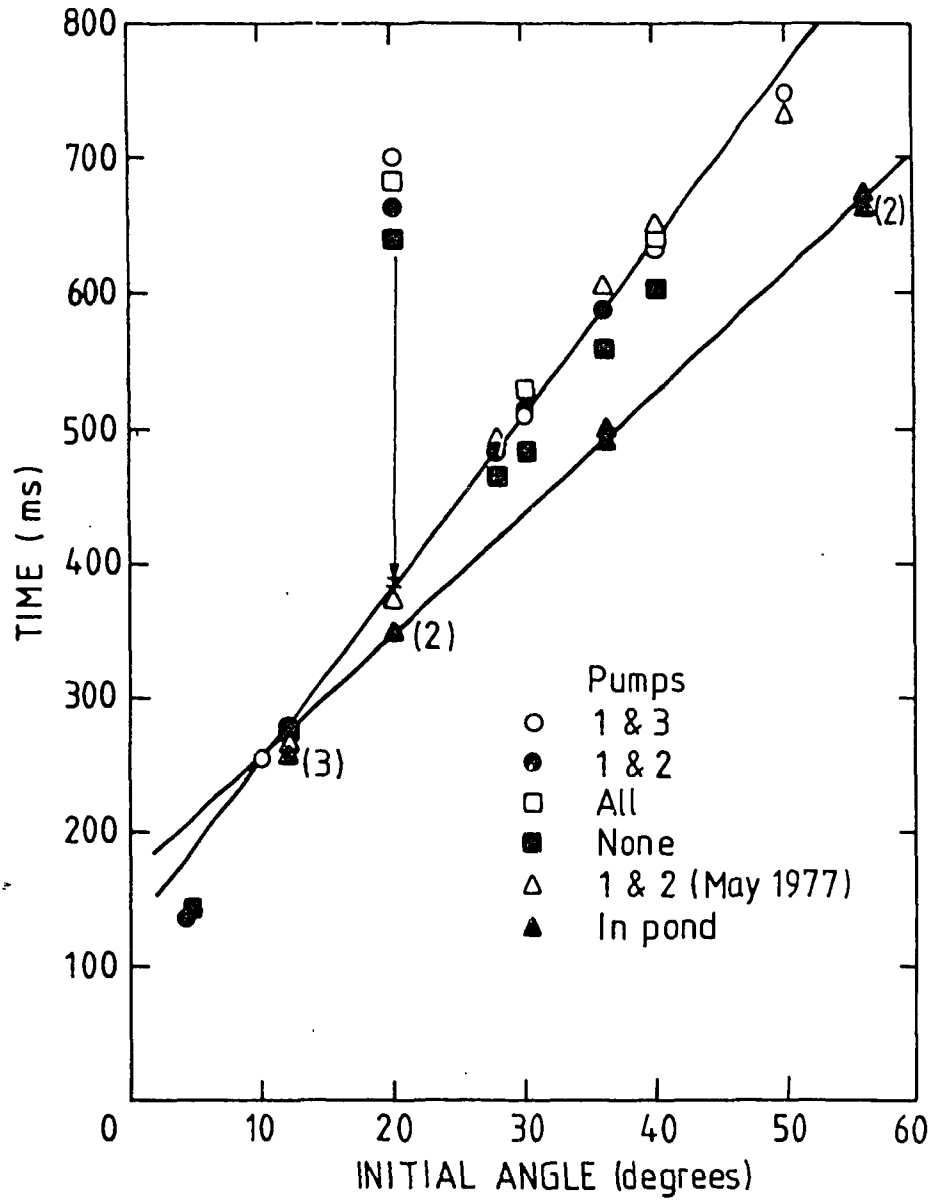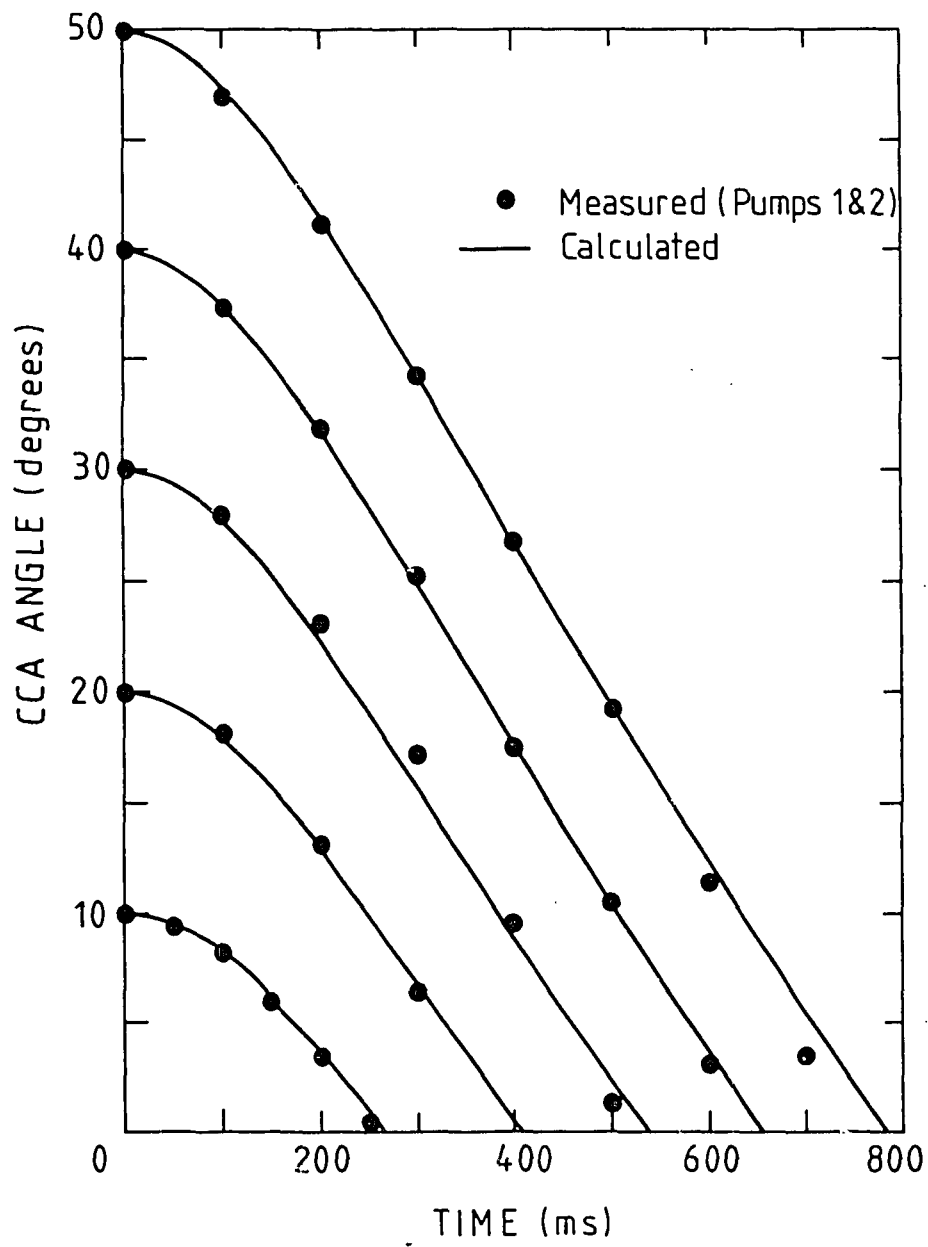
FIGURE 15. TIME TO MAGNET-RELEASE

FIGURE 16. TIME BETWEEN MAGNET-RELEASE AND CCA DOWN

FIGURE 17. COMPARISON WITH ANALYSIS