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P.16 A preliminary evaluation of a new control-knob design for electronic equipment

- by -

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SUMMARY

Two experiments were carried out using five subjects to compare performance using standard and flush fitting rotary controls for electronic equipment. It was found that the flush knob could be rotated more quickly through several revolutions, but a given setting accuracy was achieved less quickly using this flush knob.

Some of the more general advantages and disadvantages of the flush knob are outlined.

It should be noted that the primary objective of this study was to provide the participants with some experience in carrying out Human Factors studies and the time allowed was not such as to permit a comprehensive evaluation of the new knob design.

Contents

1. Acknowledgments

The members of the project group would like to express their gratitude to Mr. Singleton for his supervision and guidance, and to the members of the Ergonomics Laboratory, especially Mr. T. Gardiner for their assistance with the experimental apparatus.

2. Members of the group

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3. Duration of project

Five afternoons during the summer term were allocated to this project but it was necessary to do some additional work outside these periods.

4. Subjects

Five male subjects, students of The College of Aeronautics, Cranfield, all in their early 20's.

5. Introduction

The objective was to evaluate a flush fitting control knob designed by the Marconi Wireless Telegraphy Company Ltd. The flush knob is intended as an alternative to the standard protruding control knob on electronic equipment. It was therefore compared with a protruding knob of equivalent size. From a table of clearances for controls (Shackel and Daves 1962) the equivalent size of a standard protruding knob was estimated to be of 1 in. diameter.

Two comparison tests were carried out on the two types of knob. These were:-

Experiment 1. To measure the time taken to rotate the knobs through a fixed number of revolutions.

Experiment 2. To measure the time required to set the knobs to a particular angular position with a fixed tolerance of accuracy.

It was originally envisaged that two further studies should be done:-

Experiment 3. To determine the inclination and reach areas over which the knobs were most easily operable.

Experiment 4. To determine the maximum torque which could be applied.

Because of shortage of time it was not possible to carry out these experiments.

6. Experiment 1 - Continuous rotation

Object

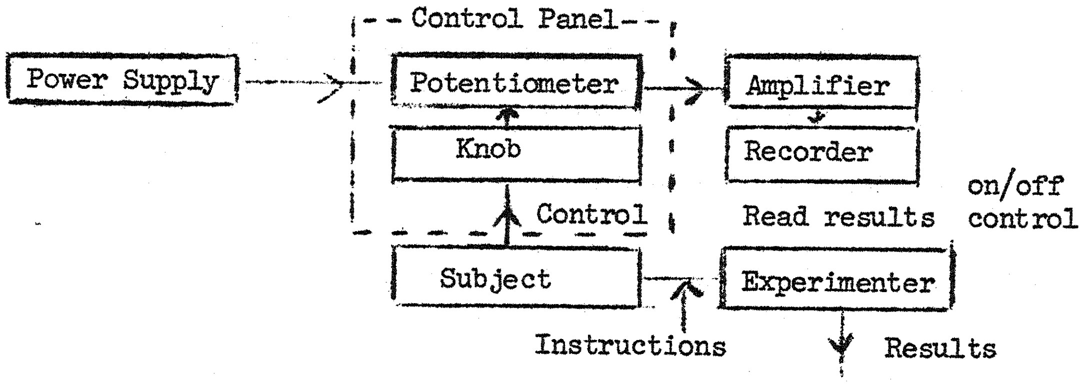
To compare the times required to continuously rotate each knob over a range of angular displacements of 0 - 18 revolutions in both clockwise and anti-clockwise directions.

Apparatus

Farrell, $\frac{1}{2}$ amp. stabilised voltage power supply type L30.
Kelvin Hughes four channel amplifier type 2.
Kelvin Hughes single channel recorder Mk 5.
Control panel.

Figure 1.1

Block Diagram of Apparatus



The knob under test was connected to the shaft of a continuous potentiometer. The stabilised power supply (10V) was connected across the potentiometer whose output was fed to one channel of the four channel amplifier. This in turn was connected to the recorder and the amplifier gain adjusted so that one revolution of the potentiometer gave a suitable deflection of the recorder stylus. One complete revolution of the knob caused the stylus to move from a datum position to a position of maximum deflection and then jump back to the datum.

Procedure

After seating himself comfortably in front of the control panel, the subject was asked to rotate the knob as fast as he could until asked to stop by the experimenter, i.e. 'standing start flying finish' test. He was allowed to practice until a reasonably consistent result was achieved. These runs were then recorded, the average of these results was taken as the measure of the subject's performance.

This task was performed with the following conditions:

A) Flush knob. Both clockwise and anti-clockwise rotation.
B) Proud knob. Both clockwise and anti-clockwise rotation.

The order of presentation of knobs and directions was randomised for the five subjects tested.

Results

Graph 1.1 shows a plot of time and angular displacement for each knob in two directions, the graphs being the mean of 5 subjects.

Graphs 1.2 - 1.5 show separate plots of each of the above curves and the maximum spread of results for the 5 subjects.

Discussion

As can be seen from the graphs the time for rotation at particular intervals of angular displacement varies widely between individual subjects, the spread of results increasing as the angular displacement increases. The most extreme case (the proud knob rotated clockwise, with an angular displacement of 18 revolutions) shows a difference in times recorded by the faster and slowest subjects of 5 seconds.

The spread of results about the mean curves is such that it is difficult to determine if there is any significant difference between the results. In order to obtain an indication of any difference, the results were ranked in order of best performance comparing each subjects performance on the two knobs with the same direction of rotation. By this method the following table was complied.

Table 1.1 Number of subjects who had best performance under a particular conditions

Angular Displacement Revs.		1	2	4	6	8	10	12	15	18
CLOCKWISE ROTATION	Flush Knob	3	3	5	5	5	5	5	5	5
	Proud Knob	2	1	0	0	0	0	0	0	0
ANTI-CLOCKWISE ROTATION	Flush Knob	1	1	3	4	4	4	4	4	4
	Proud Knob	4	44	2	1	1	1	1	1	1

The above table indicates that:-

(1) in a clockwise direction, with angular displacements of 4 revolutions and greater, all subjects recorded faster times for the flush knob.

(2) in an anti-clockwise direction, with angular displacements of 6 revolutions and above 4 out of 5 subjects recorded faster times for the flush knob.

With an angular displacement of 6 revolutions, the difference in rotation times are 1.15 secs. in a total rotation times of 3.00 secs. for rotation in a clockwise direction and 0.30 secs. in a total rotation time of 2.45 secs. for rotation in an anti-clockwise direction.

Conclusions

The experiment showed that with angular displacements of greater than about 5 revolutions, there is a difference in performance between the two types of knobs, the flush knob being superior.

7. Experiment 2.

Object

To find the time for angular adjustments, to a specified accuracy, over a range of 0 - 2.5 revolutions for both types of knob.

Apparatus

Kelvin and Hughes four channel amplifier, type 2.
Kelvin and Hughes single channel recorder, Mk. 5.
Farnell half amp stabilised voltage power supply, type L30.
Solartron C.R.T. Type CDS13.2
Electric clock - 50 c/s.
Morse key
Operator control assembly.

Rotation of the knob was transduced to voltage variation by connecting the knob shaft to a circular potentiometer. The potentiometer was connected through one channel of the amplifier to the single channel recorder where the voltage variations appeared as a trace on recording paper. The Farnell Power Supply was connected across the potentiometer. The potentiometer was also connected to the C.R.T. and the supply voltage adjusted until one complete revolution of the knob gave a full-scale deflection of a spot on the C.R.T. screen. Full scale deflection was 8 cms. A piece of transparent paper with a straight line ruled upon it was mounted behind the C.R.T. mask. The ends of this piece of paper projected out from the mask and thus a simple method of positional adjustment of the line was provided. A morse key and electric timer were connected together and provided the subject and experimenter with an approximate time taken to perform angular adjustments of the knobs.

Procedure

Five magnitudes of angular rotation were selected over the range 0 - $2\frac{1}{2}$ revolutions. These were 0 - $^1/_4$ rev., and 0 - $^5/_8$ rev., 0 - $^7/_8$ rev., 0 - $1^1/_4$ rev., and 0 - $2\frac{1}{2}$ rev. These corresponded to 2, 5, 7, 10 and 20 cms. movement on the C.R.T. screen respectively. A 10 cm. movement, for example, on the screen entailed one complete traverse (in a vertical direction) plus 2 cm.

The required accuracy was specified by making the target a space 1 mm. wide between the movable line and one of the lines on the C.R.T. screen mask. Rotation in both the clockwise and anti-clockwise directions were used for each knob. Fig. 2.2 shows a diagram of the C.R.T. screen with target and movement distance included.

After seating himself comfortably, the subject was asked to move the spot of light on the screen from the datum position to the target as quickly as possible. He timed himself using the electric clock in conjunction with the morse key. The subject was allowed to practise until some consistency had been achieved. His movements were then recorded on the trace. The average time of three to five runs was taken as the performance criterion.

The electric clock was used only as an indicator of performance. The actual time of movement was measured from the trace.

In all, there were four different experimental situations for each subject, viz: flush knob clockwise, flush anti-clockwise, proud knob clockwise and proud anti-clockwise.

The subject performed the experiment on one knob at a time (directly following experiment 1 on that knob). The order of movement distances was randomised, some subjects used the proud knob first and others the flush knob.

Results

From the recorded traces, graphs of time for rotation against extent of angular rotation were plotted for each subject for each knob for each direction of rotation. Graph 2.1 shows the mean times of the 5 subjects for each knob in each direction of rotation.

There appears to be no consistent difference in rotation time between anti-clockwise and clockwise rotation for either the flush or the proud knob. The average time for rotation was therefore calculated for each knob and the differences between the two knobs obtained.

On average, the flush knob was $^1/_5$th second slower than the proud knob.

Graphs 2.2, 2.3, 2.4 and 2.5 show the four average curves with the individual subject's results plotted on them. This gives some indication of the scatter.

Assuming that there was no consistent difference between clockwise and anti-clockwise rotations, it was possible to perform a three way analysis of variance on the results.

The results of this analysis is shown below:

Table 2.1 Analysis of Variance

Source of Variance	Sum of Squares	D.F.	Variance Estimate	F Ratio	Significance
Subjects A	23007	4	5752	9.06	Highly
Distances B	393090	4	98273	155.	"
Knobs C	24661	1	24661	38.9	"
BC	10107	4	2527	3.985	Very
CA	5366	4	1342	2.12	Not
AB	16216	16	1013	1.60	Not
ABC	18104	16	1132	1.786	Probably
Residual	158425	250	634		
Total	648977	299	2170		

Table 2.2 Means

Subject	Mean
1	123.0
2	117.8
3	119.4
4	128.9
5	102.5

Distance	Mean
$^{1}/_{4}$	67.2
$^{5}/_{8}$	99.0
$^{7}/_{8}$	115.2
$1^{1}/_{4}$	134.5
$2^{1}/_{2}$	175.7

Knobs	Mean
Flush	127.4
Proud	109.2

Grand Mean = 118.32 Standard deviation = 46.6

All readings were multiplied by 100 to suit programme for computer. Hence high values in tables above. These don't affect the values of the F ratios, however.

(a) Between Subjects Variation (A)

The Analysis of Variance shows that differences between subjects are highly significant. Inspection of the mean times for subjects showed that subject 5 had a considerably lower mean time than the others. A t test was performed comparing his mean with that of S1 to S4 combined.

The value of t obtained was 5.45 which is highly significant.

Therefore we can say that subject 5 was quicker than any other subject. We may infer that the magnitude of the 'between subjects' F ratio is affected most by subject 5's speed (and to a lesser extent by the high average time of subject 4).

(b) Interactions between Knobs and Distances (CB)

D ratio was 3.985 with 4 df. for numerator and 250 df. for denominator. Since P ($F_{4:250} < 3.82$) = 99.5% this interaction between knobs and distances is probably significant to highly significant.

The mean times of 5 subjects for each distance for each knob are shown below:

Knob	$^1/_4$	$^5/_8$	$^7/_8$	$1^1/_4$	$2^1/_2$ revs.	
Flush	.73	1.19	1.21	1.47	1.80	)
Proud	.61	.79	1.10	1.23	1.71	)seconds
Difference	.12	.40	.11	.24	.09	)

Now the least significant difference between any two means is approximately:

$$\frac{1.96\sigma}{\sqrt{n}} \text{ (at the 95\% confidence level).}$$

n = 30 = no. of readings which each mean is based upon.

σ = population variance of which $S^2 = \frac{634}{10,000}$ is the best estimate

$$\therefore \quad \text{l.s.d.} = \frac{1.96}{100}\sqrt{\frac{634}{30}}$$

$$= \frac{9}{100} = \underline{\underline{.09 \text{ secs. approx.}}}$$

Now all the pairs of means differ by more than .09 secs. except for a distance of $2\frac{1}{2}$ revs. Thus there does seem to be some significant interaction between knobs and distances although the main source seems to be distances of $^5/_8$ revs. in particular and $1^1/_4$ revs. to a lesser extent.

(c) Interaction between Knob and Subjects (CA)

The analysis reveals no significant interaction between subjects and knobs. We can therefore infer that performance in relation to the two knobs was consistent between subjects.

(d) Between Knobs Variation (C)

The F ratio of 38.9 was extremely significant. Thus performance between the knobs is definitely different. Inspection of the means shows us that the proud knob took less time to operate than the flush knob. The average difference between knobs is .182 secs. or approximately $^1/_5$th sec. confirming the result mentioned previously.

(e) Interaction between Subjects and Distances

The analysis did not indicate any significant interaction between subjects and distances.

Conclusions

The most important finding of this experiment is that there is a difference in performance between the two types of knob.

This difference is difficult to quantify as an operational difference since it varies with distance of rotation; the average value of this difference appears to be about $^1/_5$th sec., and it is up to the user and/or designer of the knobs to decide whether this difference is operationally significant. It will obviously depend upon operational requirements.

The experiment also showed that there was a wide variation between subjects in actual time of operation.

Also indicated is an interaction between knobs and distances. Subjects seemed to find difficulty in operating the flush knob quickly over a rotation of $^5/_8$ revs.

8. Discussion

Experiment

(i) Apparatus

Early in the experimental work, it was found that several different methods were employed by different subjects to turn the protruding knob as quickly as possible. Three basic methods were used:-

a) a series of 'flicks'
b) a series of turns without 'flick' and
c) movement by contact of the periphery of the knob with the finger or side of the hand.

To obtain consistency between subjects, damping was introduced on the spindle of the knob to prevent 'flicking' and the subjects were instructed to make finger up contact only with the knob. The method of turning the protruding knob then became a series of discrete turns, whereas the method for the flush knob was a continuous rotation by the finger tip.

For the five subjects, the average number of discrete turns (or grasps) per revolution of the protruding knob was 2.51 sec. in the clockwise direction and only 1.75 sec. in the anti-clockwise direction. This difference was attributed to the asymmetry of hand movements (all the subjects being right-handed). The differences between subjects of the number of discrete turns (or grasps) per revolution may have contributed to the individual differences in speed of turning the knob through several rotations.

(ii) Results

The important general result was that an operator can rotate the flush knob faster than he can the protruding knob, provided the method for rotating the protruding knob is that used in the experiment. It is possible that the stiffness of the flush knob could have varied due to friction but this was not evident on comparison of the scatter on the results for the two knobs. (This last point also applied to Experiment 2).

The graphs of speed of rotation show that scatter of the points due to individual differences, a) scarcely overlap when comparing the flush and protruding knobs, suggesting significantly different curves, and b) overlap considerably when comparing clockwise and anti-clockwise directions of rotation, suggesting the same curve. A significant difference, then, existed between the speed of rotation of the two types of knob but there was little significant difference between the speed of rotation in either direction.

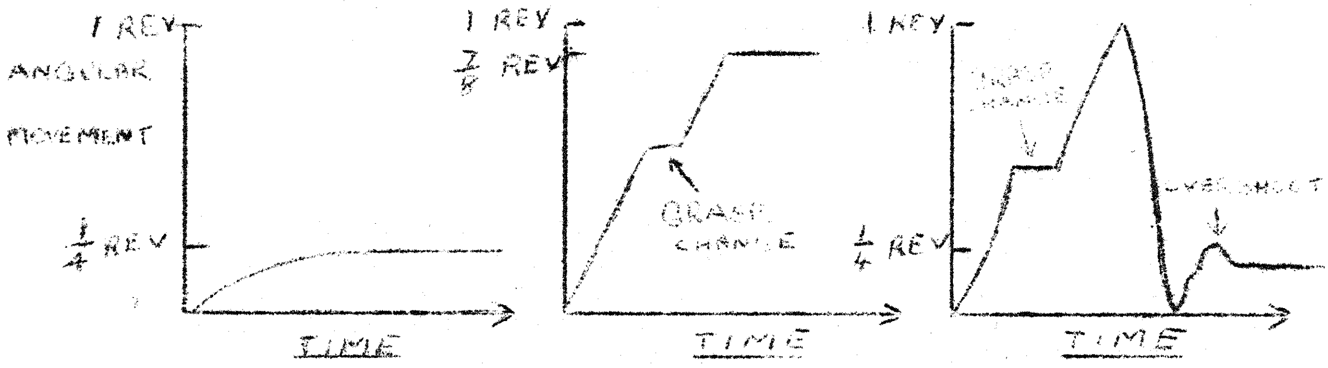
Experiment 2

(i) Apparatus

Angular rotation of the knob was converted into a vertical, linear movement of a spot on the screen of a C.R.O. (1 rev. = 1 length of screen = 8 cm.). This was undesirable but was unavoidable due to the direct drive nature of the potentiometer on which the knobs were mounted. For instance, a setting of $1^1/_4$ revs. necessitates one complete traverse of the spot on the screen, followed by its sudden reappearance at the starting point, followed by a short traverse of $^1/_4$ of the screen width. The complex nature of the movement of the spot may have tended to disturb subjects to such an extent that the result may be suspect. From this point of view a potentiometer giving an output of zero to maximum voltage in more than one revolution would have been more suitable but this would have resulted in less sensitivity.

The target size was governed by the spot size, the two being approximately equal. It was left to the subject's discretion to decide when the spot was in the target area. The experimenter had only a rough check of the subject's accuracy due to the parallax on the C.R.T. screen.

Some short setting distances were covered by one movement of the fingers, and other longer distances by a complex finger movement (see traces below).



The division between short and long setting distances may have varied between subjects.

Due to the position of the C.R.T. screen, the subjects experienced difficulty in locating the knob, especially the flush knob.

The electric clock provided knowledge of performance which served as an incentive for the subject and as information on learning for the experimenter.

The usual experimental procedure when learning is evident is to allow the subject to practise long enough to obtain three results whose values are within 5%. However, lack of time in the experiment necessitated that only roughly consistent results were recorded. It is questionable whether or not the results would be very consistent even after a very long period of practice.

(ii) Results

The results had considerable scatter due to individual differences and the differences may, in turn, be due to differences in finger lengths, particularly in the case of the flush knob. The difference between the lengths of the index and middle fingers and also the length of the finger-nail seem to be of importance when considering setting tasks with the flush knob.

No consistent difference was found in setting performance in either direction with the flush knob or the protruding knob. Setting times were, on the average, $^1/_5$th sec. longer for the flush knob than for the protruding knob. However, this was not necessarily so for an individual subject.

Apart from the numerical evidence provided by these experiments the following general points emerged from discussion of the knob designs.

Probable Advantages of new knob.

a) It is better from a safety point of view in that the possibility of accidental disturbance of the setting, and damage to operators or to apparatus is greatly reduced.

b) Control panels may be removed without the need to remove the knobs from the spindles of the controls.

c) The general appearance of a panel using these knobs is neater and less cluttered.

Probable Disadvantages of new knob

a) It cannot easily be used for a positional switch or vernier drives because the torque applicable is very small.

b) It is difficult to locate with the hand under adverse conditions such as darkness and inaccessibility.

c) It cannot easily be used below elbow height or at fully extended arm positions.

d) It cannot easily be made dust or water-proof.

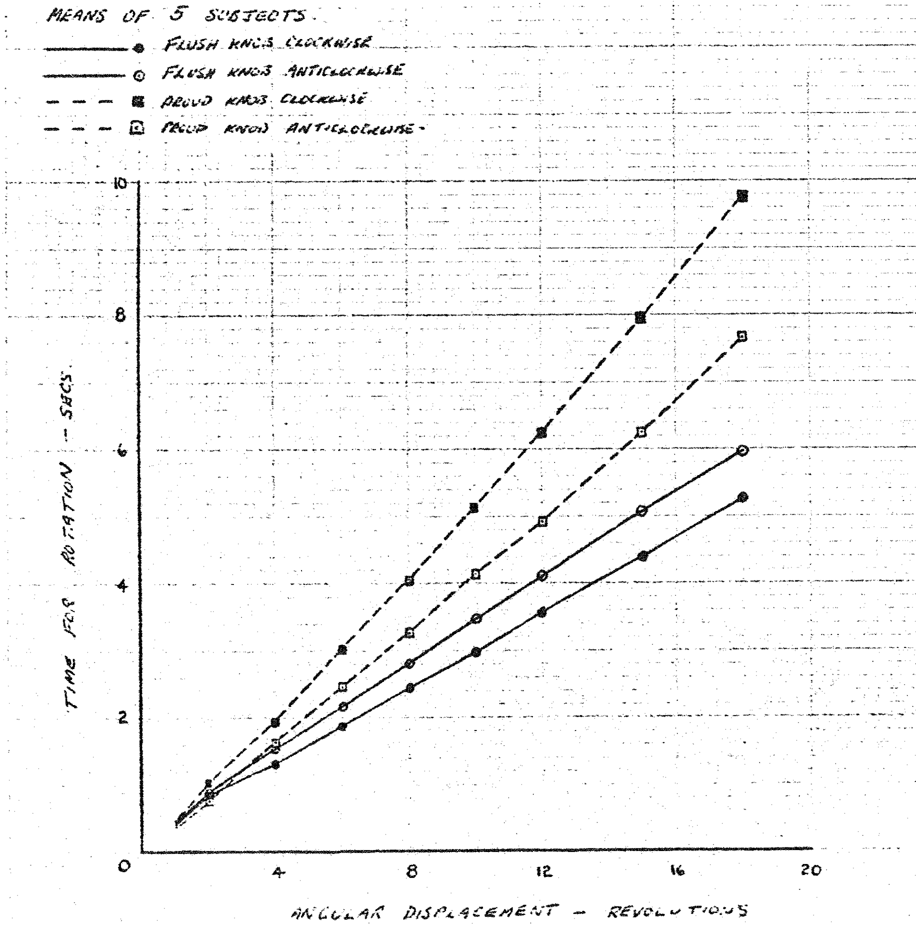
e) Performance in conditions of vibration will be more difficult than for a standard knob.

9. References

1. B. Shackel and J.R. Davis (1962) 'Choosing Control Knobs' Engineering Materials and Design. August 1962.

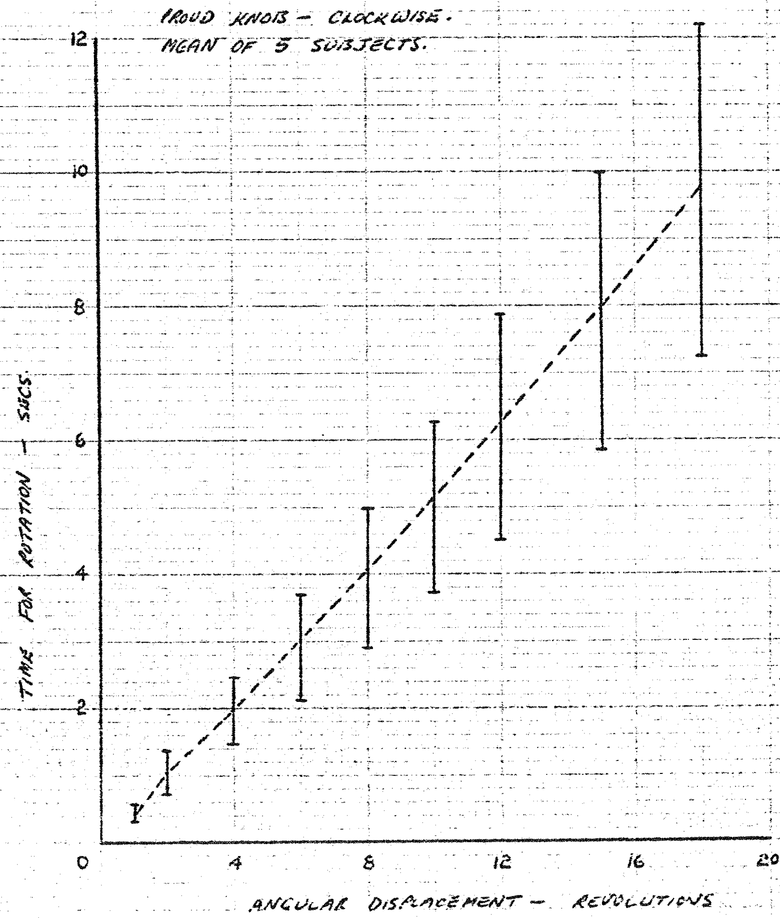
GRAPH 1.

TIME FOR ANGULAR ROTATION.

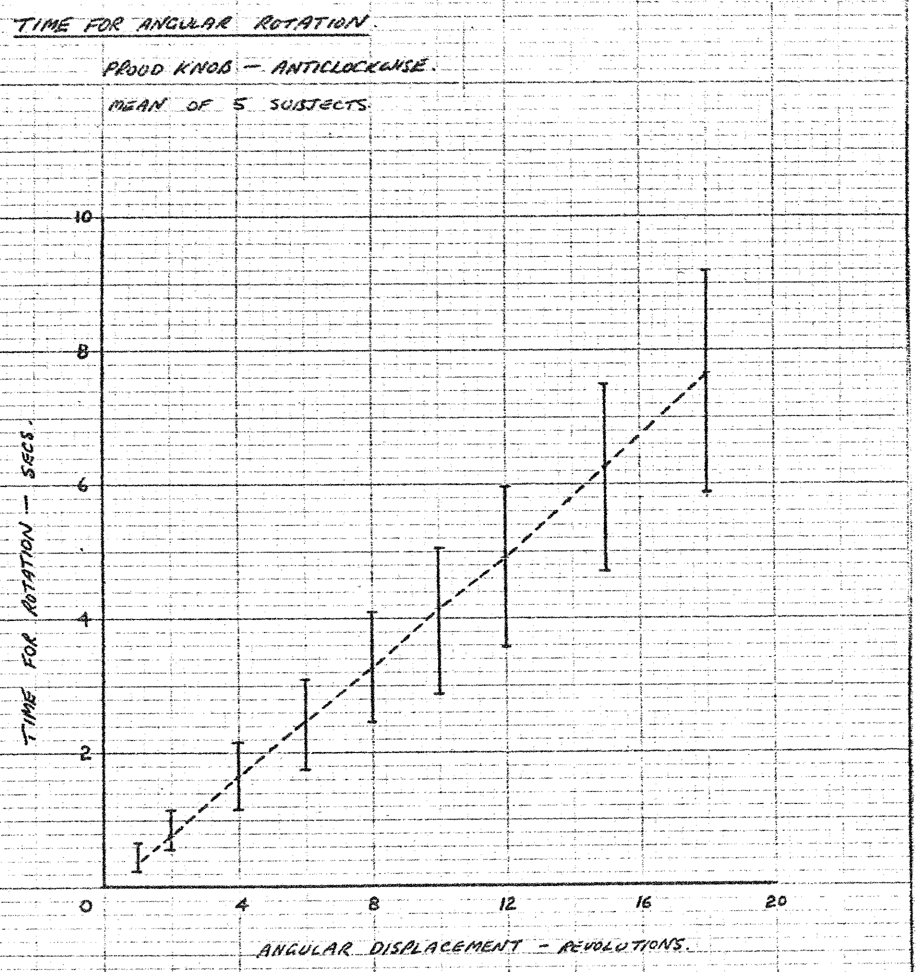


GRAPH 2.

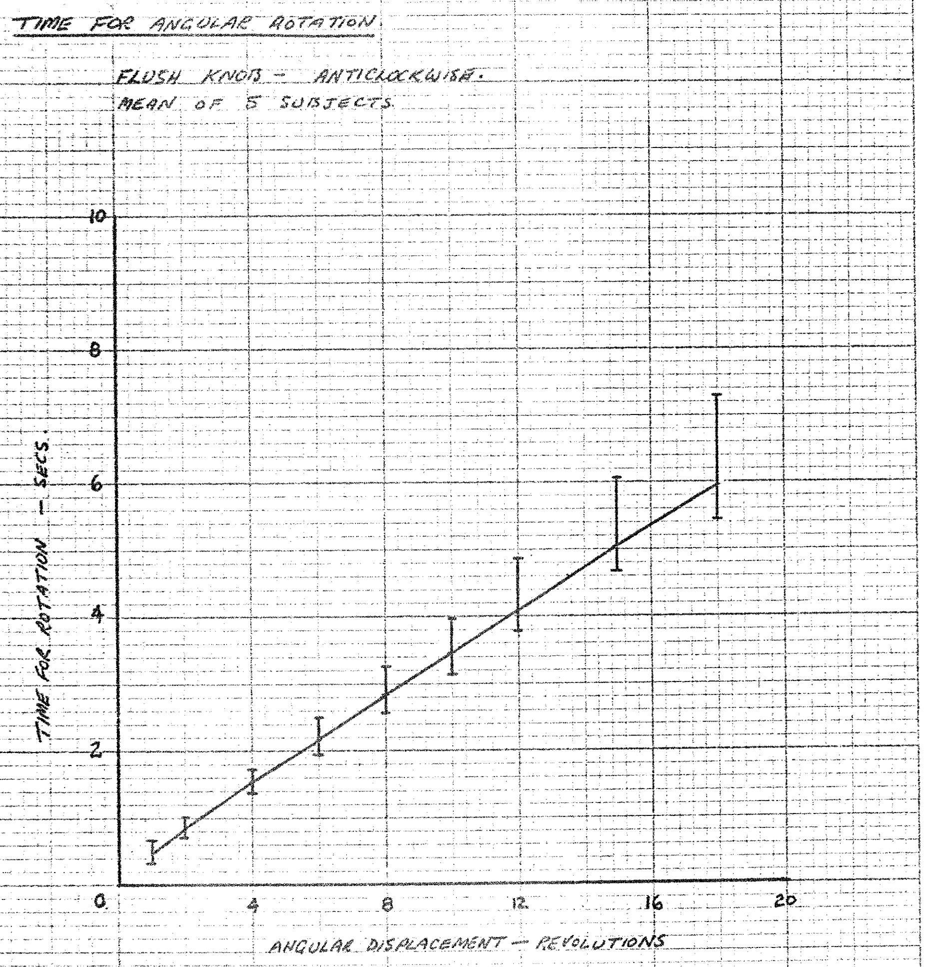
TIME FOR ANGULAR ROTATION.



GRAPH 1.3



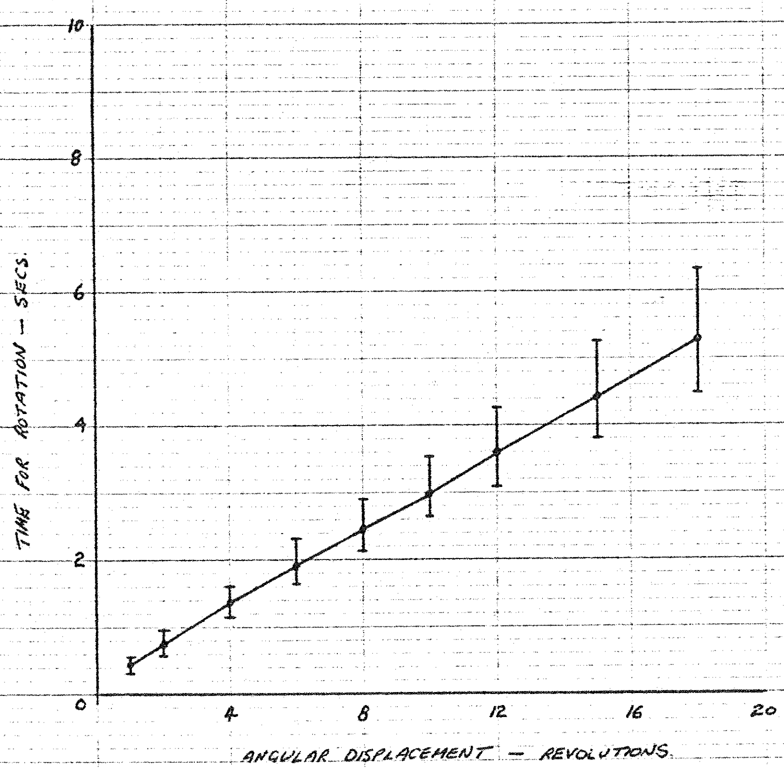
GRAPH 1.4.



GRAPH 1.5.

TIME FOR ANGULAR ROTATION.

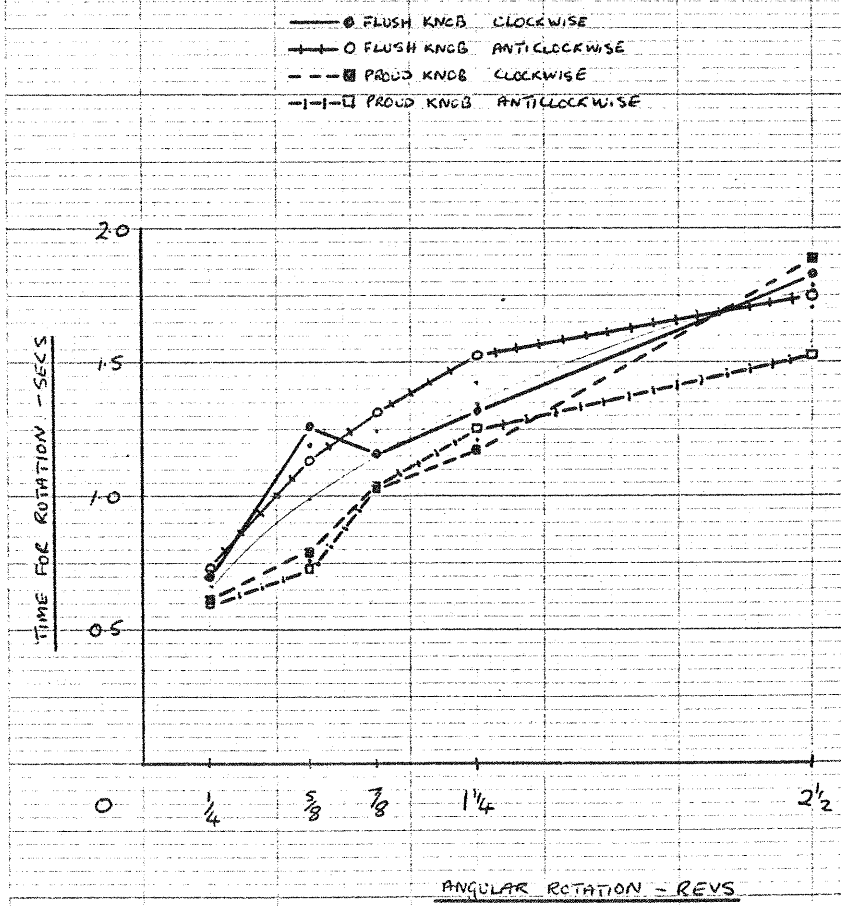
FLUSH KNOB – CLOCKWISE.
MEAN OF 5 SUBJECTS.



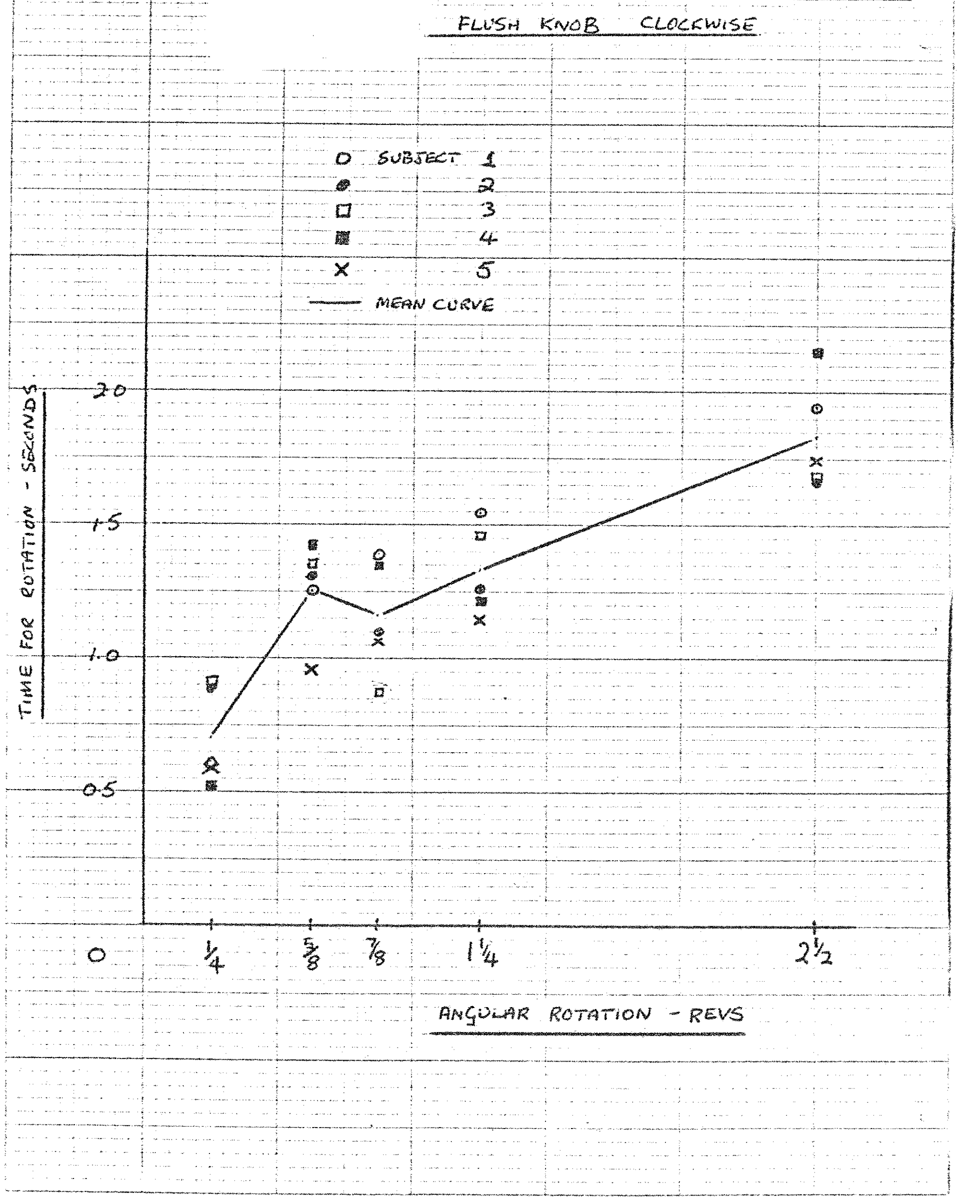
GRAPH I 2.1.

TIME FOR ANGULAR ROTATION

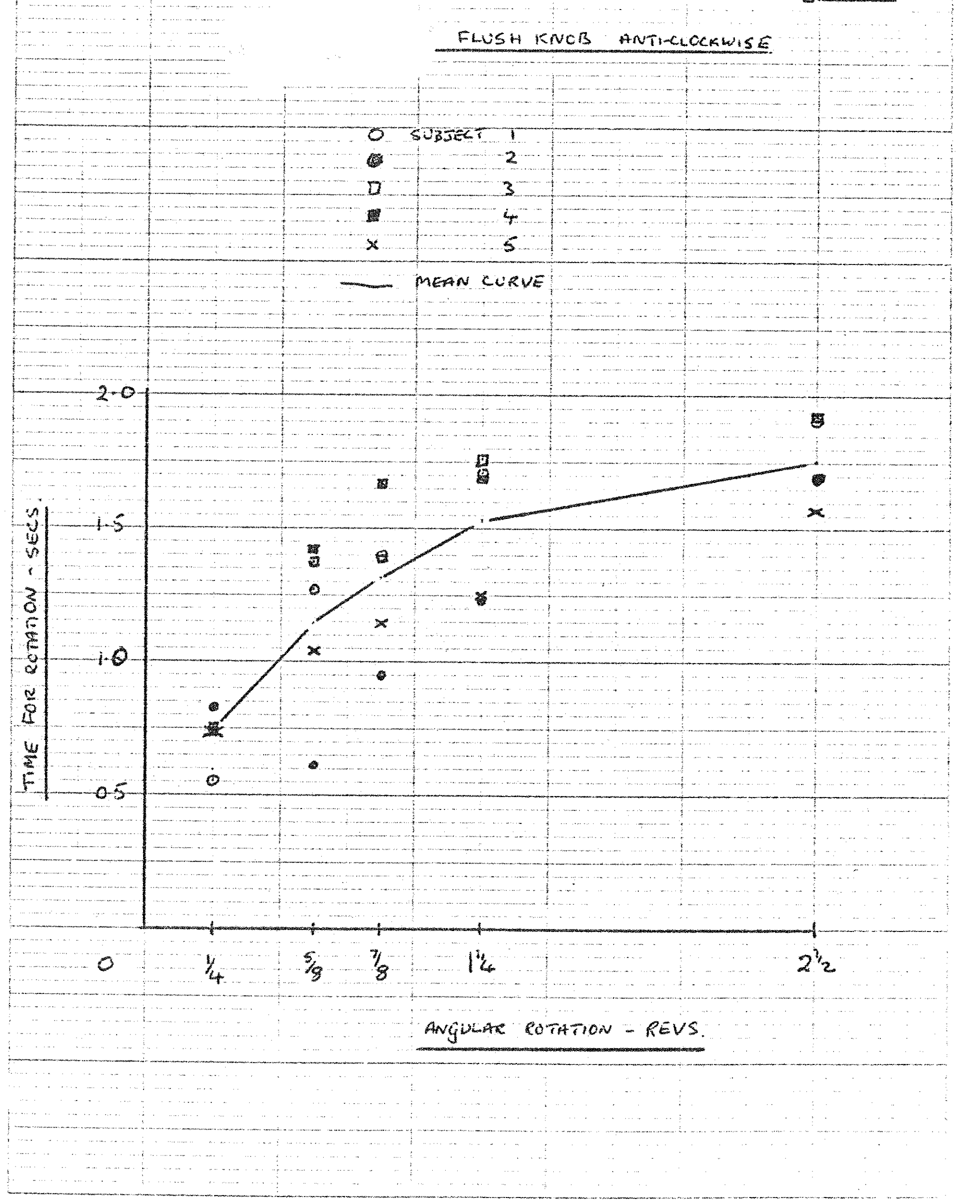
MEANS OF 5 SUBJECTS

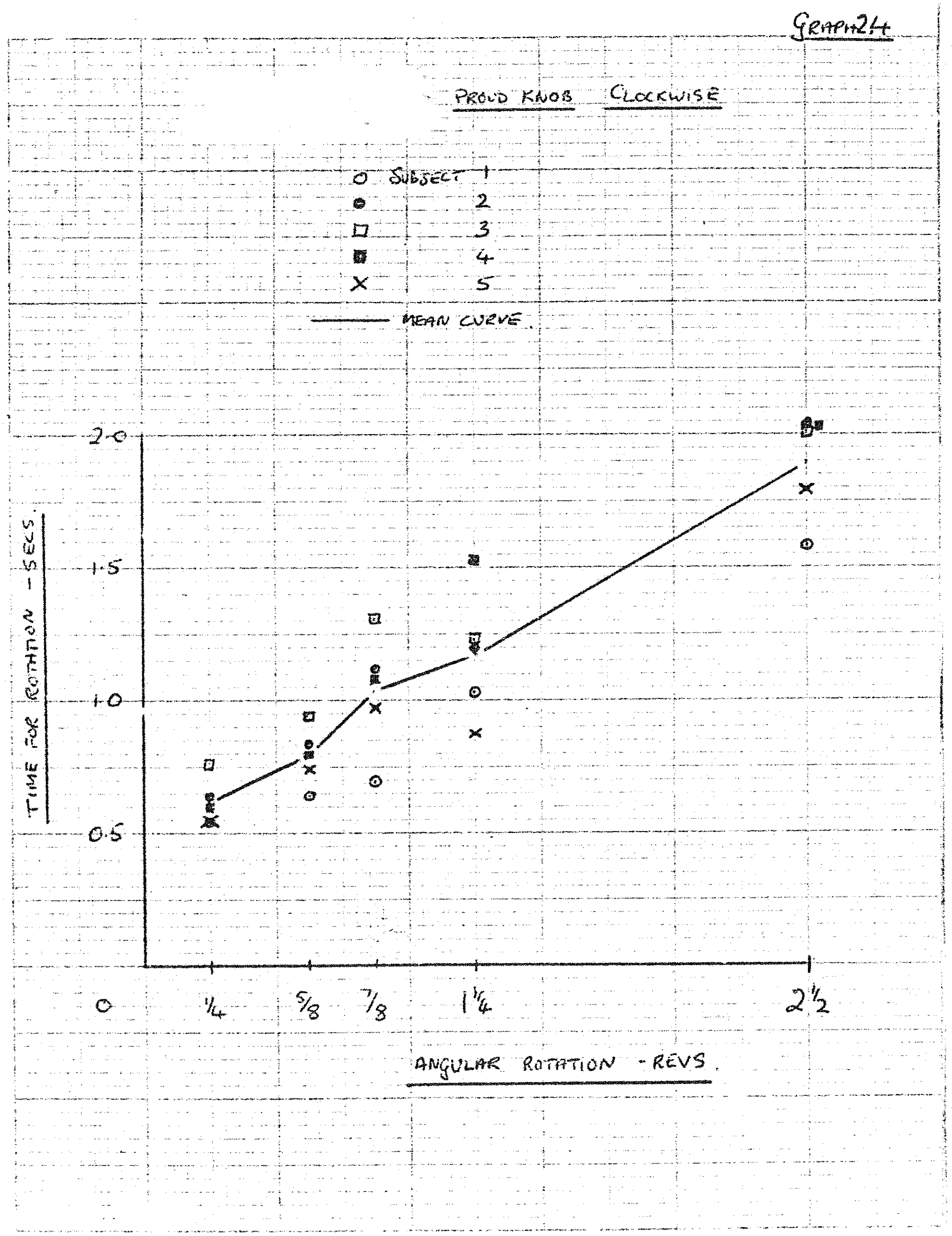


GRAPH 2.2



GRAPH 2.3




GRAPH 24
PROUD KNOB CLOCKWISE
O SUBJECT 1
2
3
4
X 5
MEAN CURVE
TIME FOR ROTATION - SECS.
2·0
1·5
1·0
0·5
0
1/4
5/8
7/8
1 1/4
2 1/2
ANGULAR ROTATION - REVS.

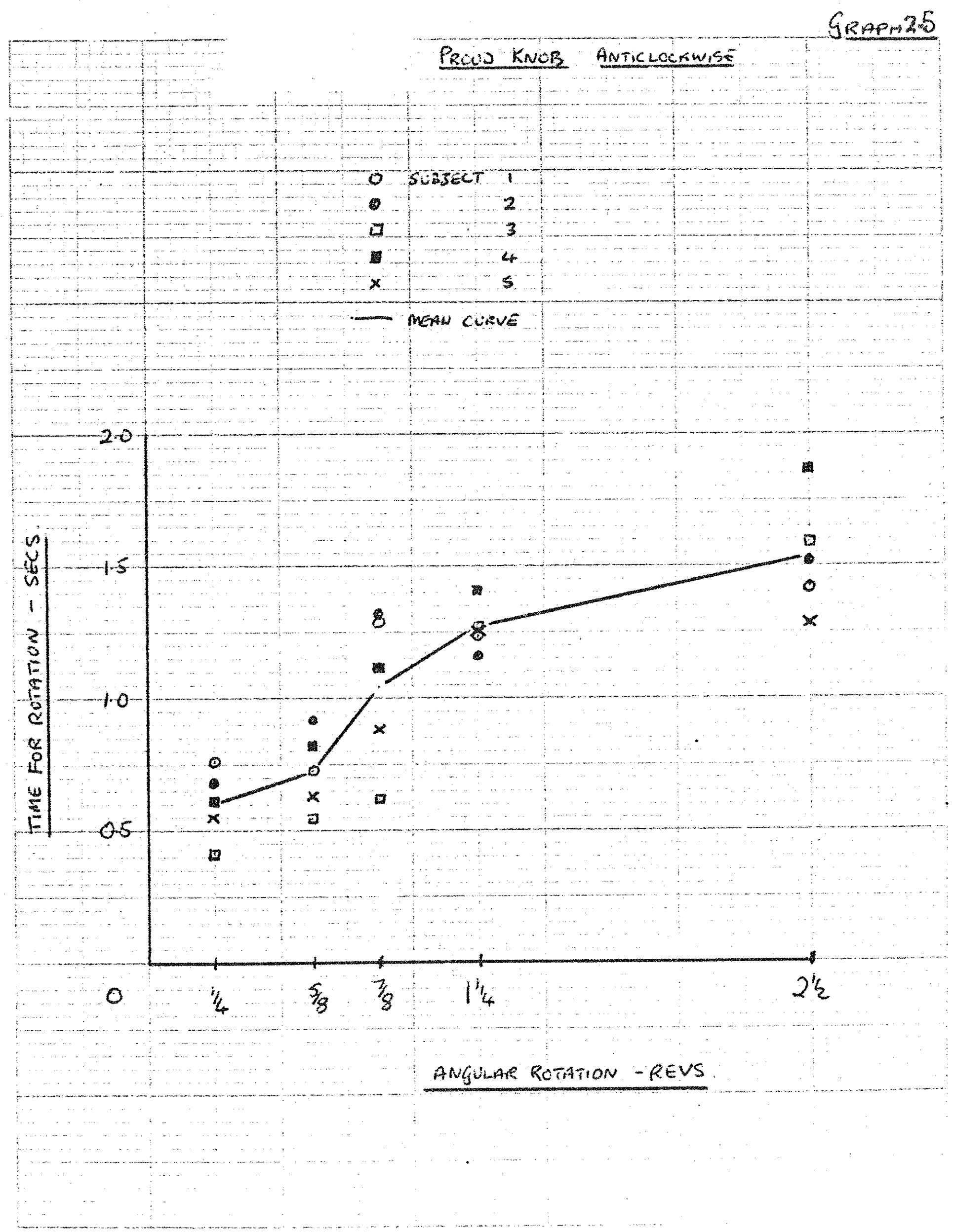

GRAPH 25
PROUD KNOB ANTICLOCKWISE
O SUBJECT 1
2
3
4
x 5
MEAN CURVE
TIME FOR ROTATION - SECS.
2·0
1·5
1·0
0·5
0
1/4
5/8
7/8
1 1/4
2 1/2
ANGULAR ROTATION - REVS.

FIG. 2:1 DIAGRAM OF EXPERIMENTAL APPARATUS

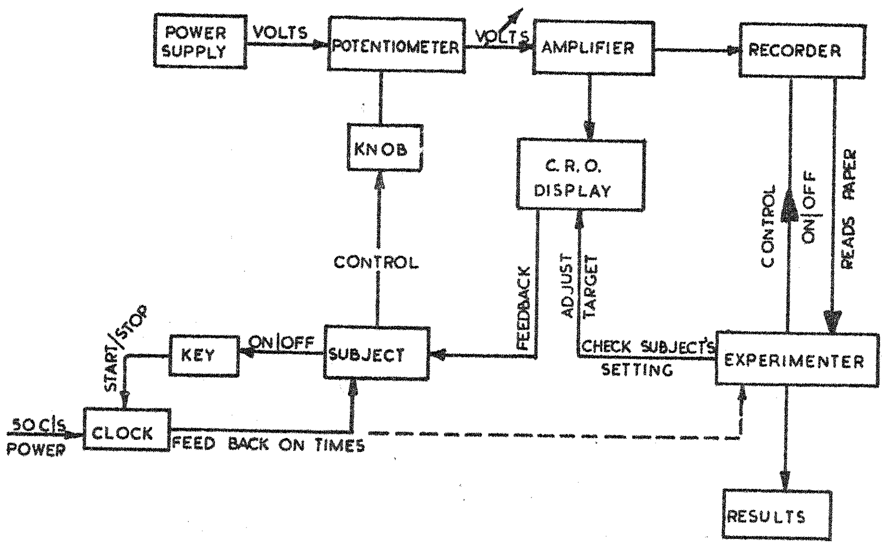


FIG. 2·2 C.R.O.T. DISPLAY