INVESTIGATION OF THE STRENGTH OF SQUARE KEY AS A MEANS OF FASTENING HUBS TO SHAFTS

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LIST OF SYMBOLS

D	Shaft diameter, in.
d	Specimen diameter, in.
d_1	Bolt diameter, in.
F	Force due to torque transmitted, lb.
F'	Force due to resisting couple, lb.
H	Depth of key, in.
h	Depth of beam, in.
I	Moment of inertia (second moment of area), in. units.
L	Length of key, in.
M	Bending moment, in. - lb.
S_{ba}	Allowable stress in bearing, p.s.i.
S_c	Crushing stress, p.s.i.
S_s	Shear stress, p.s.i.
S_{sa}	Allowable stress in shear, p.s.i.
S_t	Tensile stress, p.s.i.
S_y	Yield stress in shear, p.s.i.
T	Torsional moment, lb. - in.
T_c	Torsional moment, from consideration of crushing of the key, lb. - in.
T_s	Torsional moment, from consideration of shearing of the key, lb. - in.
T_y	Yield torque, lb. - in.
t	Thickness, in.
W	Width of key, in.
y	Normal distance of the outer fibre of the beam from the neutral axis, in.

INTRODUCTION

The square key is probably the most common type of key used for fastening hubs to shafts. It is a common practice to keep the width of the key equal to one quarter of the shaft diameter. A question arises about the validity of this proportioning of the key with respect to shaft size?

It was therefore undertaken to test square keys of five different widths - $\frac{D}{2}$, $\frac{D}{3}$, $\frac{D}{4}$, $\frac{D}{5}$ and $\frac{D}{6}$ but of equal theoretical shear strength and to determine the influence of key size on its strength. Shaft diameter, D, was maintained constant for these tests and the keys were a tight fit in the keyway of the shaft as well as the hub.

Another important aspect, which has been considered, is the evaluation of the effect of clearance between key and keyway. For example, in case of the feather keys, which are a tight fit in the shaft keyway and a running fit in the hub keyway, the extent of clearance between key and hub keyway may have significant effect on the torque transmitting capacity of the key.

It was therefore adopted to investigate the influence of clearance between key and hub keyway on the strength of the key. For this purpose three conditions of clearance - 0.000 in., 0.003 in. and 0.006 in. between key and hub keyway, were chosen and the investigation was carried out with the optimum size of key, determined as a result of the first part of the investigation.

The investigation was extended to cover the effect of shaft size on the strength of key. To achieve this object four different shaft sizes were selected and tests were conducted with the optimum size of key and with the above mentioned three conditions of clearance.

SUMMARY

To proceed with the design of the test set-up, it was considered desirable to establish the torsional yield strength of mild steel which was to be subsequently used for the fabrication of the designed parts. Three standard test specimen, made out of the same lot of rolled stock as was used later for the fabrication of test parts, were tested on the torsion testing machine. Torque-twist curves were plotted and an average value of yield strength of the material was determined. A suitable test fixture was then designed so that the test parts could be subjected to a known torque, between the grips of the torsion testing machine.

Consistent with the shape of the grips of the machine, it was found that a maximum of 1 in. diameter shaft could be tested on the machine. The other three shaft sizes were then decided to be $\frac{7}{8}$ in., $\frac{3}{4}$ in. and $\frac{5}{8}$ in. All the test shafts were made in lengths equal to four times the diameter.

The test key lengths were chosen such that their shear strength was half that of the shafts. This adoptation was called for from consideration of the maximum size of test shaft and also the maximum amount of torque which could be applied to the test

fixture, without causing its material to yield.

All test shafts and keys were manufactured out of the same lot of rolled stock. The section chosen had a diameter of $1\frac{1}{8}$ in., from which the maximum shaft size of 1 in. could be machined out. The manufacturing process was kept the same throughout.

The hubs were made in the form of discs of different thicknesses, depending upon the length of the keys tested. Cast iron was chosen as the material for the hubs because of the ease with which different hub lengths could be obtained and also because of its high strength in compression, as compared to mild steel.

In order to determine the accurate value of torque to which the test parts were subjected, the machine scale was calibrated. This was achieved by applying a known torque to the machine and noting the corresponding reading on the machine scale. A torsion beam, which could be fixed in the rigid grip of the machine, was specially fabricated for this purpose. A calibration curve was then plotted from a set of observations and thus the true value of torque could be found for any observation on the machine scale. This procedure was repeated before each set of tests, performed on any day.

To obtain a more accurate torque-twist curve, the observations were taken at a closer interval of twist than provided for by the markings on the machine. For this purpose additional graduations were marked on the machine. To ensure reproducibility of the data, each test was replicated with three similar test parts and the results were rationalized.

The analysis of the test results enabled the following conclusions to be drawn:-

The optimum size of square key is for width equal to one quarter of the shaft diameter. The strength of the key is not decreased on account of clearance in hub keyway upto a magnitude of 0.006 in. There is, however, a decrease of strength as the clearance is increased from 0.003 in. to 0.006 in. The key strength increases with the reduction in shaft size, irrespective of the clearance in hub keyway.

FORCES ON KEY
DUE TO
TRANSMITTED TORQUE

FIG. 1.1

CHAPTER - I

DESIGN PROCEDURE

1.1 THEORETICAL ASPECTS:

The forces acting on a square key, which is tight fit in the keyway of the shaft as well as the hub, are shown in FIG. 1.1.

Since the line of action of the resultant forces F on the key can not be exactly determined, an assumption is made that they act at the surface of the shaft.(1)

The transmitted torque, $T = F \cdot \frac{D}{2}$

The compressive force F, due to transmitted torque, which acts on the surfaces a b and d e calls for a resisting couple acting on the surfaces c d and a f. This resisting couple is indicated in FIG. 1.1 by equal and opposite forces F'.

The strength of the key, based on shearing of the longitudinal cross-section, is given by —

$$T_s = F \cdot \frac{D}{2} = W \cdot L \cdot S_s \times \frac{D}{2}$$

And the strength of the key, based on crushing of the sides, is given by —

$$T_c = F \cdot \frac{D}{2} = \frac{H}{2} \cdot L \cdot S_c \times \frac{D}{2}$$

For the two strengths to be equal,

$$T_s = T_c$$

i.e. $$W \cdot L \cdot S_s \cdot \frac{D}{2} = \frac{H}{2} \cdot L \cdot S_c \cdot \frac{D}{2}$$

or $$W \cdot 2\, S_s = H \cdot S_c$$

It can, therefore, be seen that if the key is made of Mild Steel for which $S_c = 2\, S_s$ approximately, $W = H$ for equal strength of the key in shearing as well as crushing. Thus a square key is the most appropriate shape from consideration of strength.

For the key to be made out of the same material as that of the shaft, the length of the key required to transmit the full torque capacity of the shaft is determined by equating the shear strength of the key to the torsional shear strength of the shaft.

Hence, $$W \cdot L \cdot S_s \cdot \frac{D}{2} = \frac{\pi}{16} \cdot D^3 \cdot S_s \times 0.75$$

The factor 0.75, recommended by the code for Transmission Shafting, U.S.A.,[2] has been introduced on the R.H.S. of the equation in order to take into account the weakening effect of the keyway in the shaft.

If the width of the key is taken as equal to $\frac{D}{4}$,

$$L = \frac{\pi}{2} \cdot D \times 0.75$$

$$= 1.18\, D$$

However, while proportioning the test parts, key length was kept as half of this theoretical value, in case of keys with width equal to $\frac{D}{4}$. This was done in order to keep the shear strength of the keys as half that of the shafts. This adoptation was called for from consideration of the maximum size of the shaft which could be tested in the test-fixture fabricated for the purpose. The torsion end-pieces of the test-fixture could have a maximum shaft diameter of 1 in., which was also kept as the maximum size of the shafts to be tested.

In case of the keys which had the sides of the square cross-section of some other proportion than $\frac{D}{4}$, the length of any particular key was determined by keeping the shear area same in both the cases.

1.2 TORSIONAL YIELD STRENGTH OF MATERIAL:

To proceed with the design, it was considered desirable to establish the torsional yield strength of the mild steel which was to be subsequently used for fabrication of the test parts.

Three standard specimen of the mild steel were tested on the torsion testing machine and the results were plotted on graph paper. It was found from the torque-twist curves that yielding of the specimen occured at an average torque of 2468 lb. - in.

The yield point stress, $S_y = \frac{16 \cdot T_Y}{\pi \cdot d^3}$

Hence, for the specimen diameter of $\frac{13}{16}$ in.,

$$S_y = \frac{16 \times 2458}{\pi \times 0.54} \text{ p.s.i.}$$

$$= 23{,}200 \text{ p.s.i.}$$

1.3 TORSION END PIECES AND BOLTS:

The maximum size of the shaft between the grip end and the flange could be 1 in., from consideration of the shape of the grips of the torsion testing machine. This portion of the torsion end pieces was never allowed to yield during the course of experimentation.

The maximum loading of the end pieces would occur while testing the largest size of shafts, i.e. of 1 in. diameter.

Torque required to yield the keys, while testing 1 in. diameter shafts

$$= W . L . 23{,}200 \times \frac{D}{2}$$

$$= \frac{D}{4} . 0.59\,D . 23{,}200 \times \frac{D}{2}$$

$$= \frac{0.59 \times 23{,}000}{8} . D^3$$

$$= 1712.5 \text{ lb.-in.}$$

In order to obtain a torque-twist plot beyond the yield point, let the maximum amount of torque that might be applied to the test fixture be taken as 2,250 lb.-in.

Considering the maximum size of test-shaft, i.e. of 1 in. diameter, the number of bolts for fastening the torsion end piece flange were adopted to be 3. This choice is in agreement with the recommendation made by Maleev & Hartman.[3] The bolt circle diameter was established from the layout drawing as $2\frac{7}{8}$ in.

For shearing of the bolts,

$$2,250 = 3 \times \frac{\pi}{4} d_1^2 \cdot S_{sa} \times \frac{23}{8} \times \frac{1}{2}$$

Taking S_{sa} = 6,000 p.s.i. for mild steel

$$d_1 = 0.333 \text{ in., say } \frac{3}{8} \text{ in.}$$

The flange thickness was kept equal to the diameter of the bolts, i.e. $\frac{3}{8}$ in.

Considering bearing pressure on the flange or crushing at the bolts,

$$2,250 = 3 \times d_1 \cdot t \cdot S_{ba} \times \frac{1}{2} \cdot \frac{23}{8}$$

$$= 3 \times \frac{3}{8} \cdot \frac{3}{8} \cdot S_{ba} \times \frac{1}{2} \cdot \frac{23}{8}$$

or S_{ba} = 3,720 p.s.i., which is quite safe for mild steel.

Also considering shearing of the flange at 1 in. diameter,

$$2,250 = \pi \cdot 1 \cdot \frac{3}{8} \cdot S_{sa} \times \frac{1}{2}$$

or S_{sa} = 3,820 p.s.i., which is again quite safe for mild steel.

The outside diameter of the flange was decided from the layout drawing as $3\frac{3}{4}$ in.

Spigot and socket centring was provided for proper alignment of the bolted hubs to the end piece flanges. Also, in order that each bolt carried an equal share of load, the bolt shanks were machined accurately and the holes in the flanges were reamed. The bolt lengths were decided from consideration of the lengths of the different hubs which had to be fastened to the end piece flanges, and were determined from layout sketches. Two sets of bolts were required — one for 1 in. diameter shaft assembly and the other for the remaining three shaft size assemblies.

The shop drawings of the torsion end pieces and the two sets of bolts — B-1, A-2 and A-27, may be seen in APPENDIX - C.

1.4 SHAFTS AND HUBS:

The length of each test-shaft was kept four times its diameter. This proportion gave sufficient space to accommodate the nuts on the bolts, which were used to fasten the hubs to the torsion end pieces. Four different shaft sizes of 1 in., $\frac{7}{8}$ in., $\frac{3}{4}$ in. and $\frac{5}{8}$ in. were chosen for the purpose of testing.

The shape of the hubs was a departure from the conventional one. Discs of thicknesses equal to the length of the different keys and of outside diameter equal to that of the torsion end piece flanges, served the purpose of hubs. Each hub was provided with a mating socket for receiving the spigot on the torsion end piece and three reamed holes, symmetrically placed on the pitch circle diameter, were provided for the purpose of bolting.

Each test shaft was fastened at its ends to two different hubs with the help of keys. At one end the test key was placed, while at the other a taper key of shear strength equal to that of the shaft was placed. The taper key was also of square cross-section with sides equal to $\frac{D}{4}$ and was provided with a gib head. One such key and one corresponding hub were required for the entire set up of one shaft size.

The shop drawings of the test shafts, hubs and keys have been placed in APPENDIX - C, and bear numbers from A-3 to A-26.

CHAPTER - II

FABRICATION OF TEST PARTS

2.1 CHOICE OF MATERIAL:

All the shafts and keys used for the purpose of tests were manufactured out of the same lot of rolled stock. $1\frac{1}{8}$ in. round section was chosen, from which the maximum shaft size of 1 in. could be machined out.

The hubs were made of gray close-grained Cast Iron. This choice was made because of the ease with which the material could be cast into the desired shape, machinability and high strength in compression, the latter being approximately twice that of Mild Steel.(4)

2.2 FABRICATION METHODS:

The keyways on the shafts were cut on the milling machine with a side-milling cutter. The keyways in the hubs were made by hand-filing, since they could not be produced to the desired accuracy by any machine in the workshop. The keys were also finished by hand-filing owing to the difficulty in accurately machining, the relatively small size keys, with the machines available in the workshop.

The alignment of the bolt holes in the torsion end pieces and the hubs was enabled by a hole-reaming jig, which was specially fabricated for the purpose. The shop drawing of the jig — A-1, is placed in APPENDIX - C. The jig could be screwed on to the face of the torsion end piece flange or the hub disc while reaming the holes. It also served as a quick means for marking centres of the holes.

The allowances and the tolerances, provided in dimensioning the shafts and the mating holes in the hubs, were determined for the condition of "medium fit".[5]

The taper provided on the gib head keys was 1 in 100.

2.3 SHOP DRAWINGS USED IN FABRICATION:

The shop drawings of the bolt hole reaming jig, test fixtures and test parts are placed in APPENDIX - C and bear numbers A-1 thru A-27 & B-1.

CHAPTER - III

CALIBRATION OF THE MACHINE

3.1 DESIGN OF CALIBRATION SET-UP:

In order to determine the actual value of torque applied to the test parts, it was considered desirable to calibrate the machine scale observations.

The maximum expected value of yield torque was 1712.5 lb.-in., as calculated earlier for tests with 1 in. diameter shafts. A set-up which would enable calibration of the machine scale readings upto 2,000 lb.-in. would be sufficient.

The known torque was applied to the machine by means of a torsion beam which was equally loaded in opposite directions at the ends. The torsion beam had a torsion piece welded at its centre, which was of the same shape as that of the grip end of a standard test-specimen of the machine. The beam could thus be held in the rigid grip of the machine. Loading of the beam equally, but in opposite directions, was enabled by putting the load vertically downwards at one end and pulling the other end vertically upwards with an equal force. This was achieved by providing two loading loops near the ends of the torsion beam. At one end a loading pan was suspended from the loop and known weights could be placed on the pan. At the other end the loading loop was attached to one end of a wire rope which was passed round a pulley, held on angle iron frame, and a loading pan was attached to its other end. During the course of loading of the torsion beam, known weights of equal magnitude could be placed on the two pans.

It was decided to have the distance between the two points of loading as 40 in., such that a maximum weight of 50 lb. was required at each end to provide the maximum torque of 2,000 lb.-in. A $1\frac{1}{2}$ in. x $\frac{1}{2}$ in. thick section was selected for the torsion beam. The section was checked for bending due to loading as well as for shearing at the $\frac{13}{16}$ in. diameter, which was the effective diameter of the torsion piece welded at the centre of the beam.

For bending of the beam,

$$M = S_t \cdot \frac{I}{y}$$

$$= S_t \cdot \frac{t \cdot h^2}{6}$$

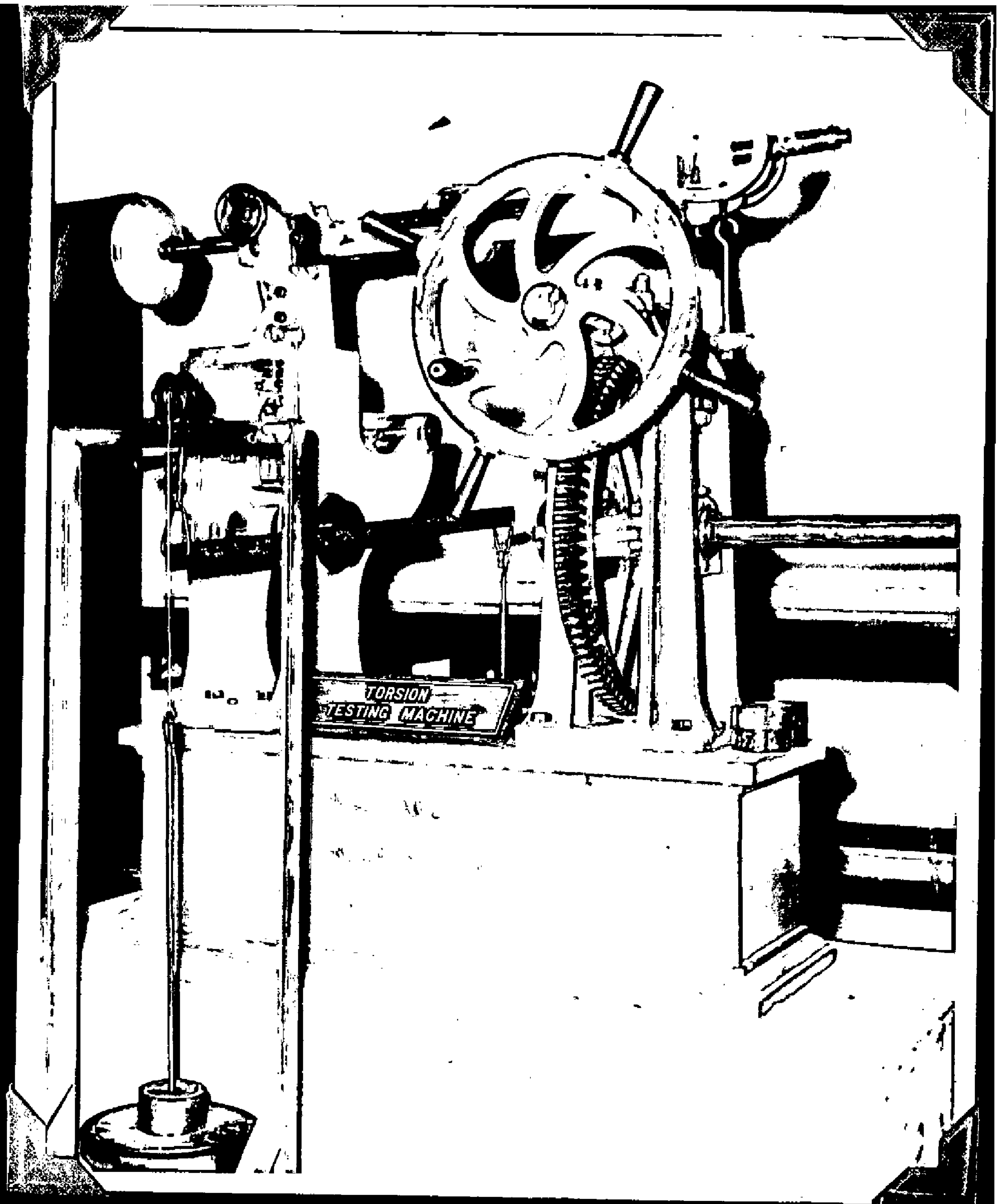
or $$1000 = S_t \cdot \frac{1}{2} \cdot \frac{(1.5)^2}{6}$$

or $S_t = 5340$ p.s.i., which is quite safe for mild steel.

For shearing at $\frac{13}{16}$ in. diameter,

$$2000 = \pi \cdot \frac{13}{16} \cdot \frac{1}{2} \cdot S_s \times \frac{1}{2} \cdot \frac{13}{16}$$

or $S_s = 3860$ p.s.i., which is again quite safe.



CALIBRATION SET UP IN POSITION ON THE MACHINE

FIG. 3.1

Shop drawings A-28 thru A-30 & B-2, placed in APPENDIX-C, illustrate the details and assembly of the torsion beam. In FIG. 3.1 a general view of the calibration set-up has been shown in position on the machine. The angle iron frame, supporting the C.I. pulley of an effective diameter $1\frac{1}{2}$ in., was 46 in. high above the floor and had a space of 14 in. between the vertical members. The frame had supporting legs near the base to maintain it in the vertical position. The frame was of welded construction, from $1\frac{1}{4}$ in. x $1\frac{1}{4}$ in. x $\frac{1}{4}$ in. thick angle section.

3.2 CALIBRATION PROCEDURE:

The machine was calibrated before each set of experiments, on any day. The microscope mounted on the machine was adjusted to read zero on the scale attached to the free end of the lever arm, when the lever arm was set horizontal with the help of a spirit level. The torsion piece, which formed an integral part of the torsion beam, was then inserted in the rigid grip of the machine and loading pans were put in position at the two ends. The machine scale was made to read zero and the balance weight on the lever arm was adjusted till zero was observed in the centre of the field of view. The set-up was now ready for physical loading and in the process of zero setting of the machine, any effect due to difference of weights of the loading pans was cancelled out. Known weights of equal magnitude were put on both the pans simultaneously and the slide block with vernier graduations was moved along the arm by handwheel control. This was done till 'zero' was spotted out in the centre of field of view of the microscope. The machine scale reading at this instant was noted. A series of such observations were taken in order to calibrate the machine in the desired range.

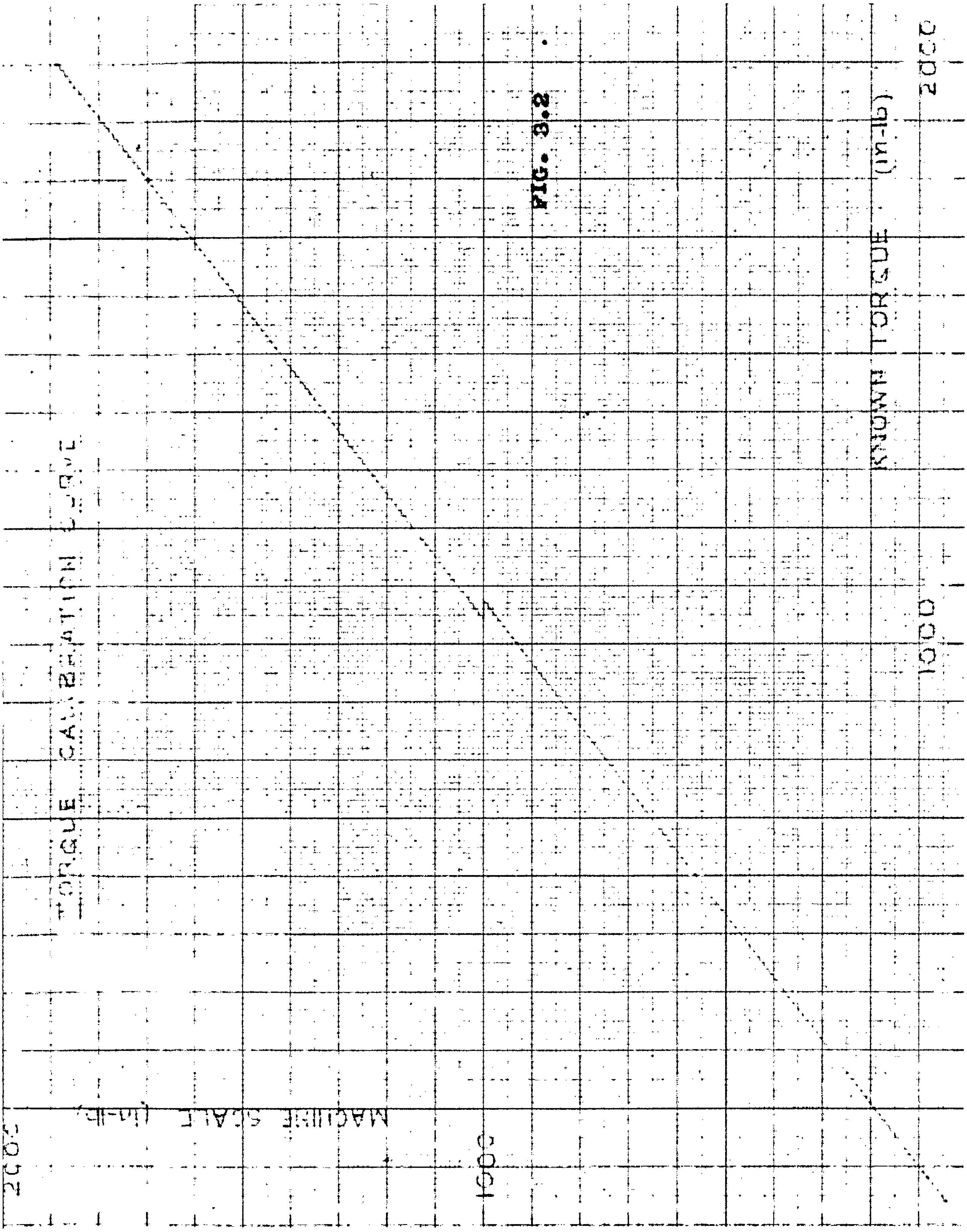
A sample of observations taken for the purpose of calibration are shown in TABLE 3.1.

TABLE - 3.1

Sample observations for calibration of the machine

Loading at the ends of the torsion beam lb.	Machine scale reading of torque lb.-in.	Known value of torque lb.-in.
1	44	40
2	81	80
5	192	200
10	362	400
15	562	600
20	747	800
25	930	1000
30	1150	1200
35	1330	1400
40	1506	1600
45	1696	1800
50	1886	2000

The observations were plotted on graph paper and the calibration curve obtained is illustrated in FIG. 3.2. From this curve the true value of torque can be found for any machine scale observation, within the range of calibration.



TORQUE CALIBRATION CURVE
KNOWN TORQUE (in-lb)
2000
1000
MACHINE SCALE (in-lb)
2000
1000

FIG. 3.2

CHAPTER - IV

TESTING

4.1 THE MACHINE AND ITS ADJUSTMENT:

The tests were performed on the torsion testing machine installed in the Material Testing Laboratory of the University of Roorkee. The machine had a capacity of 10,000 lb.-in. and could handle test specimen upto 1 in. diameter and 12 in. long. The makers of the machine were W. & T. Avery Ltd., Birmingham.

The machine was of lever-arm type construction. At the free end, the arm carried a graduated scale, the markings of which were observed through a microscope. Zero setting was achieved by means of a balance weight, which could adjust the beam in horizontal position. While taking observation of the value of torque, to which the test parts were subjected, a slide block with vernier graduations could be moved across the length of the arm through manually operated geared system. The vernier arrangement enabled the observations to be taken upto an accuracy of 1 lb.-in.

The twist was applied to the test specimen by holding it at the two ends in the grips of the machine. One of the grips was held rigidly while the other was given rotation by providing motion to a worm wheel through rotation of a worm, whose spindle carried a hand wheel. One quarter rotation of the hand wheel corresponded to 1 degree of twist of the test specimen. To obtain a larger number of points for the plot of the Torque-Twist Curve, it was decided to take observations at an interval of 0.25 degree and for this purpose additional markings were done on the machine.

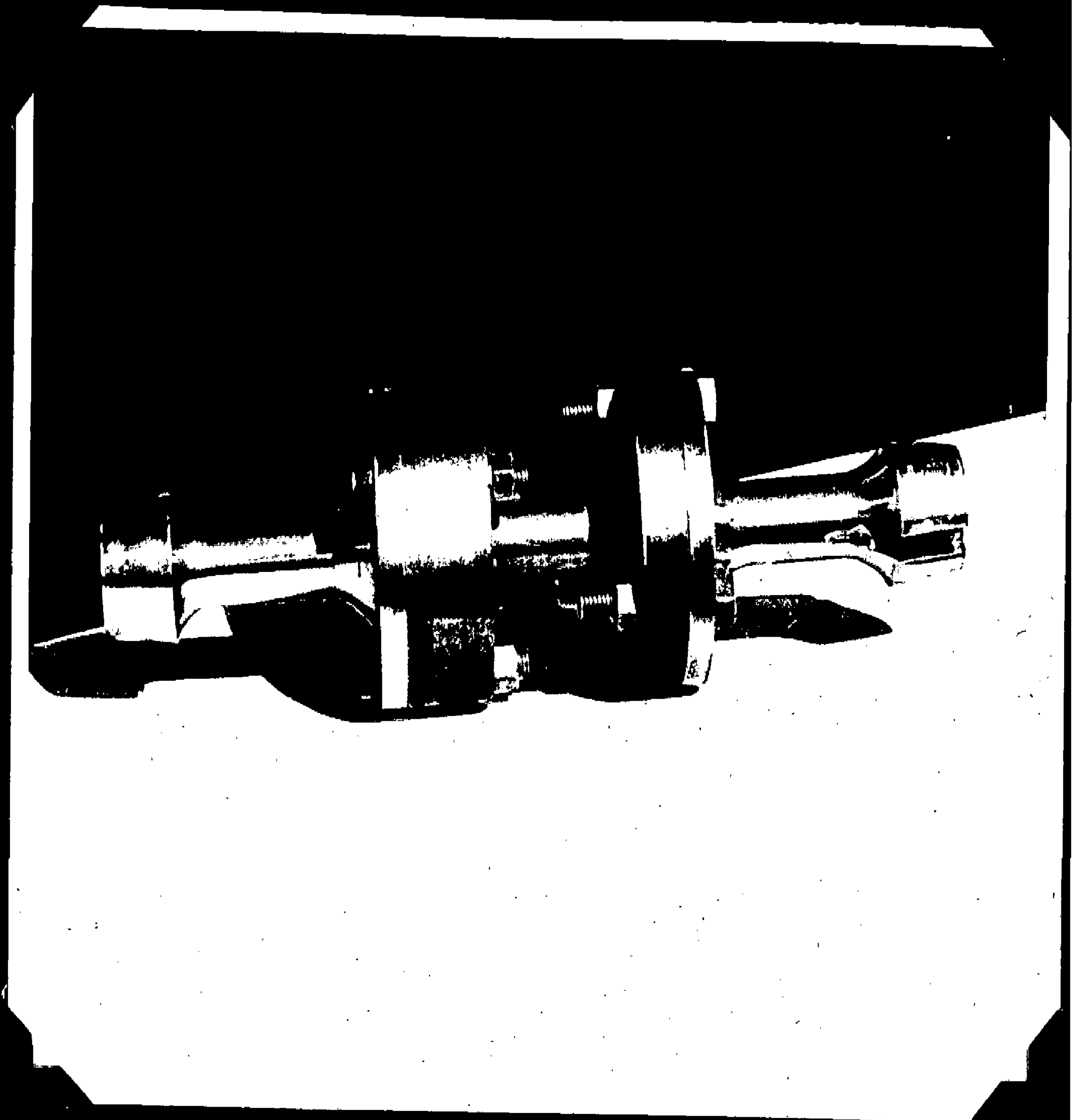
Each time a test was conducted, the lever arm of the machine was made perfectly horizontal with the help of a spirit level. The microscope was then adjusted such that 'zero' on the graduated scale was located in the centre of the field of view. The spirit level was then removed and the torque scale was set at zero by sliding the vernier block. The balance weight was then adjusted such that 'zero' was again obtained in the centre of the field of view through the microscope. This corresponded to the zero setting of the torque measurement.

4.2 METHOD OF TESTING:

The test set up for any particular shaft size consisted of — the shaft; the test key & the corresponding hub; the taper key & the corresponding hub; and the torsion end pieces & a set of six bolts, suitable for the assembly. The set up was assembled together and put between the grips of the machine for the purpose of testing.

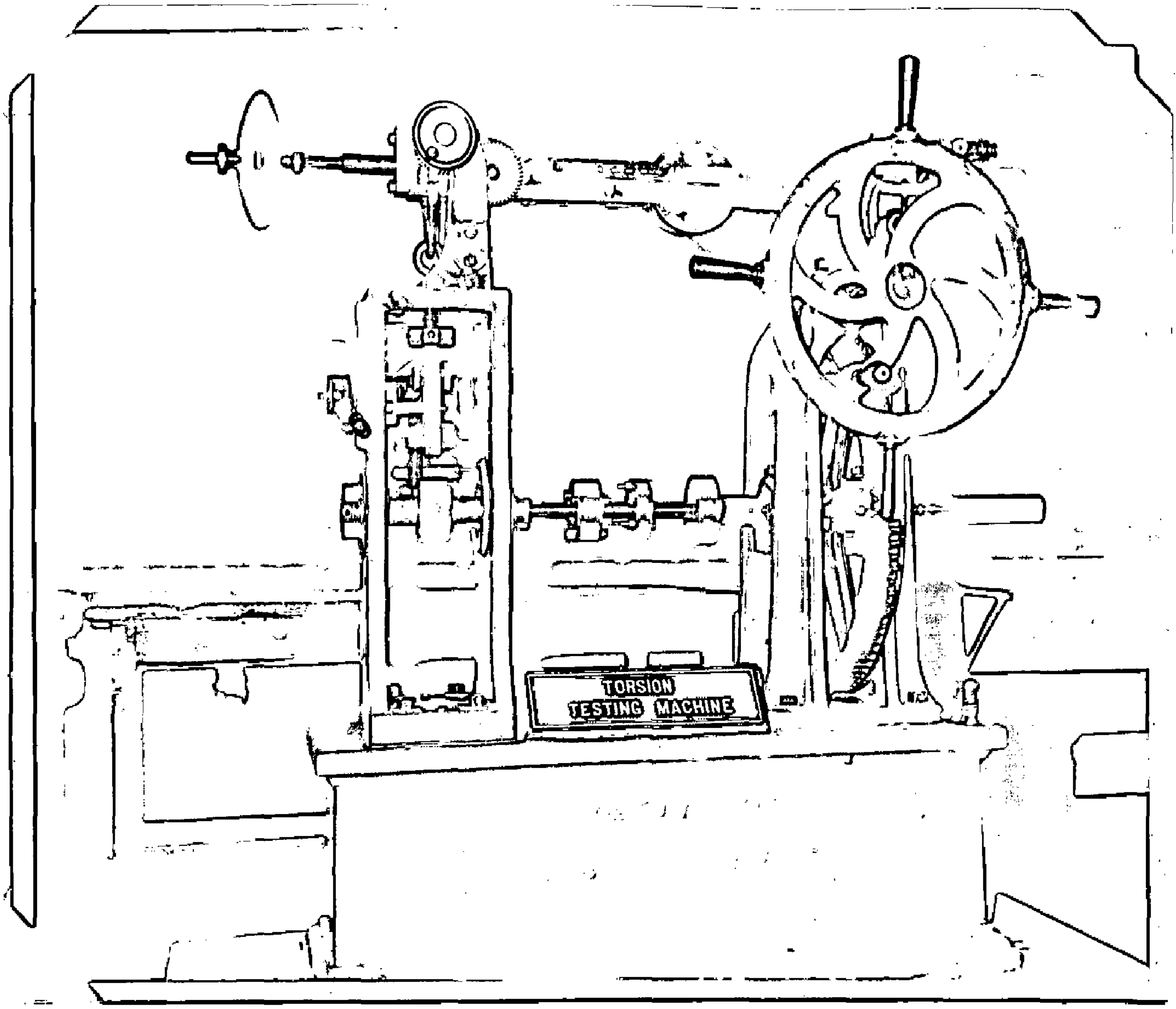
FIG. 4.1 shows the test assembly for a 1 in. diameter shaft with a test key of $\frac{D}{4}$ size. A sectional view of the assembly is illustrated in shop drawing C-1, placed in APPENDIX-C. FIG. 4.2 shows the same assembly in position on the machine.

Each test was replicated with three similar test parts and the results were rationalized.



TEST ASSEMBLY FOR 1 in. DIAMETER SHAFT
WITH A TEST KEY OF $\frac{D}{4}$ SIZE

FIG. 4.1



[illegible] ASSEMBLY FOR 1 in. DIAMETER SHAFT IN POSITION ON THE MACHINE

FIG. 4.2

CHAPTER - V

TEST RESULTS AND THEIR ANALYSIS

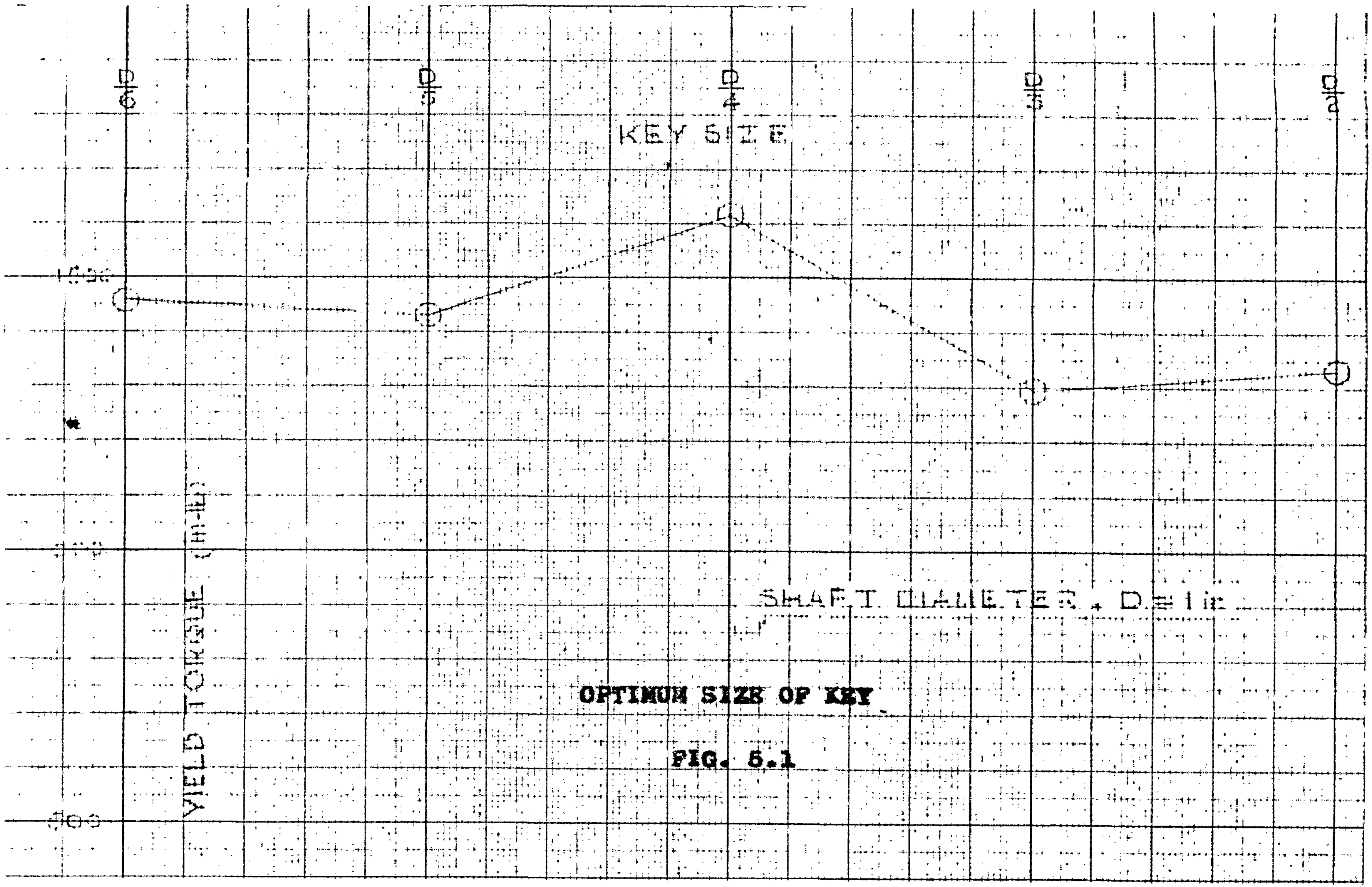
5.1 THE DATA FROM THE TESTS:

The data obtained during different tests has been presented in the TABLE I thru XVI, placed in APPENDIX - A. The tables also contain the calibrated values of torque corresponding to each observation.

The calibrated values of torque in lb.-in. have been plotted against twist in degrees, as shown in FIG. I thru XVI placed in APPENDIX - B. The yield point of a specimen has been marked with a small circle on these curves. The magnitudes of yield torque were noted for the three specimens, for which each test was conducted, and the results were rationalized. The net results obtained in this manner have been presented in the following analysis.

5.2 EFFECT OF KEY SIZE ON THE STRENGTH:

The shaft diameter was maintained constant during the tests, its size being 1 in. Also, the keys were a tight fit in the keyways of the shaft as well as the hub. TABLE 5.1 shows the values of yield torque found for different sizes of the key and the corresponding plot has been shown in FIG. 5.1.



OPTIMUM SIZE OF KEY

FIG. 5.1

TABLE - 5.1

Values of yield torque for different sizes of the key

KEY SIZE	YIELD TORQUE lb.-in.
$\frac{D}{6}$	1458
$\frac{D}{5}$	1430
$\frac{D}{4}$	1616
$\frac{D}{3}$	1292
$\frac{D}{2}$	1340

The optimum key size, i.e., the proportion which gives the highest strength for a given shaft size, is observed to be $\frac{D}{4}$. This tallies with the practice prevalent in the industry.

5.3 EFFECT OF SHAFT SIZE AND HUB KEYWAY CLEARANCE ON THE STRENGTH:

The tests were conducted for the optimum size of key and with four different shaft sizes of 1 in., $\frac{7}{8}$ in., $\frac{3}{4}$ in. and $\frac{5}{8}$ in. Three conditions of clearance — 0.000 in., 0.003 in. and 0.006 in., were evaluated in each shaft size.

The theoretical value of yield torque, T_y, for a test key which is tight fit in the keyways and corresponds to a shaft size D, is given by -

$$T_y = L.\ W.\ S_y \times \frac{D}{2}$$

$$= 0.59\ D \times \frac{D}{4} \times 23{,}200 \times \frac{D}{2}\ \text{lb.-in.}$$

$$= 1712.5\ D^3\ \text{lb.-in.}$$

The values of T_y have been worked out for the four different sizes of shafts and are given in TABLE - 5.2

TABLE - 5.2

Calculated values of yield torque for test keys

SHAFT SIZE in.	CALCULATED YIELD TORQUE lb. - in.
1	1712.5
$\frac{7}{8}$	1147
$\frac{3}{4}$	721.5
$\frac{5}{8}$	417.5

The values of yield torque, determined experimentally, for test keys corresponding to different shaft sizes and with different conditions of clearance in hub keyway, are shown in TABLE - 5.3.

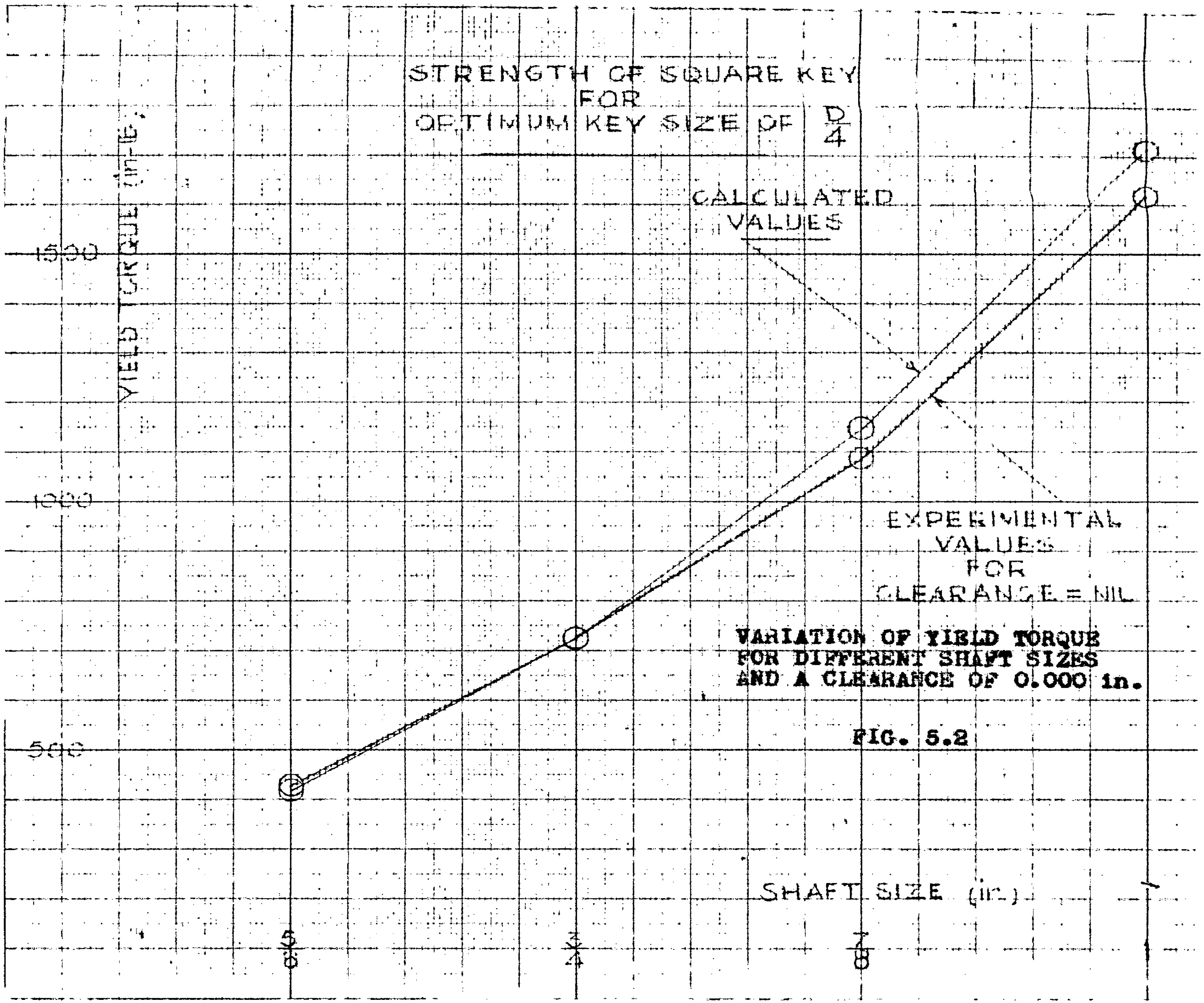
TABLE - 5.3

Observed values of yield torque for test keys

SHAFT SIZE in.	YIELD TORQUE FOR VARIOUS CLEARANCES		
	NIL	0.003 in.	0.006 in.
1	1616	1630	1623
$\frac{7}{8}$	1083	1093	1088
$\frac{3}{4}$	725	753	743
$\frac{5}{8}$	425	460	445

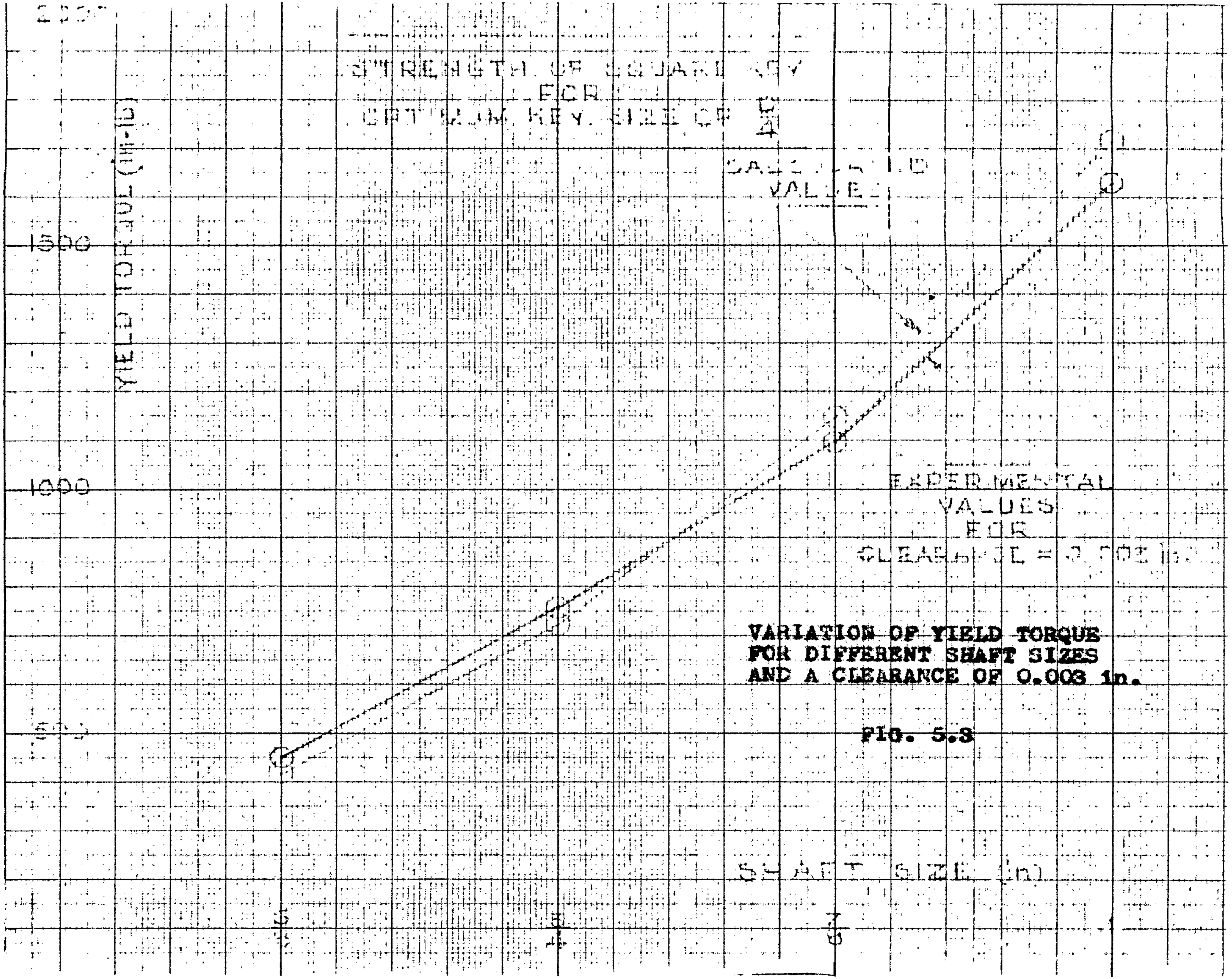
FIG. 5.2, 5.3, 5.4, display the variation of yield torque for different shaft sizes and for the three conditions of clearance. In each figure the calculated values of yield torque have also been plotted for the purpose of reference.

It will be observed that the experimental values of the yield torque are lower than the calculated values in case of shafts with 1 in. and $\frac{7}{8}$ in. diameter and higher than the calculated values in case of shafts with $\frac{3}{4}$ in. and $\frac{5}{8}$ in. diameter.



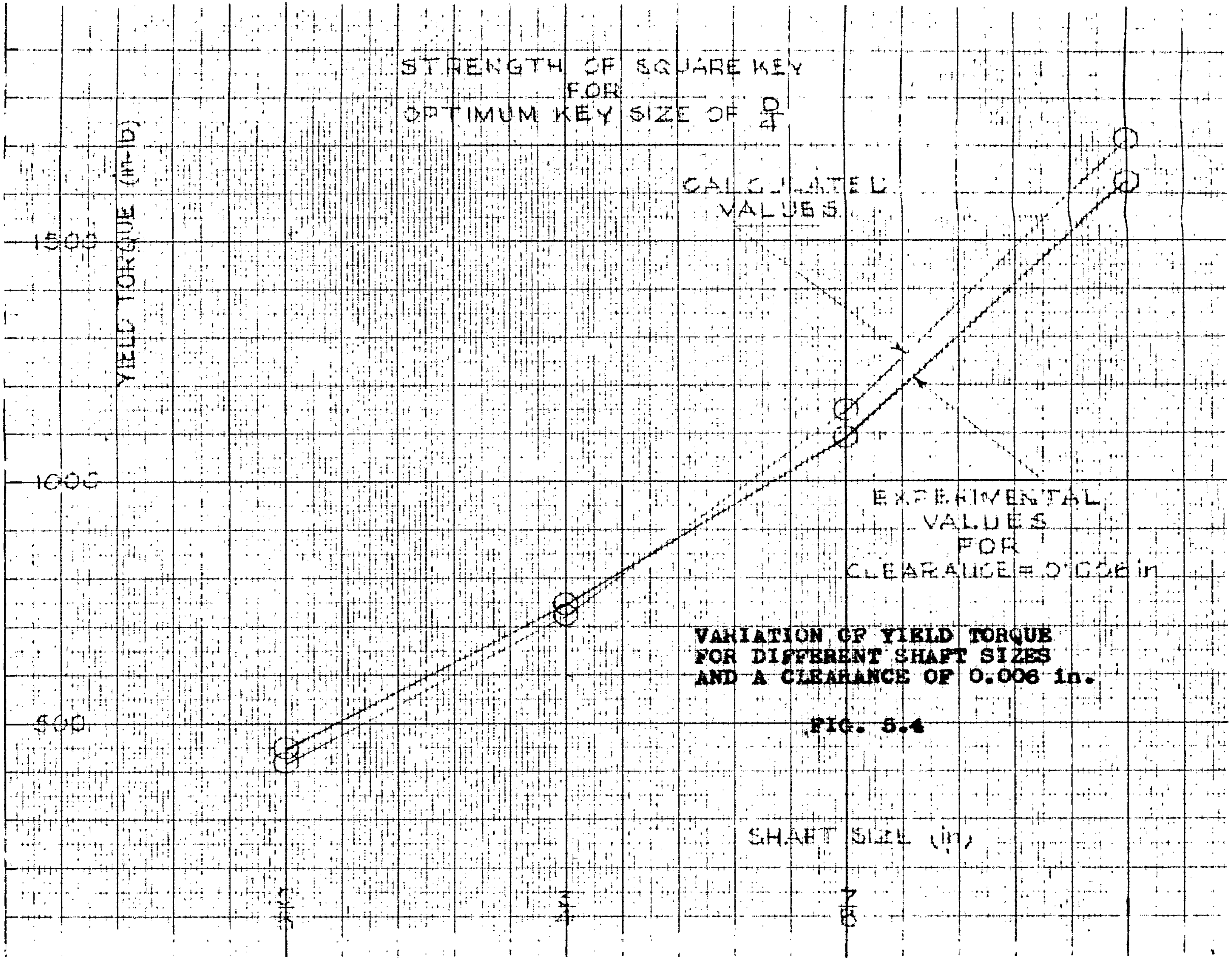
VARIATION OF YIELD TORQUE FOR DIFFERENT SHAFT SIZES AND A CLEARANCE OF 0.000 in.

FIG. 5.2



VARIATION OF YIELD TORQUE
FOR DIFFERENT SHAFT SIZES
AND A CLEARANCE OF 0.003 in.

FIG. 5.3



VARIATION OF YIELD TORQUE FOR DIFFERENT SHAFT SIZES AND A CLEARANCE OF 0.006 in.

FIG. 5.4

The percent increase or decrease of the experimental values of yield torque from the calculated values is shown in TABLE - 5.4.

TABLE - 5.4

Percent variation of the experimental value of yield torque from calculated value.

SHAFT SIZE in.	PERCENT INCREASE (+) OR DECREASE (-) OF YIELD TORQUE FOR VARIOUS CLEARANCES		
	NIL	0.003 in.	0.006 in.
1	- 6%	- 5%	- 5.5%
$\frac{7}{8}$	- 5.8%	- 5%	- 5.5%
$\frac{3}{4}$	+ 0.5%	+ 4.3%	+3%
$\frac{5}{8}$	+ 1.7%	+ 7.8%	+6.5%

FIG. 5.5 displays the percent variation of experimental values of yield torque from calculated values, for different shaft sizes and for the three conditions of clearance.

It will be observed that the experimental values happen to be nearer the calculated values for a shaft size of $\frac{13}{16}$ in., which was the diameter of the specimens tested on the torsion testing machine for estimation of the yield strength of material.

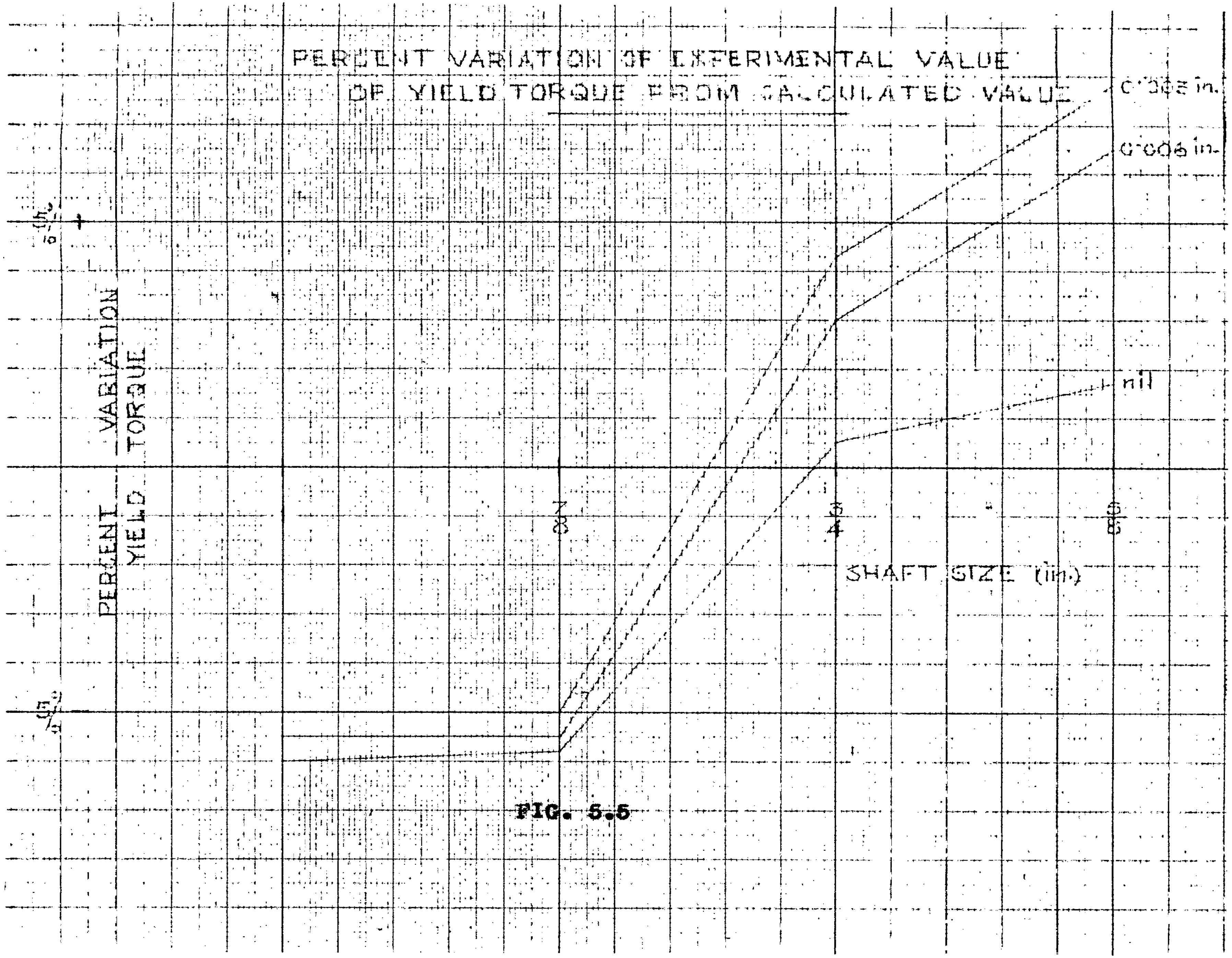

PERCENT VARIATION OF EXPERIMENTAL VALUE
OF YIELD TORQUE FROM CALCULATED VALUE
0·006 in.
nil
PERCENT VARIATION
YIELD TORQUE
7/8
3/4
5/8
SHAFT SIZE (in.)

FIG. 5.5

One more approach, for the comparison of key strength, can be based on the percent variation of the strength from condition of no clearance to a specific clearance in hub keyway. The figures obtained in case of different shaft sizes are shown in TABLE 5.5.

TABLE - 5.5

Percent increase of key strength with clearance, for different shaft sizes.

SHAFT SIZE in.	PERCENT INCREASE OF KEY STRENGTH FROM TIGHT FIT TO SPECIFIC CLEARANCE	
	0.003 in.	0.006 in.
1	0.87%	0.43%
$\frac{7}{8}$	0.92%	0.46%
$\frac{3}{4}$	3.80%	2.50%
$\frac{5}{8}$	6.00%	4.80%

FIG. 5.6 shows the percent increase of key strength with clearance in hub keyway, for the two values of clearance and the four shaft sizes. The percent increase of strength decreases as the clearance is increased from 0.003 in. to 0.006 in. However, the percent increase of strength is more for the smaller sizes of shafts.

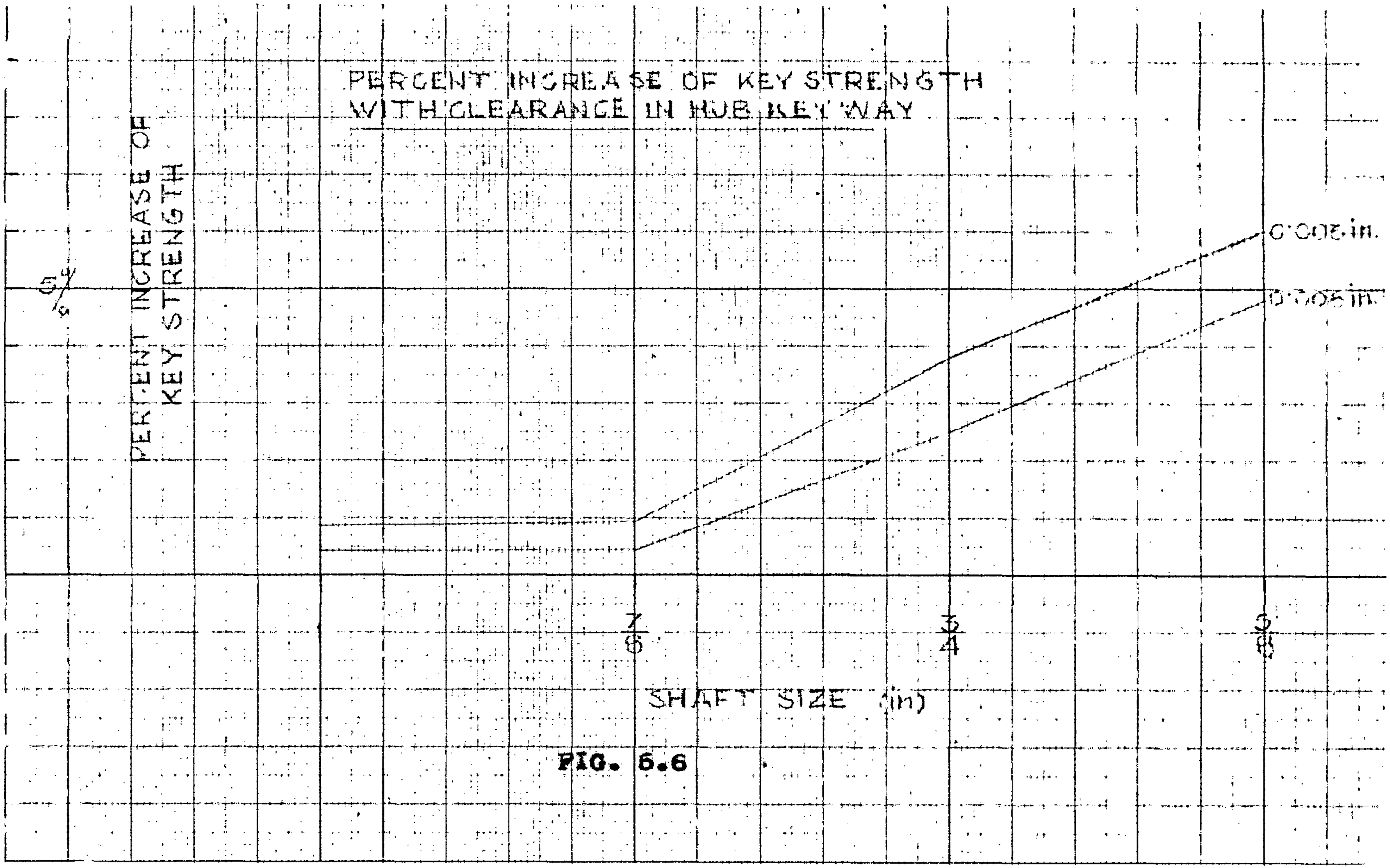

PERCENT INCREASE OF KEY STRENGTH
WITH CLEARANCE IN HUB KEYWAY
PERCENT INCREASE OF
KEY STRENGTH
5%
7/8
3/4
5/8
SHAFT SIZE (in)

FIG. 6.6

CHAPTER - VI

CONCLUSION

6.1 INFORMATION DERIVED FROM THE INVESTIGATION:

A review of the detailed analysis of test results brings forward the following main points:-

1. The optimum size of square key is for width equal to one quarter of the shaft diameter. This tallies well with the practice prevalent in the industry.

2. Contrary to the expectations, strength of key is not decreased on account of clearance in the hub keyway, upto a magnitude of 0.006 in.

3. The key strength, however, decreases if the hub keyway clearance is increased from 0.003 in. to 0.006 in.

4. The key strength increases with the reduction in shaft size, irrespective of the clearance in the hub keyway.

5. The percent increase of key strength due to a clearance in hub keyway is more for the lower sizes of shafts.

6.2 POSSIBLE EXPLANATION:

The slight improvement in the strength of the key due to a clearance in the hub keyway may be due to the absence of compressive stresses in the cross-section of the key, which develop in the key, as has been suggested by Black[6], if it is a tight fit in the keyways. The compressive stresses, set up in the cross-section of the key due to cold-working during a tight fit assembly, happen to be in the same direction as those due to transmitted torque and hence tend to yield the key at a smaller torque than expected. The latter belief has also been advanced by Seely & Smith, while discussing the effect of residual stresses.[7]

The decrease in key strength due to increase of clearance beyond 0.003 in. may be accounted for due to failure of the key by predominant effect of crushing of the material. It has been suggested by Vallance & Doughtie[8] that for a key which is fitted on all the four sides, the permissible crushing stress for the usual key materials is at least twice the permissible stress in shear. But when the key is not fitted on all the four sides, the permissible crushing stress is about 1.7 times the permissible shear stress, and the key must be checked for crushing. The results of the investigation agree well with the opinion expressed by Vallance & Doughtie.

6.3 SCOPE FOR FURTHER WORK:

The aspects of the problem of key strength investigated for the purpose of this dissertation form only a modest part, though essential, of a more complete picture.

The investigation can be carried further with more conditions of clearance in hub keyway and with other shapes of keys, e.g., rectangular and circular cross-sections.

It may also provide an interesting study to establish the yield strength of the material from a specimen of the same diameter as the test shaft and to compare the calculated and observed values of the key strength.

APPENDIX - A

TABLE I.

SHAFT SIZE - 1 in.

KEY SIZE - $\frac{D}{6}$

CLEARANCE - NIL

Twist (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	5	5	3	3	17	17
0.50	37	37	6	6	33	33
0.75	69	69	22	22	73	73
1.00	48	48	52	52	104	104
1.25	91	91	46	46	147	155
1.50	136	145	32	32	207	220
1.75	190	205	72	72	279	295
2.00	268	285	111	118	363	385
2.25	352	375	70	70	446	475
2.50	451	480	70	70	541	586
2.75	553	588	70	70	644	690
3.00	658	704	131	140	750	804

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	747	800	182	195	850	910
3.50	825	885	257	275	963	1035
3.75	903	965	337	360	1100	1135
4.00	998	1070	436	475	1200	1245
4.25	1150	1190	531	568	1302	1360
4.50	1247	1300	634	678	1398	1470
4.75	1346	1410	746	800	1495	1575
5.00	1470	1550	854	916	1602	1696
5.25	1580	1670	976	1045	1698	1805
5.50	1694	1800	1137	1175	1796	1910
5.75	1782	1896	1269	1325	-	-
6.00	1862	1982	1397	1465	-	-
6.25	-	-	1510	1590	-	-
6.50	-	-	1633	1728	-	-
6.75	-	-	1757	1868	-	-

TABLE II.

SHAFT SIZE - 1 in.

KEY SIZE - $\frac{D}{5}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	7	7	5	5	2	2
0.50	35	35	34	34	23	23
0.75	37	37	41	41	27	27
1.00	72	72	35	35	20	20
1.25	111	116	39	39	27	27
1.50	150	156	59	59	28	28
1.75	210	224	97	97	77	77
2.00	279	295	140	145	37	37
2.25	367	390	196	205	43	43
2.50	451	480	256	268	46	46
2.75	553	590	319	338	56	56
3.00	650	695	402	426	130	135

Contd.

TWIST (degrees)	TORQUE (lb.-in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	738	800	491	525	182	190
3.50	826	885	586	627	235	248
3.75	922	990	670	720	296	313
4.00	1046	1086	780	837	360	380
4.25	1144	1183	879	945	436	465
4.50	1230	1280	982	1056	513	548
4.75	1329	1390	1112	1158	596	638
5.00	1419	1490	1213	1268	661	708
5.25	1528	1615	1321	1386	721	773
5.50	1628	1724	1415	1490	795	853
5.75	1746	1855	1506	1590	872	948
6.00	-	-	1600	1693	946	1018
6.25	-	-	1699	1800	1077	1120
6.50	-	-	1794	1904	1160	1210
6.75	-	-	1868	1983	1256	1315
7.00	-	-	-	-	1346	1415
7.25	-	-	-	-	1462	1540
7.50	-	-	-	-	1557	1645
7.75	-	-	-	-	1669	1766
8.00	-	-	-	-	1766	1873

TABLE III.

SHAFT SIZE - 1 in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	4	4	9	9	30	30
0.50	9	9	39	39	27	27
0.75	42	42	54	54	23	23
1.00	2	2	80	80	23	23
1.25	48	48	22	22	23	23
1.50	98	98	34	34	61	61
1.75	151	155	63	63	111	115
2.00	212	220	104	106	176	186
2.25	279	295	141	146	242	253
2.50	351	370	205	215	310	325
2.75	425	455	286	300	378	398
3.00	530	570	367	385	442	468

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	628	674	456	483	518	548
3.50	719	774	551	585	580	615
3.75	833	895	639	678	646	685
4.00	937	1010	746	793	712	755
4.25	1105	1150	838	890	793	840
4.50	1213	1268	920	975	869	924
4.75	1349	1420	994	1055	939	995
5.00	1486	1566	1155	1170	1066	1077
5.25	1622	1713	1261	1280	1167	1183
5.50	1718	1820	1361	1386	1285	1305
5.75	1810	1920	1467	1495	1390	1416
6.00	-	-	1582	1618	1510	1540
6.25	-	-	1688	1728	1626	1665
6.50	-	-	1785	1834	1740	1785
6.75	-	-	1856	1905	1853	1900
7.00	-	-	1900	1950	-	-

TABLE IV.

SHAFT SIZE - 1 in.

KEY SIZE - $\frac{D}{3}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	9	9	66	66	13	13
0.50	19	19	130	135	28	28
0.75	60	60	184	190	51	51
1.00	99	99	265	280	27	27
1.25	142	147	332	350	68	68
1.50	207	215	404	425	103	105
1.75	282	296	458	485	156	160
2.00	362	380	529	562	208	218
2.25	480	506	596	632	270	285
2.50	603	638	669	710	343	360
2.75	723	768	749	795	425	450
3.00	834	885	842	895	498	527

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	952	1010	940	998	586	620
3.50	1106	1118	1082	1095	669	710
3.75	1214	1230	1181	1197	744	788
4.00	1295	1318	1284	1305	804	855
4.25	1368	1395	1364	1390	891	946
4.50	1461	1494	1459	1490	986	1048
4.75	1549	1582	1564	1598	1122	1135
5.00	1620	1658	1683	1725	1208	1225
5.25	1701	1745	1797	1845	1313	1335
5.50	1784	1833	1903	1952	1420	1447
5.75	1864	1915	-	-	1528	1560
6.00	1944	1995	-	-	1618	1655
6.25	-	-	-	-	1722	1765
6.50	-	-	-	-	1809	1858
6.75	-	-	-	-	1902	1955

TABLE V.

SHAFT SIZE - 1 in.

KEY SIZE - $\frac{D}{2}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	2	2	2	2	8	8
0.50	8	8	5	5	19	19
0.75	12	12	5	5	25	25
1.00	12	12	9	9	34	34
1.25	31	31	16	16	68	68
1.50	2	2	22	22	100	100
1.75	39	39	26	26	144	148
2.00	39	39	59	59	191	196
2.25	60	60	87	87	252	265
2.50	102	102	129	130	320	336
2.75	157	160	176	185	390	412
3.00	228	238	228	238	458	485
3.25	297	312	273	285	541	575
3.50	365	385	340	366	620	656
3.75	446	472	411	433	701	744

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
4.00	532	565	479	505	772	818
4.25	610	647	547	580	864	915
4.50	692	733	633	670	949	1005
4.75	783	830	710	754	1077	1088
5.00	875	930	790	836	1153	1168
5.25	960	1020	855	905	1235	1250
5.50	1078	1088	953	1010	1320	1343
5.75	1156	1168	1078	1088	1394	1419
6.00	1247	1264	1156	1170	1452	1480
6.25	1332	1355	1223	1240	1528	1561
6.50	1424	1450	1316	1337	1605	1640
6.75	1512	1542	1390	1415	1670	1710
7.00	1586	1622	1466	1497	1732	1778
7.25	1669	1710	1532	1568	1799	1845
7.50	1746	1790	1601	1637	1860	1910
7.75	1813	1860	1674	1715	1919	1970
8.00	1836	1885	1730	1774	1931	1985
8.25	-	-	1790	1835	-	-
8.50	-	-	1856	1905	-	-
8.75	-	-	1908	1960	-	-

TABLE VI.

SHAFT SIZE - 1 in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - 0.003 in.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	11	11	9	9	3	3
0.50	13	13	9	9	3	3
0.75	16	16	9	9	10	10
1.00	18	18	9	9	23	23
1.25	36	36	9	9	3	3
1.50	36	36	15	15	32	32
1.75	53	53	15	15	36	36
2.00	75	75	45	45	42	42
2.25	106	110	45	45	49	49
2.50	144	150	66	66	37	37
2.75	206	215	89	92	60	60
3.00	274	290	110	114	100	105
3.25	356	377	144	150	141	147

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.50	433	458	177	185	202	213
3.75	523	554	233	245	265	280
4.00	610	647	292	308	341	361
4.25	712	753	368	390	409	433
4.50	785	830	428	453	488	515
4.75	900	953	496	525	568	602
5.00	1000	1060	566	600	669	710
5.25	1162	1190	664	702	753	798
5.50	1260	1295	739	782	843	892
5.75	1364	1409	840	887	935	990
6.00	1461	1510	944	1000	1079	1100
6.25	1571	1630	1096	1119	1162	1190
6.50	1663	1730	1199	1230	1252	1287
6.75	1758	1832	1322	1362	1331	1372
7.00	1858	1943	1433	1483	1438	1487
7.25	-	-	1576	1635	1529	1585
7.50	-	-	1681	1748	1629	1693
7.75	-	-	1793	1870	1723	1795
8.00	-	-	1865	1950	1842	1890
8.25	-	-	1888	1974	1939	1966

TABLE VII.

SHAFT SIZE - 1 in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - 0.006 in.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	2	2	2	2	15	15
0.50	7	7	5	5	28	28
0.75	16	16	22	22	37	37
1.00	35	35	22	22	37	37
1.25	45	45	30	30	67	67
1.50	53	53	32	32	98	98
1.75	69	69	36	36	152	152
2.00	47	47	62	62	200	205
2.25	61	61	97	97	268	278
2.50	81	81	145	145	330	345
2.75	100	100	199	205	397	416
3.00	152	152	262	273	453	478

Contd.

TWIST (degrees)	TORQUE (lb.-in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	215	220	336	350	512	538
3.50	275	285	405	425	544	574
3.75	343	360	470	495	588	620
4.00	410	430	545	575	628	664
4.25	491	516	602	637	705	745
4.50	570	600	650	687	795	840
4.75	648	685	689	730	859	910
5.00	723	764	722	763	901	953
5.25	808	855	774	820	982	1040
5.50	892	942	848	900	1110	1150
5.75	976	1033	928	983	1210	1250
6.00	1116	1155	1043	1055	1288	1312
6.25	1243	1268	1156	1174	1394	1428
6.50	1360	1390	1261	1283	1495	1530
6.75	1479	1505	1350	1378	1600	1643
7.00	1582	1622	1460	1493	1690	1737
7.25	1690	1737	1564	1603	1760	1812
7.50	1779	1830	1667	1710	1844	1900
7.75	1827	1882	1768	1820	1927	1987
8.00	1894	1950	1863	1920	-	-

TABLE VIII.

SHAFT SIZE - $\frac{7}{8}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	10	10	1	1	6	6
0.50	11	11	1	1	24	24
0.75	36	36	25	25	38	38
1.00	68	75	22	22	92	101
1.25	121	134	46	51	152	167
1.50	171	190	35	35	209	227
1.75	236	260	41	41	272	298
2.00	298	325	83	95	342	375
2.25	382	418	120	134	410	447
2.50	449	490	158	175	494	538
2.75	563	614	205	225	586	638
3.00	682	745	252	276	677	736

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	778	848	311	340	804	875
3.50	884	965	387	423	931	1015
3.75	992	1081	464	518	1094	1118
4.00	1129	1156	555	605	1197	1228
4.25	1229	1260	652	710	1289	1325
4.50	1317	1352	765	835	1370	1410
4.75	1402	1444	874	955	1452	1496
5.00	1465	1510	973	1060	1520	1570
5.25	1510	1560	1128	1155	1586	1640
5.50	1579	1634	1212	1244	1667	1725
5.75	1634	1690	1301	1336	1725	1788
6.00	1716	1778	1365	1415	1794	1860
6.25	1787	1854	1430	1474	-	-
6.50	-	-	1510	1560	-	-
6.75	-	-	1586	1640	-	-
7.00	-	-	1651	1707	-	-
7.25	-	-	1724	1783	-	-
7.50	-	-	1797	1863	-	-

TABLE IX.

SHAFT SIZE - $\frac{7}{8}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - 0.003 in.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	5	5	5	5	4	4
0.50	5	5	5	5	4	4
0.75	5	5	5	5	5	5
1.00	5	5	5	5	13	13
1.25	5	5	36	36	13	13
1.50	14	14	64	70	28	28
1.75	14	14	112	124	25	25
2.00	29	29	173	190	38	38
2.25	45	50	248	272	44	50
2.50	72	80	339	380	52	57
2.75	103	115	452	493	82	90
3.00	150	165	562	612	104	115
3.25	216	237	660	720	135	148
3.50	307	337	753	822	169	184

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.75	411	439	852	928	211	228
4.00	507	554	946	1033	258	280
4.25	620	675	1052	1075	308	333
4.50	723	788	1140	1167	375	407
4.75	826	900	1233	1265	437	472
5.00	907	988	1303	1340	497	535
5.25	998	1090	1384	1425	568	612
5.50	1132	1160	1466	1510	641	694
5.75	1213	1244	1555	1605	720	777
6.00	1263	1298	1642	1700	788	850
6.25	1343	1382	1715	1777	869	936
6.50	1429	1473	1783	1850	951	1026
6.75	1506	1557	1852	1925	1070	1103
7.00	1579	1633	-	-	1142	1178
7.25	1660	1718	-	-	1200	1240
7.50	1736	1800	-	-	1256	1300
7.75	-	-	-	-	1310	1356
8.00	-	-	-	-	1350	1398
8.25	-	-	-	-	1404	1455
8.50	-	-	-	-	1448	1502

TABLE X.

SHAFT SIZE - $\frac{7}{8}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - 0.006 in.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	1	1	6	6	3	3
0.50	11	11	12	12	3	3
0.75	13	13	26	26	3	3
1.00	33	33	47	53	3	3
1.25	46	52	68	78	16	16
1.50	38	38	96	105	16	16
1.75	34	34	136	148	32	32
2.00	34	34	190	205	41	46
2.25	61	68	260	280	41	46
2.50	87	100	346	368	41	46
2.75	128	144	464	494	46	54
3.00	195	215	598	635	62	70
3.25	284	310	715	758	75	85
3.50	382	418	826	875	89	100
3.75	509	555	929	985	106	118

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
4.00	623	680	1083	1085	125	138
4.25	742	808	1146	1152	150	163
4.50	848	924	1231	1246	174	188
4.75	958	1045	1286	1303	206	222
5.00	1098	1122	1364	1390	239	255
5.25	1174	1204	1432	1464	279	299
5.50	1255	1290	1509	1543	326	348
5.75	1325	1362	1568	1605	380	405
6.00	1404	1448	1652	1699	438	466
6.25	1479	1524	1721	1775	494	525
6.50	1546	1598	1774	1833	545	578
6.75	1624	1680	1854	1920	622	660
7.00	1696	1757	-	-	695	735
7.25	1771	1836	-	-	768	814
7.50	1838	1910	-	-	842	892
7.75	-	-	-	-	932	988
8.00	-	-	-	-	1000	1060
8.25	-	-	-	-	1130	1135
8.50	-	-	-	-	1181	1193
8.75	-	-	-	-	1242	1258
9.00	-	-	-	-	1292	1310

TABLE XI.

SHAFT SIZE - $\frac{3}{4}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	3	3	4	4	2	2
0.50	33	33	4	4	3	3
0.75	97	105	4	4	22	22
1.00	151	164	14	14	10	10
1.25	197	212	39	42	30	30
1.50	247	267	67	74	24	24
1.75	311	336	90	98	61	67
2.00	392	422	116	125	110	120
2.25	469	505	146	158	146	158
2.50	546	590	179	192	168	182
2.75	605	655	219	237	192	207
3.00	677	730	269	290	241	260

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	742	800	330	357	290	313
3.50	801	865	393	425	357	385
3.75	858	926	456	492	426	458
4.00	911	980	523	565	498	536
4.25	955	1028	588	635	554	598
4.50	1000	1077	660	712	615	665
4.75	1091	1127	714	770	674	728
5.00	1133	1170	766	826	722	780
5.25	1184	1225	806	870	774	835
5.50	1226	1268	852	918	830	895
5.75	1267	1310	899	968	830	948
6.00	1310	1355	948	1022	932	1002
6.25	1352	1400	996	1072	980	1056
6.50	1389	1437	1079	1112	1070	1103
6.75	1426	1478	1120	1156	1119	1153
7.00	1463	1517	1166	1205	1166	1205

TABLE XII.

SHAFT SIZE - $\frac{3}{4}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	1	1	2	2	6	6
0.50	4	4	21	21	6	6
0.75	22	22	11	11	6	6
1.00	49	55	15	15	10	10
1.25	20	20	22	22	10	10
1.50	36	36	42	42	41	41
1.75	66	72	74	80	68	75
2.00	113	123	125	135	127	137
2.25	164	180	174	190	182	198
2.50	229	246	231	250	247	266
2.75	291	315	282	305	316	340
3.00	357	385	336	365	382	412

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	428	462	388	420	445	480
3.50	491	528	449	485	509	547
3.75	554	598	494	532	573	618
4.00	605	652	545	590	628	677
4.25	665	720	597	642	679	732
4.50	719	776	641	692	733	790
4.75	770	830	683	738	783	845
5.00	809	873	724	780	822	888
5.25	855	923	[illegible]	[illegible]	875	945
5.50	892	960	815	880	925	998
5.75	942	1018	857	925	976	1052
6.00	984	1062	900	970	1033	1098
6.25	1054	1088	946	1020	1095	1130
6.50	1101	1136	988	1063	1135	1170
6.75	1146	1182	1071	1105	1192	1230
7.00	1179	1217	1102	1136	1226	1270

TABLE XIII.

SHAFT SIZE - $\frac{3}{4}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - 0.006 in.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	15	15	12	12	9	9
0.50	28	28	18	18	19	19
0.75	61	67	23	23	35	35
1.00	96	102	43	45	14	14
1.25	146	158	69	75	37	37
1.50	201	217	109	118	59	65
1.75	255	275	158	172	88	96
2.00	307	330	223	240	133	145
2.25	370	400	275	298	182	198
2.50	425	460	333	360	234	253
2.75	483	520	385	415	302	327
3.00	535	575	445	478	377	406

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	586	630	505	545	446	480
3.50	644	694	568	612	510	548
3.75	697	750	623	670	582	628
4.00	741	798	683	735	638	687
4.25	796	857	733	790	682	736
4.50	843	908	754	812	733	790
4.75	892	960	798	862	787	850
5.00	931	1003	844	910	837	902
5.25	981	1057	890	960	886	953
5.50	1059	1090	933	1005	931	1003
5.75	1109	1143	970	1045	977	1052
6.00	1146	1184	1048	1080	1056	1088
6.25	1190	1230	1085	1118	1101	1135
6.50	1232	1274	1130	1167	1142	1178
6.75	1275	1320	1165	1202	1187	1226
7.00	1313	1360	1200	1240	1233	1276

TABLE XIV.

SHAFT SIZE - $\frac{5}{8}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	19	19	48	48	20	20
0.50	22	22	85	93	38	38
0.75	39	39	114	124	51	53
1.00	32	32	146	160	65	72
1.25	61	66	177	193	75	80
1.50	82	90	216	235	91	98
1.75	104	112	244	265	103	112
2.00	132	145	270	294	119	130
2.25	163	177	299	323	132	145
2.50	197	212	330	357	159	173
2.75	229	247	359	390	190	205
3.00	267	287	388	420	222	240

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	300	325	409	443	249	270
3.50	338	367	435	473	289	314
3.75	374	405	461	500	311	337
4.00	411	446	486	527	341	370
4.25	422	457	507	550	366	397
4.50	442	480	530	573	408	442
4.75	465	505	551	597	433	471
5.00	491	531	571	619	460	498
5.25	515	560	590	638	482	523
5.50	536	582	612	663	505	546
5.75	557	603	631	683	530	574
6.00	579	627	650	704	554	600
6.25	598	648	667	723	576	625
6.50	617	670	686	745	604	655
6.75	631	684	704	763	625	677
7.00	652	706	720	780	649	704

TABLE XV.

SHAFT SIZE - $\frac{5}{8}$ in.

KEY SIZE - $\frac{D}{4}$

CLEARANCE - NIL

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	2	2	2	2	2	2
0.50	3	3	2	2	4	4
0.75	3	3	10	10	7	7
1.00	7	7	10	10	17	17
1.25	9	9	13	13	22	22
1.50	14	14	23	23	38	38
1.75	14	14	38	38	22	22
2.00	22	22	55	60	49	52
2.25	22	22	34	35	69	72
2.50	40	40	38	38	90	96
2.75	60	65	38	38	120	128
3.00	85	93	47	50	149	160

Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	113	122	80	85	179	192
3.50	139	151	107	116	216	230
3.75	165	180	143	152	250	267
4.00	188	205	176	187	289	307
4.25	215	235	210	224	327	349
4.50	240	260	238	253	361	385
4.75	267	290	275	294	395	420
5.00	291	316	308	328	424	450
5.25	320	347	342	365	441	468
5.50	350	378	375	400	464	494
5.75	380	413	411	437	490	522
6.00	398	438	441	468	515	547
6.25	427	465	472	500	536	564
6.50	452	490	496	527	554	590
6.75	477	516	528	560	575	612
7.00	499	540	560	595	598	635

TABLE XVI.

SHAFT SIZE - $\frac{5}{8}$ in.

KEY SIZE - $\frac{D}{4}$

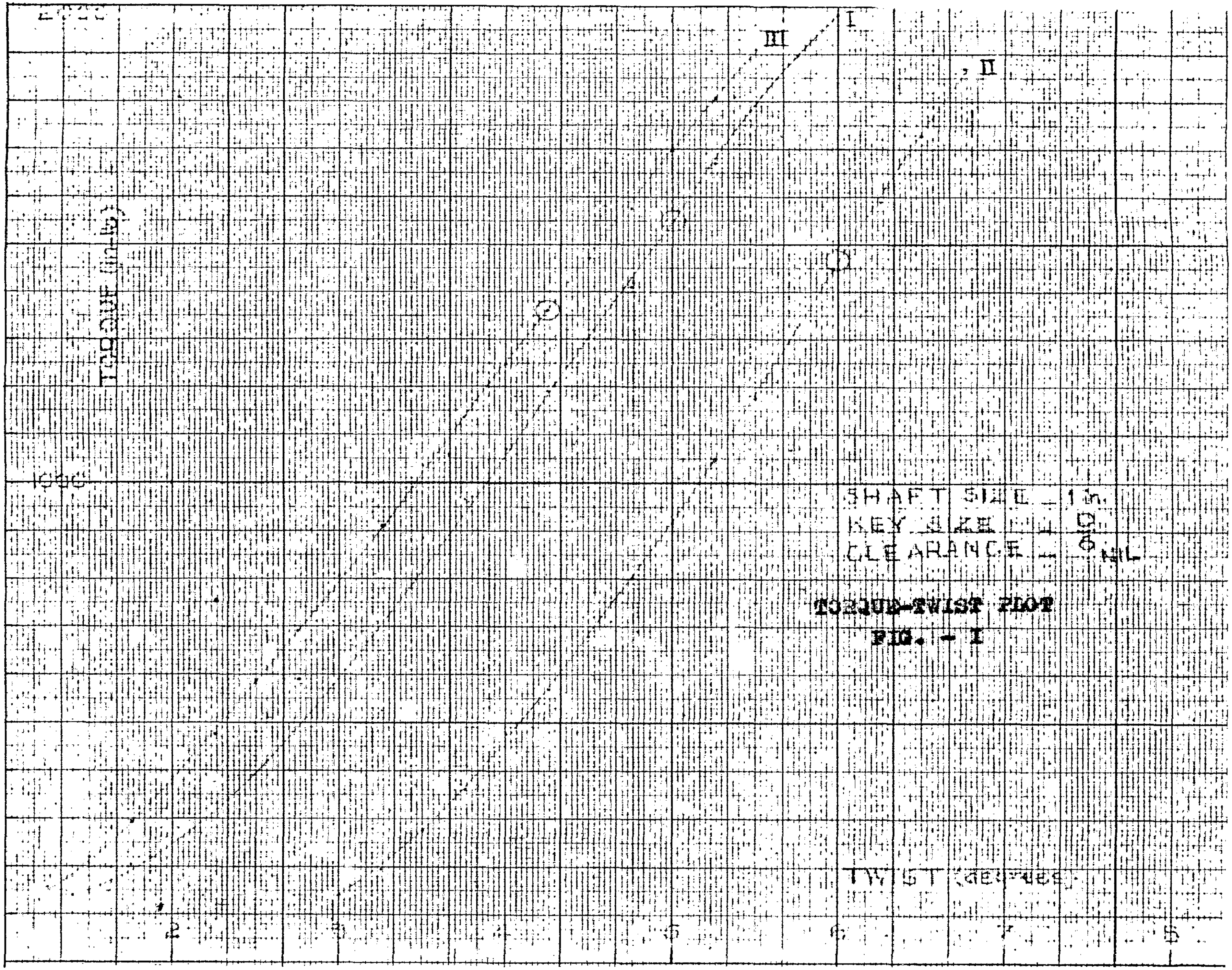
CLEARANCE - 0.006 in.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
0.25	2	2	3	3	17	17
0.50	2	2	3	3	14	14
0.75	10	10	3	3	14	14
1.00	10	10	3	3	26	26
1.25	10	10	3	3	37	37
1.50	22	22	3	3	50	55
1.75	18	18	3	3	62	67
2.00	18	18	3	3	77	82
2.25	18	18	16	16	99	105
2.50	26	26	16	16	129	138
2.75	40	40	22	22	155	165
3.00	66	70	24	24	200	214

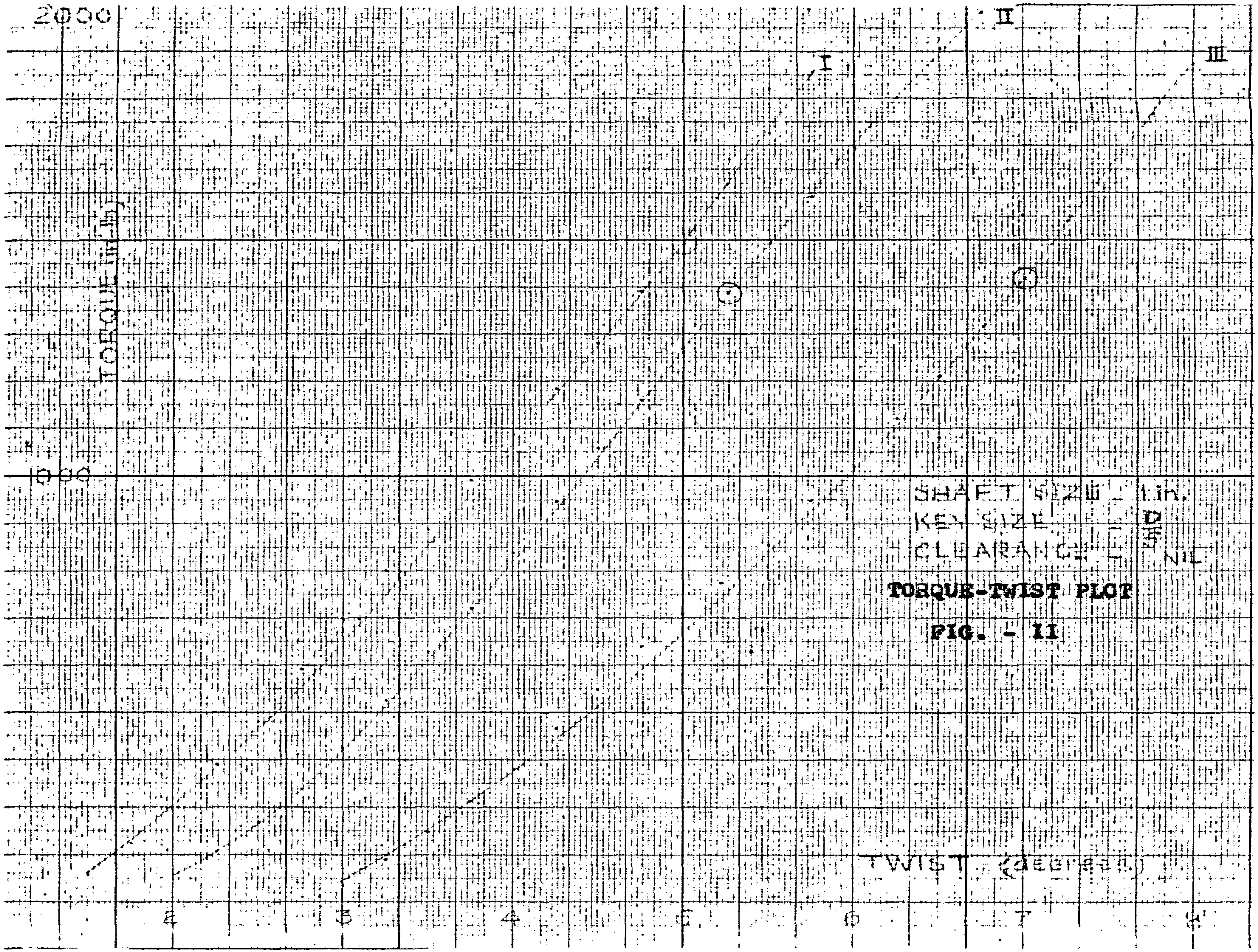
Contd.

TWIST (degrees)	TORQUE (lb. - in.)					
	I SPECIMEN		II SPECIMEN		III SPECIMEN	
	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
3.25	89	95	21	21	240	255
3.50	120	128	21	21	282	300
3.75	157	168	32	32	320	340
4.00	192	205	38	38	352	375
4.25	226	241	63	67	381	405
4.50	259	275	89	95	405	433
4.75	294	312	131	140	427	454
5.00	322	343	170	182	447	476
5.25	350	373	207	221	470	500
5.50	380	404	246	261	494	525
5.75	408	433	290	308	514	546
6.00	432	458	326	347	530	563
6.25	441	470	361	385	545	580
6.50	446	475	398	422	563	600
6.75	469	498	427	450	578	615
7.00	487	518	450	472	589	623

APPENDIX - B

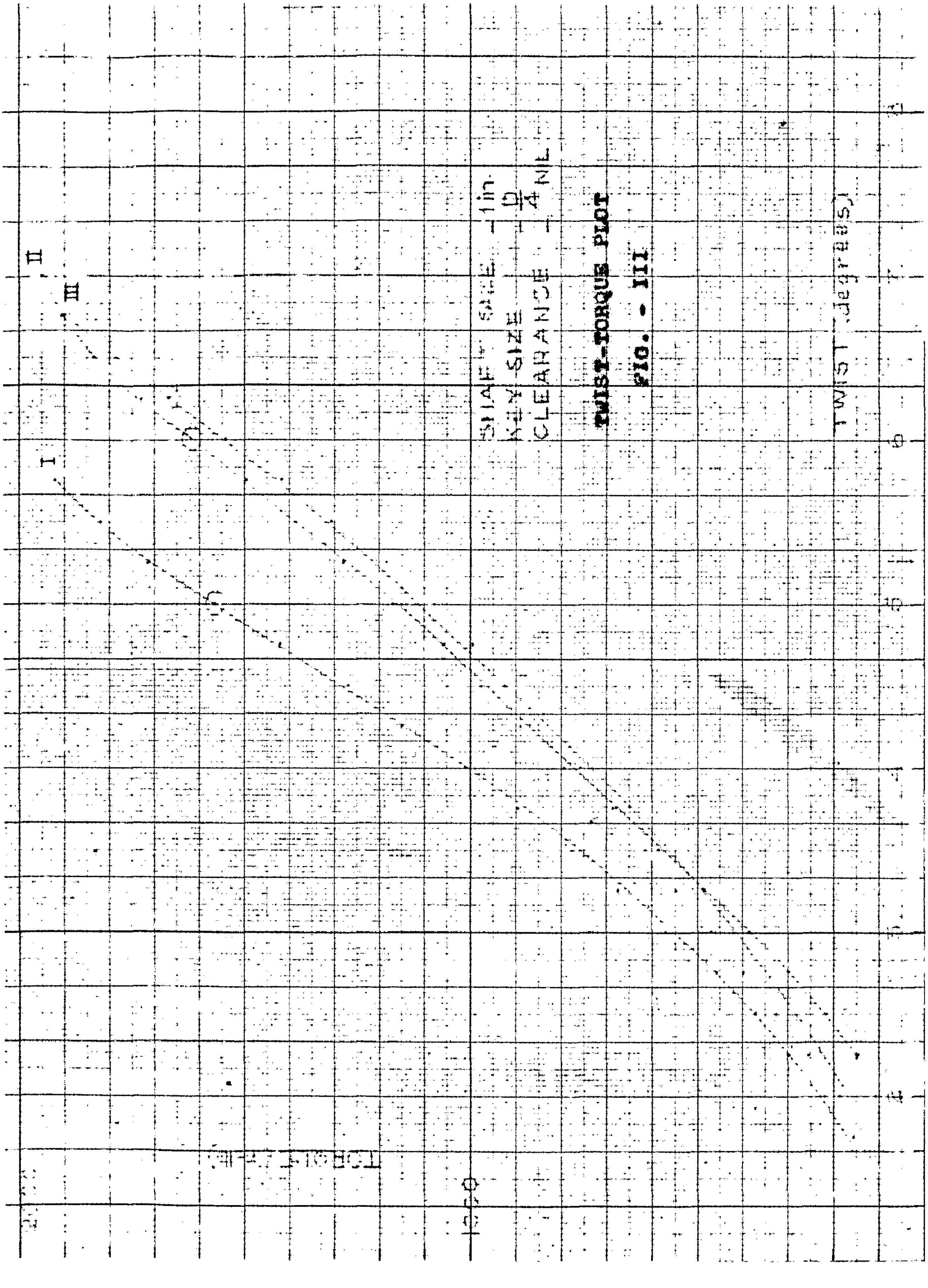


TORQUE-TWIST PLOT
FIG. - I

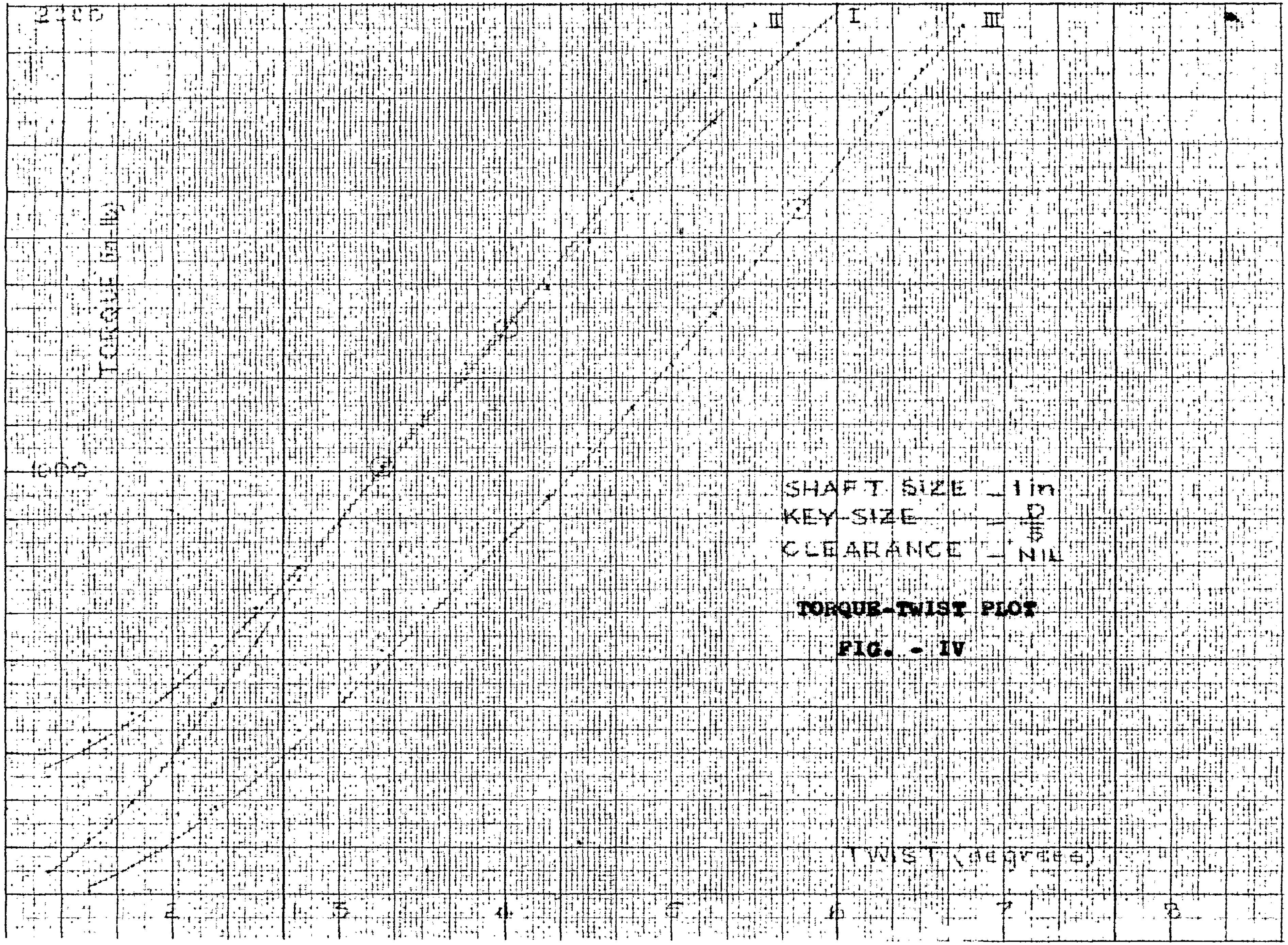


TORQUE-TWIST PLOT

FIG. – II

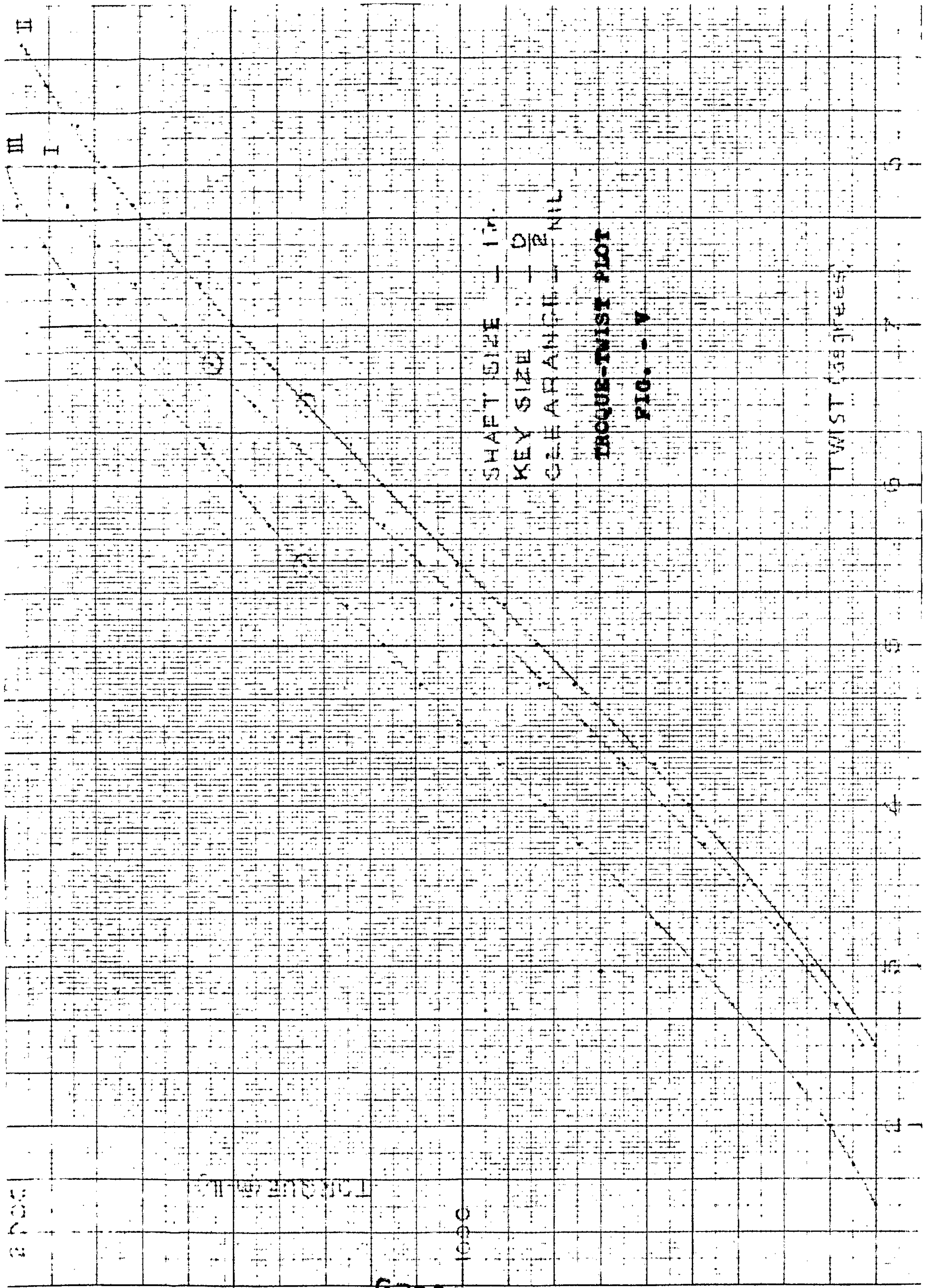


SHAFT SIZE — 1in.
KEY SIZE — D/4
CLEARANCE — NIL
TWIST-TORQUE PLOT
FIG. - III
TWIST (degrees)
I
II
III



TORQUE-TWIST PLOT

FIG. - IV



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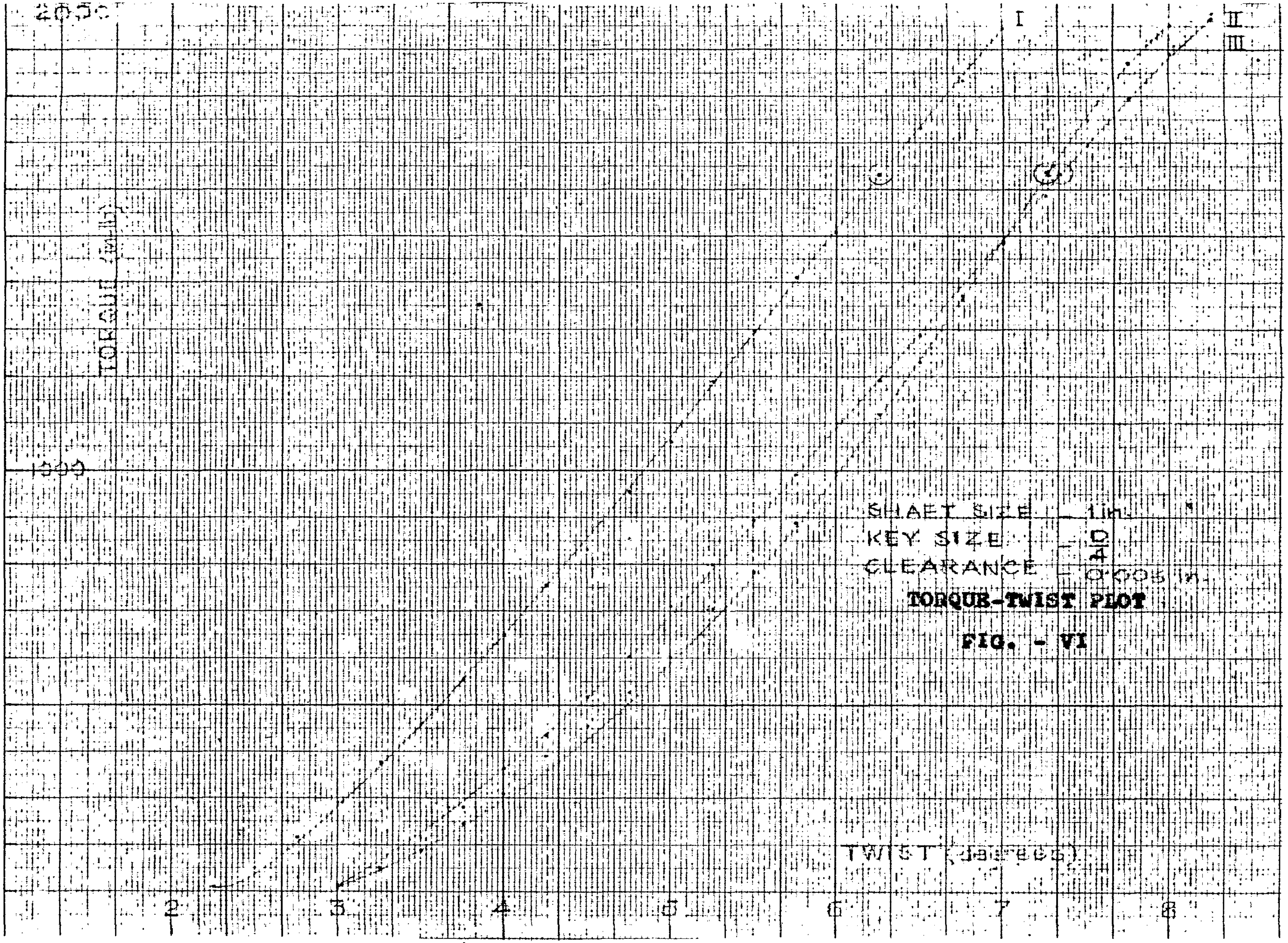
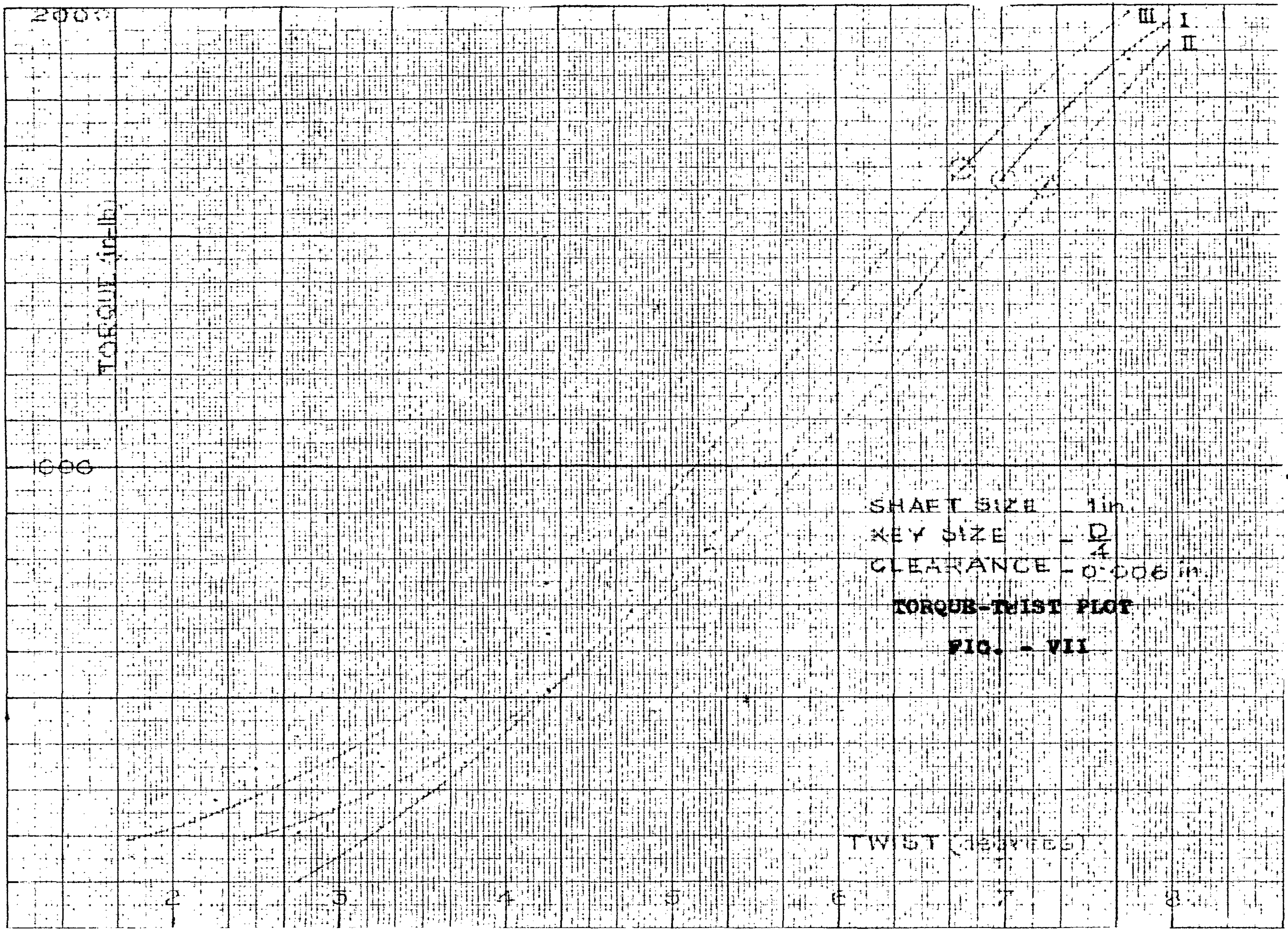
ROORKEE



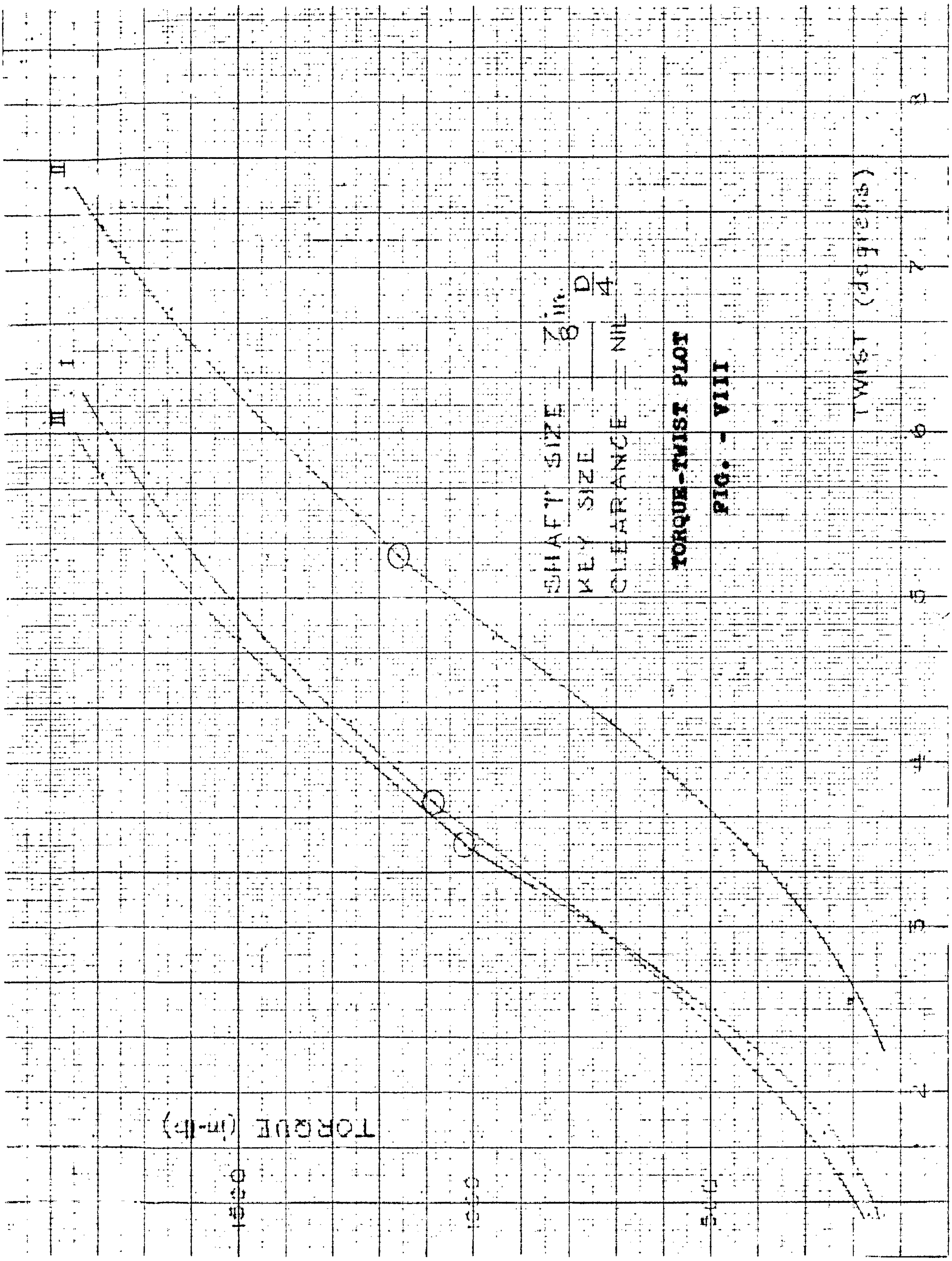
TORQUE-TWIST PLOT

FIG. - VI



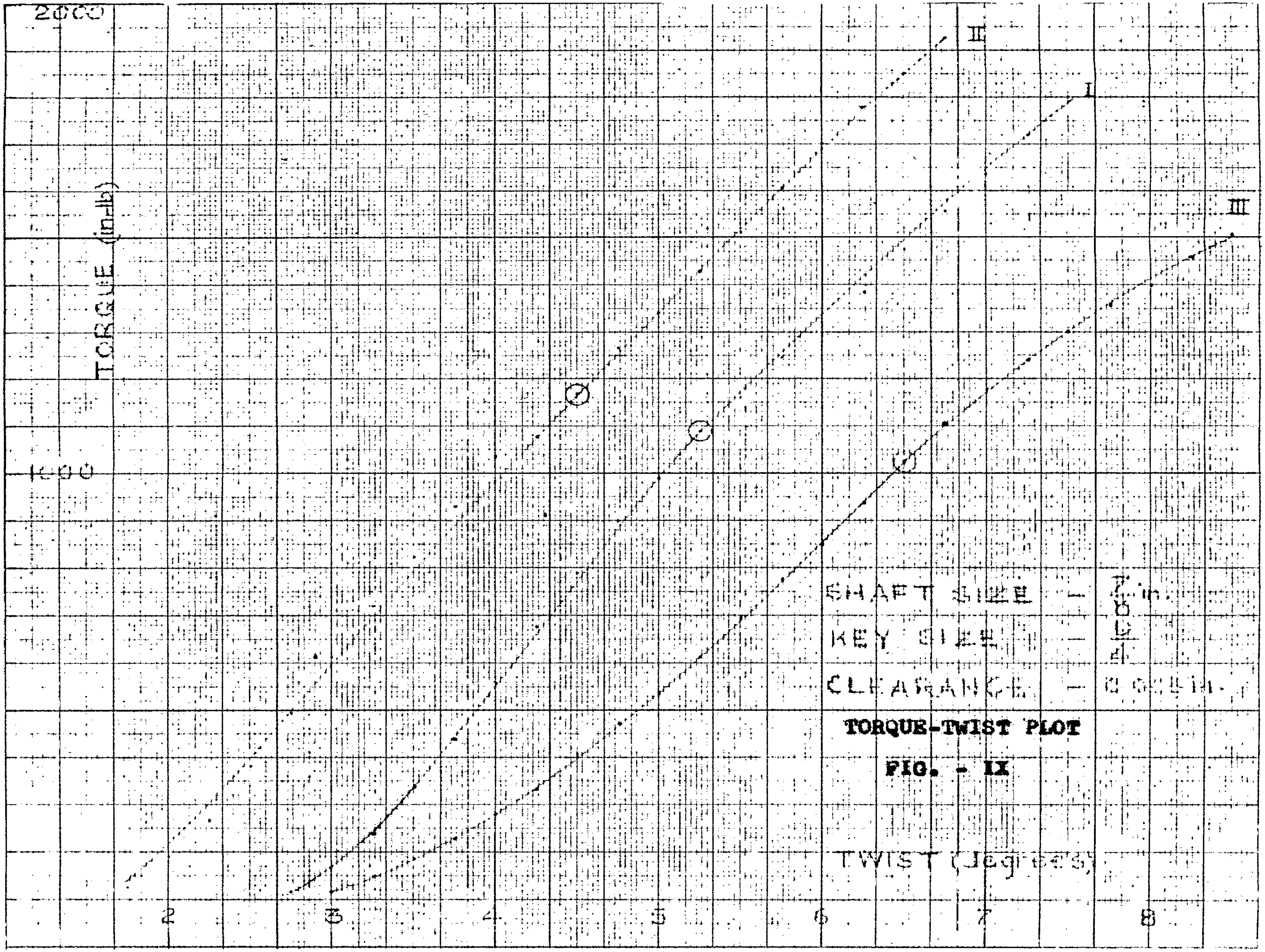
TORQUE-TWIST PLOT

FIG. - VII



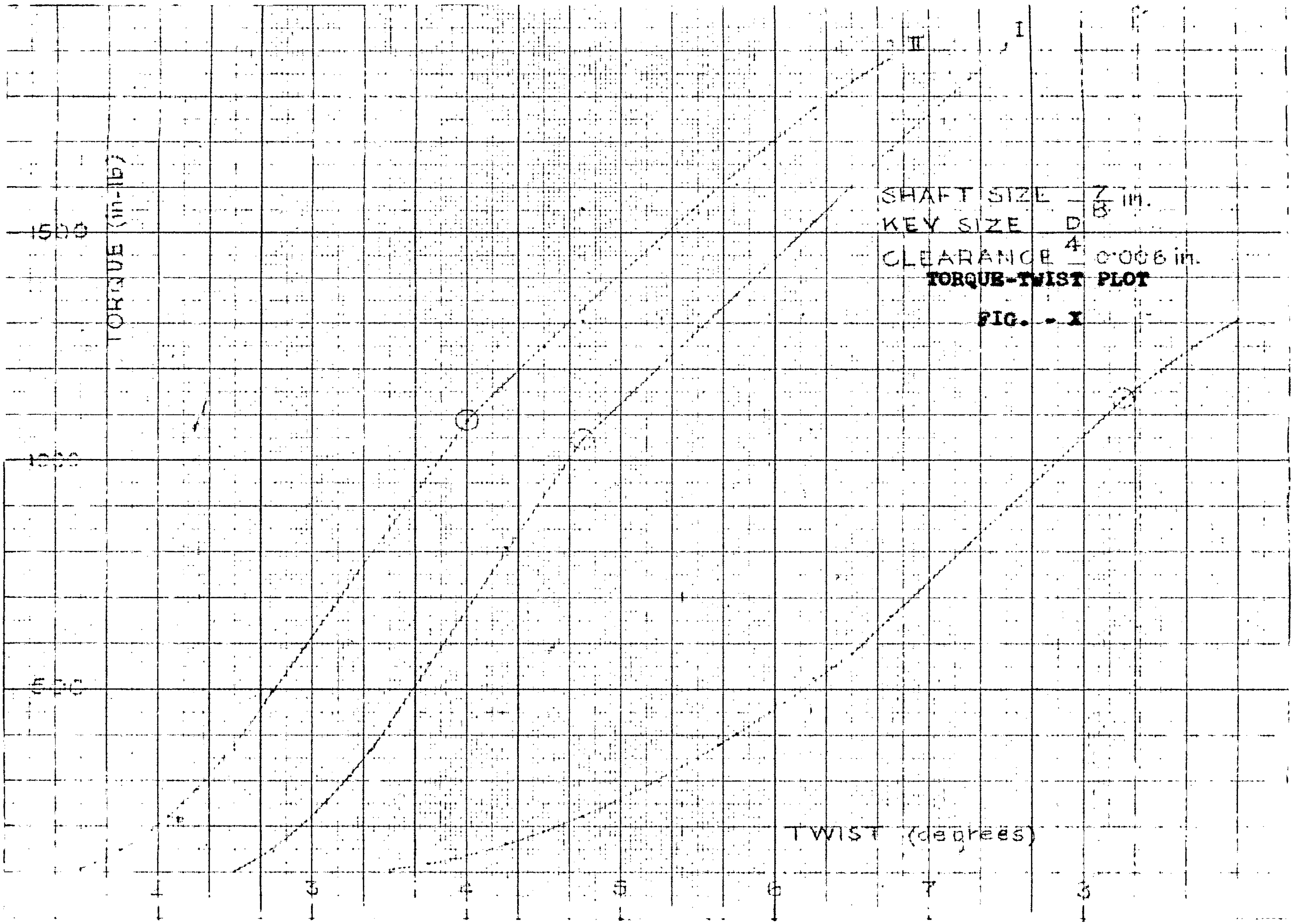
TORQUE-TWIST PLOT

FIG. - VIII



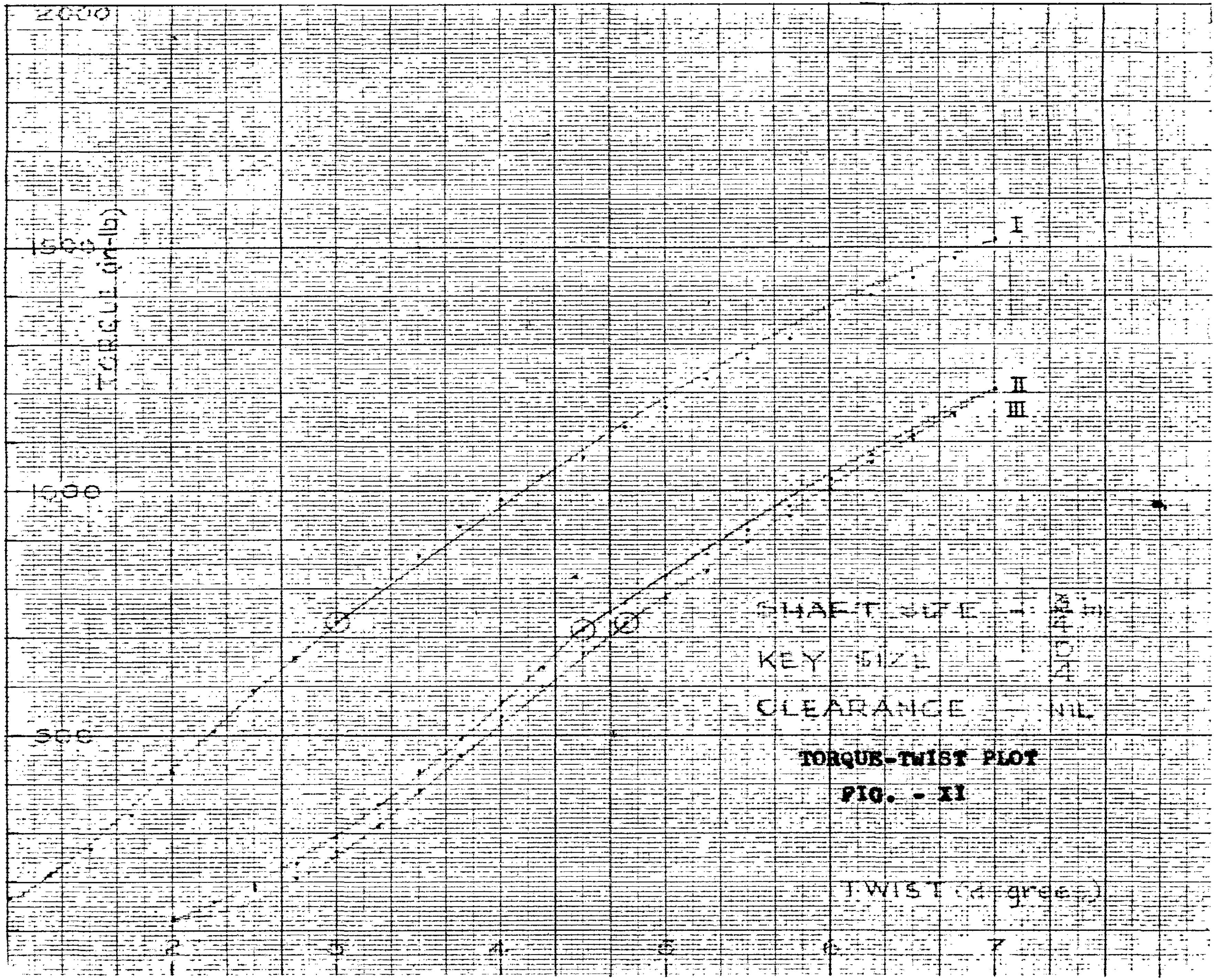
TORQUE-TWIST PLOT

FIG. - IX



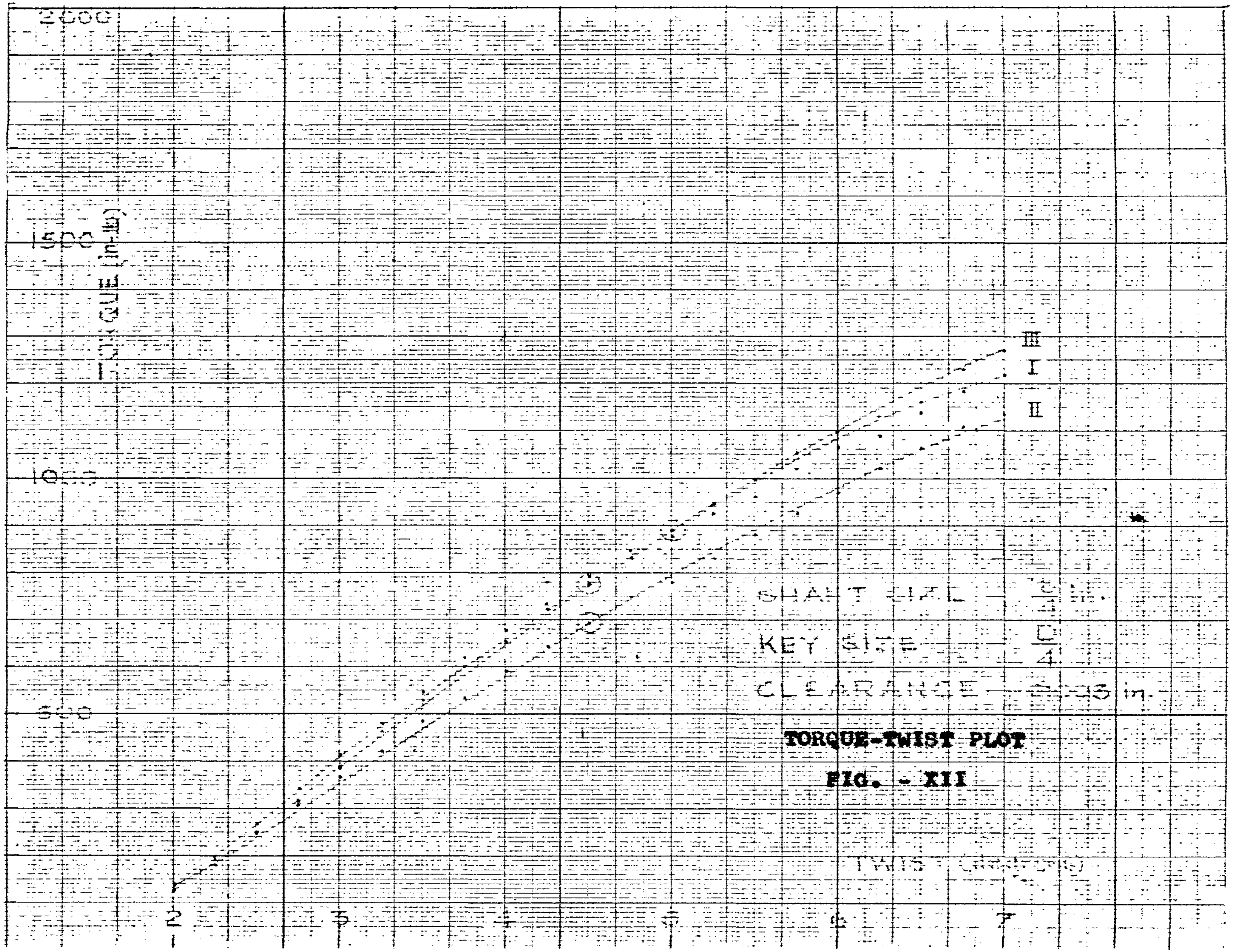
TORQUE-TWIST PLOT

FIG. - X



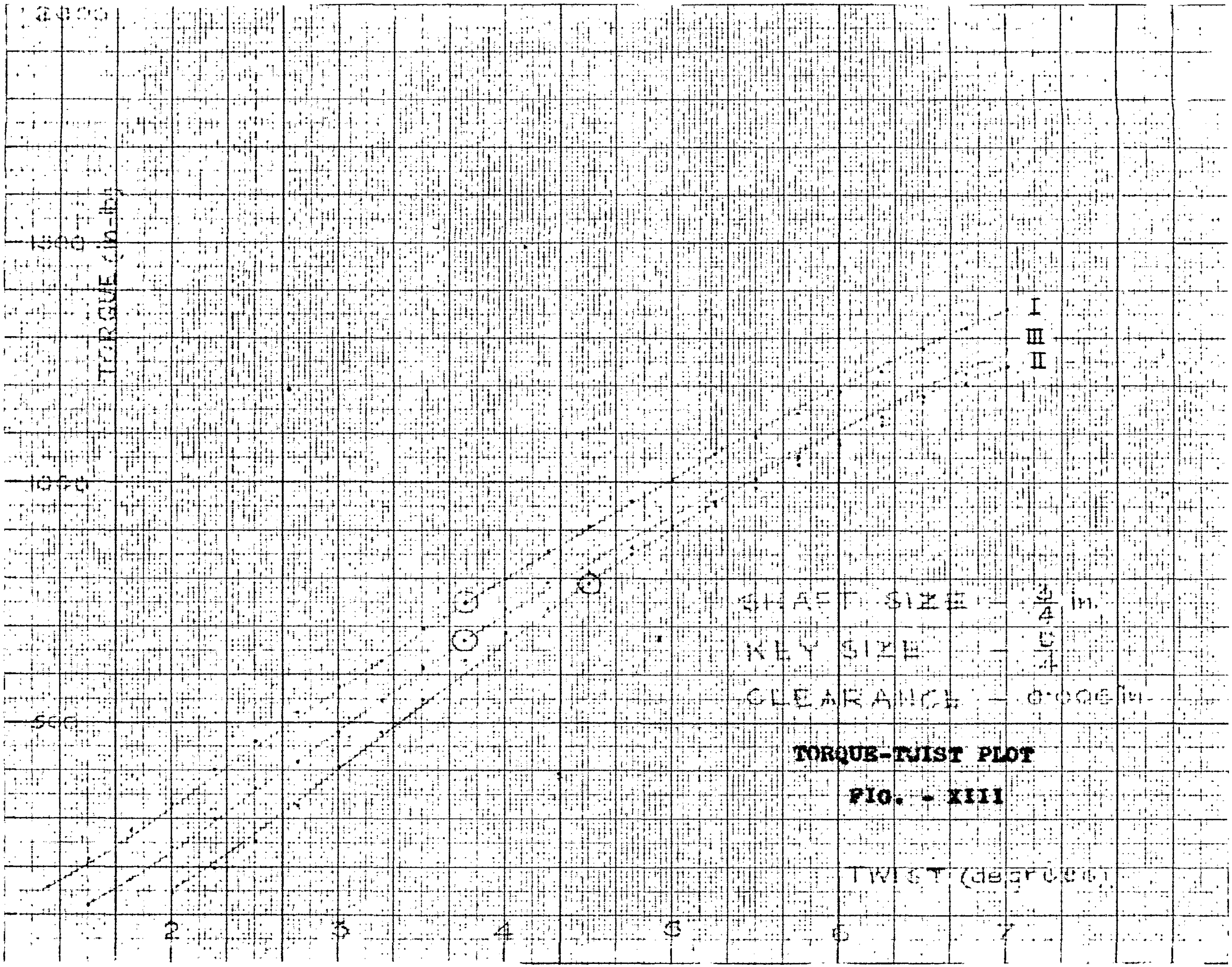
TORQUE-TWIST PLOT

FIG. - XI



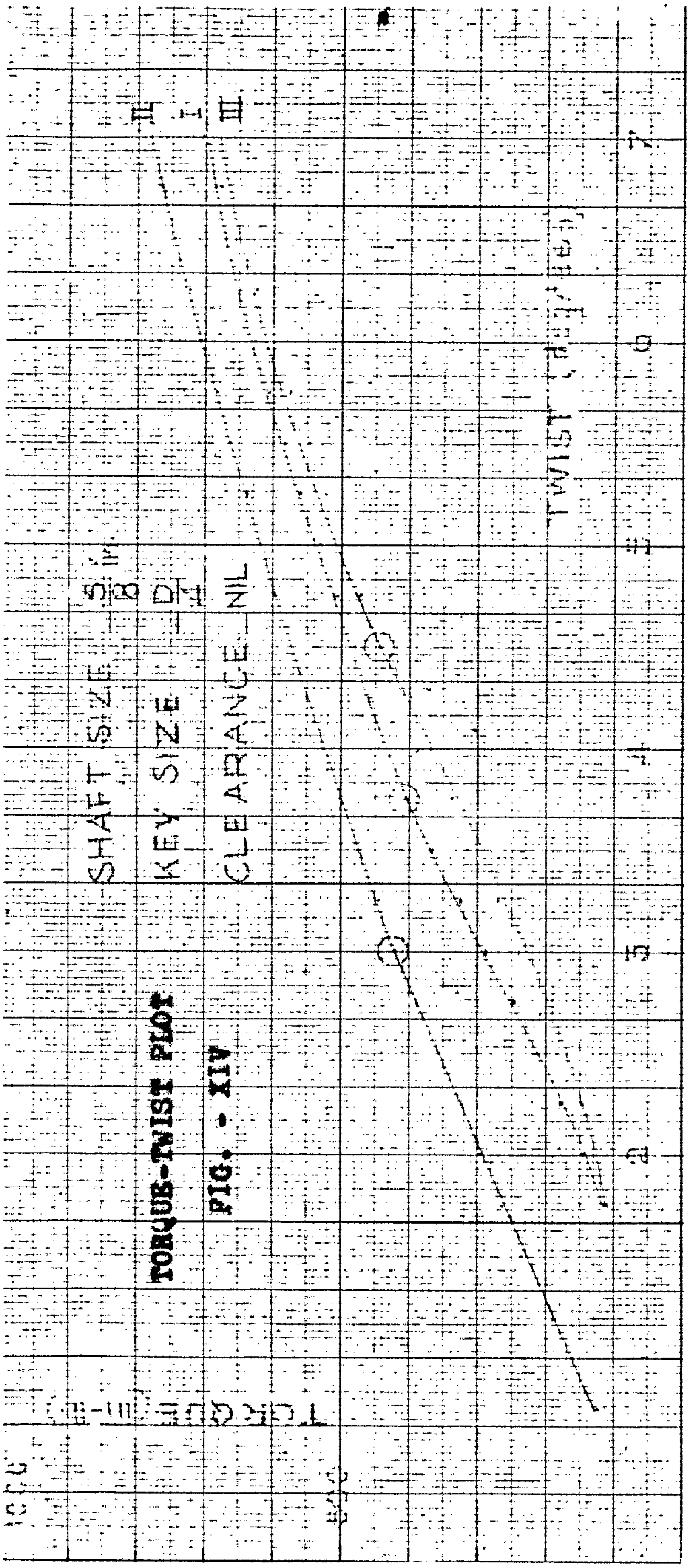
TORQUE-TWIST PLOT

FIG. - XII



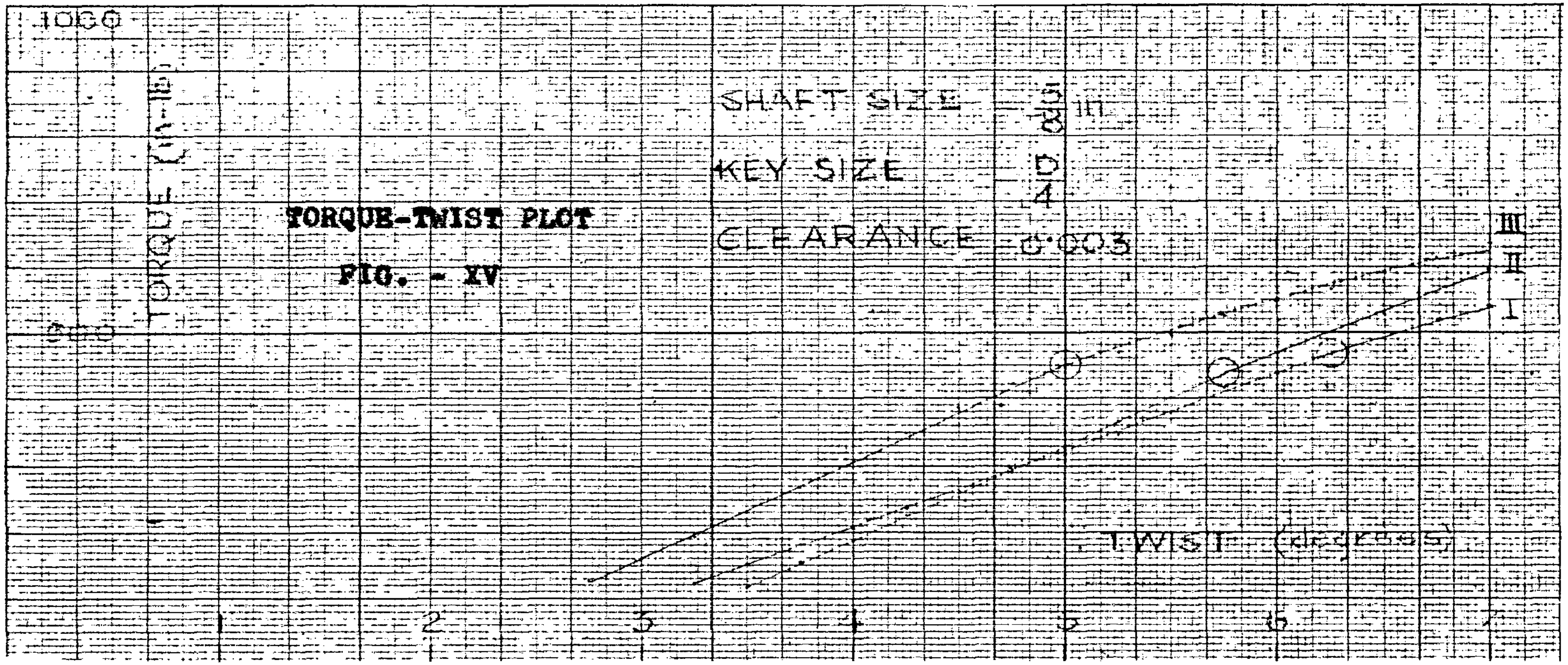
TORQUE-TWIST PLOT

FIG. - XIII



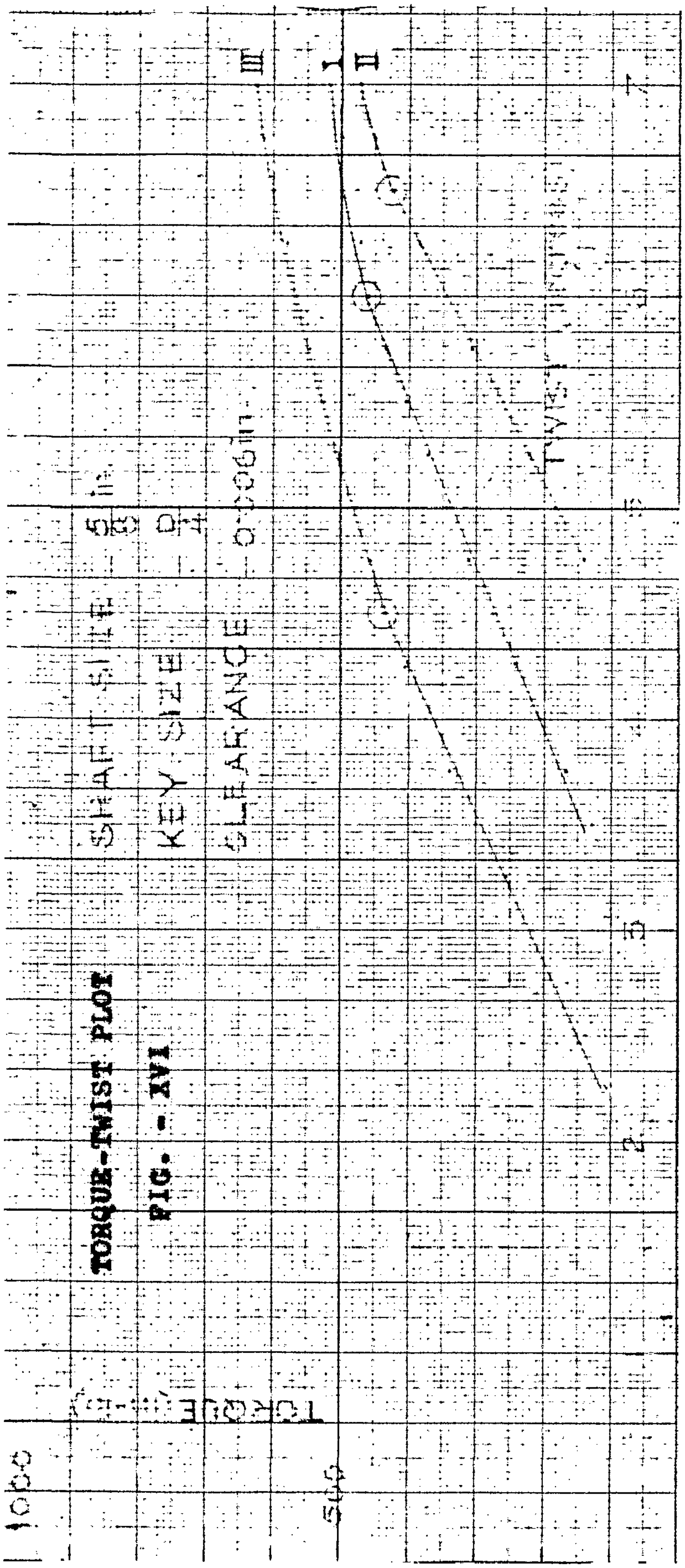
TORQUE-TWIST PLOT

FIG. - XIV



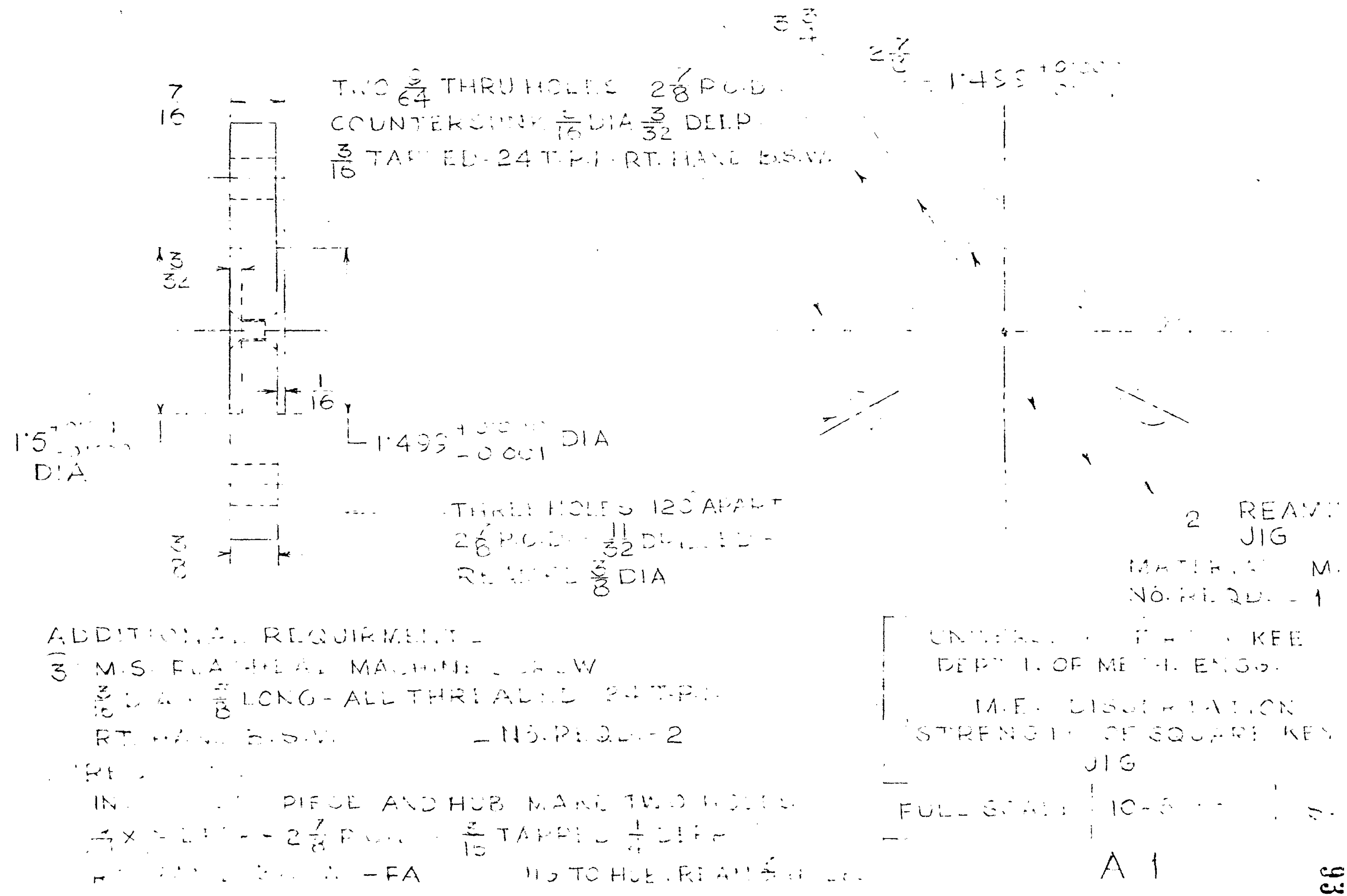
TORQUE-TWIST PLOT

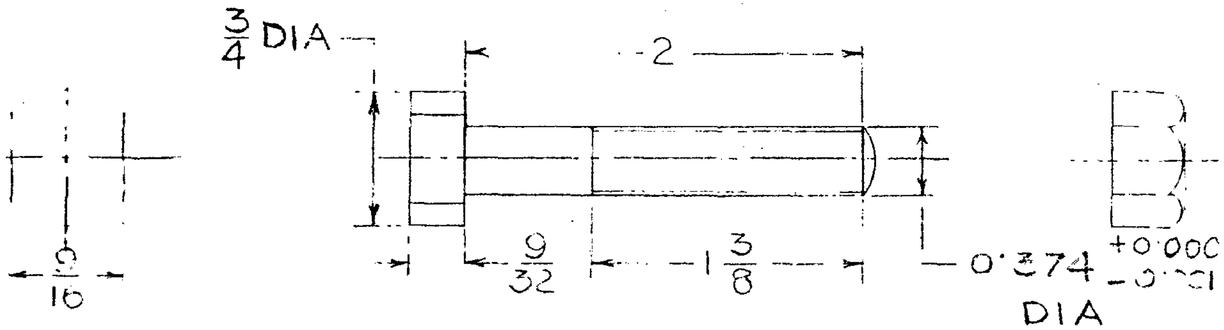
FIG. - XV



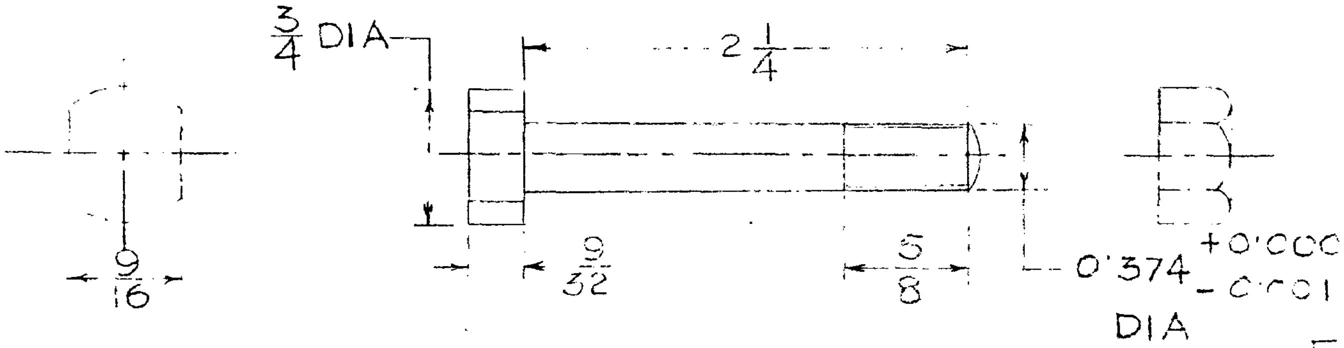
TORQUE-TWIST PLOT
FIG. - XVI
SHAFT SIZE
KEY SIZE
CLEARANCE
TORQUE
TWIST
1000
500
I
II
III
2
3
4
5
6
7

APPENDIX - C

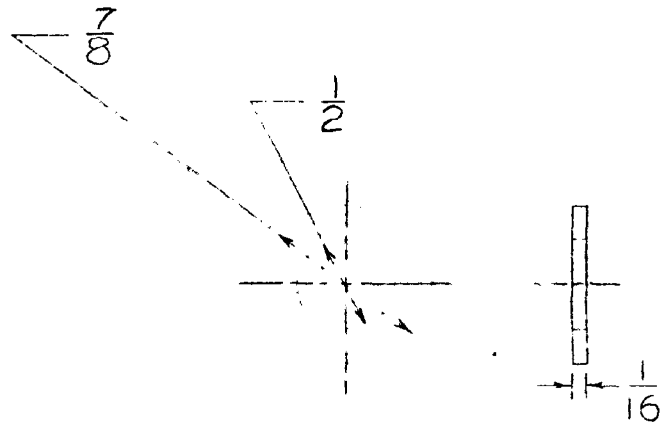

TWO 9/64 THRU HOLES 2 7/8 P.C.D.
COUNTERSUNK 5/16 DIA 3/32 DEEP
3/16 TAPPED-24 T.P.I. RT. HAND B.S.W.
1·499 DIA
THREE HOLES 120° APART
3/8 DIA
ADDITIONAL REQUIRMENTS
M.S. MACHINE
LONG-ALL THREADED
RT. HAND B.S.W.
PIECE AND HUB MAKE TWO HOLES
2 7/8 P.C.D.
2 REAMER
JIG
No. REQD. 1
DEPT. OF MECH. ENGG.
M.E. DISSERTATION
STRENGTH OF SQUARE KEY
JIG
FULL SCALE
A 1



4 M.S. BOLTS RT. HAND B.S.W. - 16 T.P.I. - WITH NUTS
No. REQD. - 3



5 M.S. BOLTS - RT. HAND B.S.W. - 16 T.P.I. - WITH NUTS
No. REQD. - 3



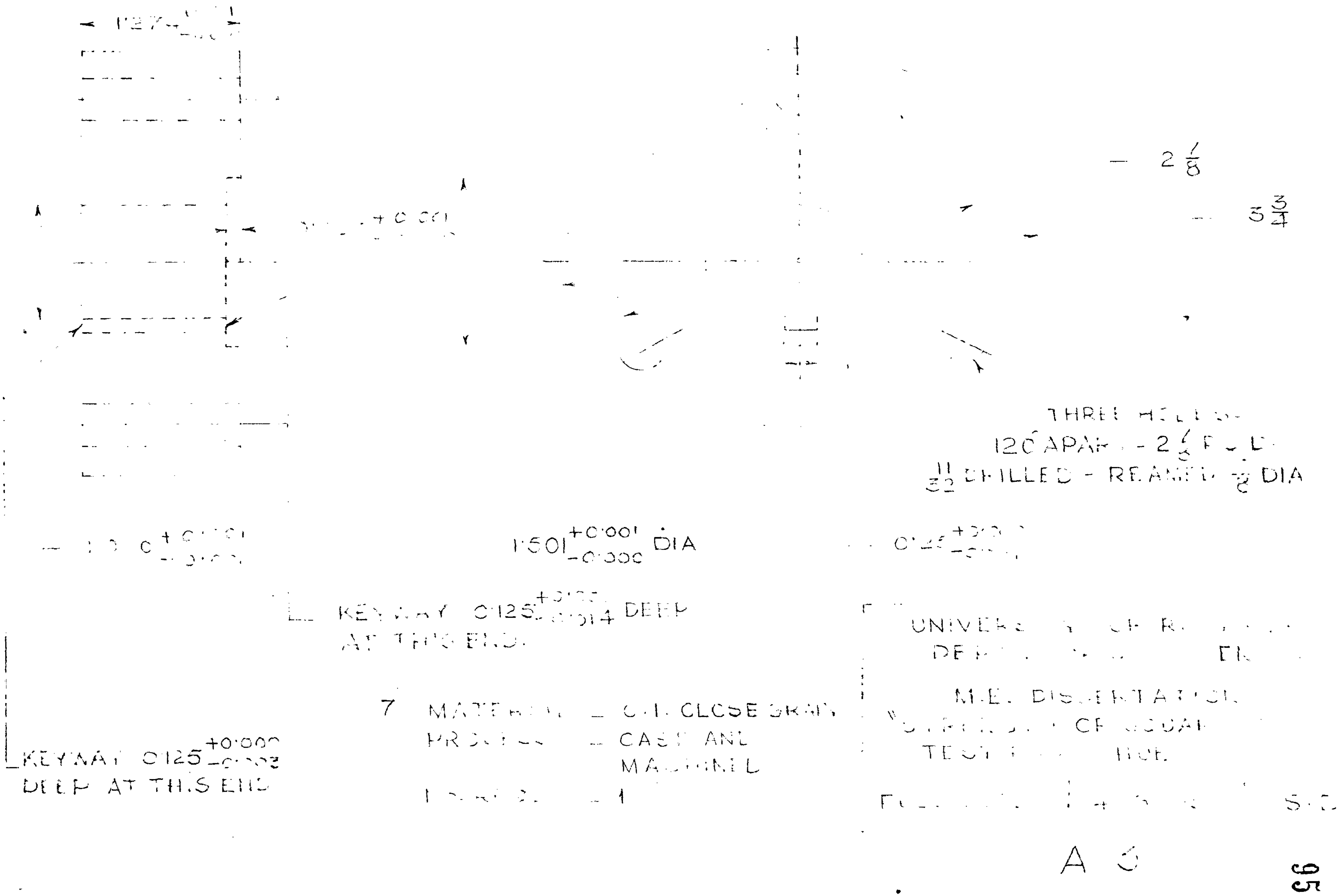
6 M.S. WASHERS
No. REQD. - 6

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

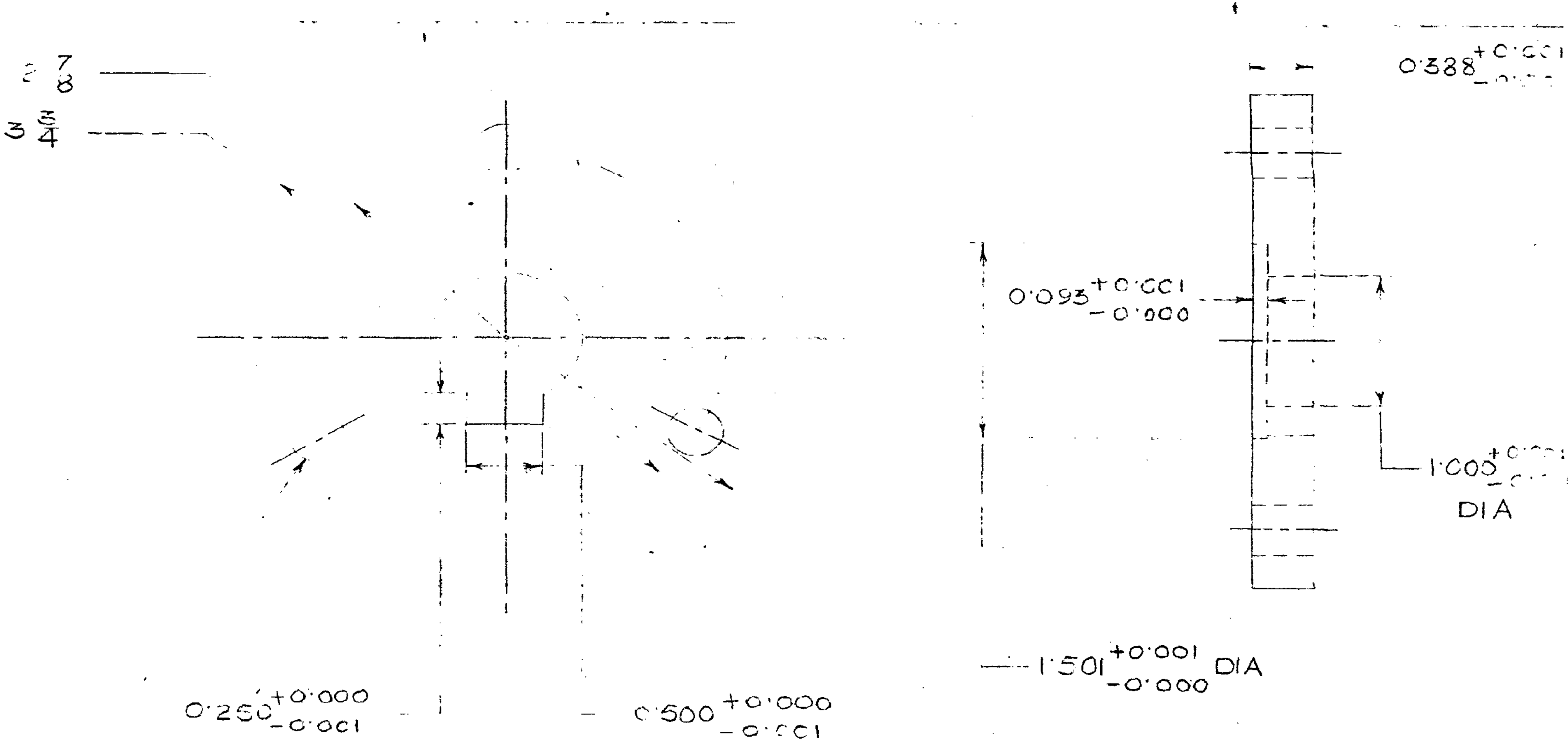
M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
FIXTURE

FULL SCALE	11-6-63	S. D

A-2



THREE HOLES
120° APART
DRILLED - REAMED DIA
1·501 +0·001 -0·000 DIA
KEYWAY 0·125 DEEP
AT THIS END
KEYWAY 0·125 +0·000
DEEP AT THIS END
7
MATERIAL — C.I. CLOSE GRAIN
PROCESS — CAST AND
MACHINED
UNIVERSITY OF
M.E. DISSERTATION
A 6



THREE [illegible] - 120° APART -
$2\frac{7}{8}$ P.C.D. $\frac{11}{32}$ DRILLED -
PLANED $\frac{3}{8}$ DIA

8 MATERIAL – C.I. CLOSE GRAINED
PROCESS – CAST AND MACHINED
[illegible] REQD. – 1

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE [illegible]"
TEST PART – HUB

FULL SCALE	14-6-62	S.D.

A-4

THREE HOLES 120 APART. 2 7/8 P.C.D.
11/32 DRILLED. REAMED 3/8 DIA

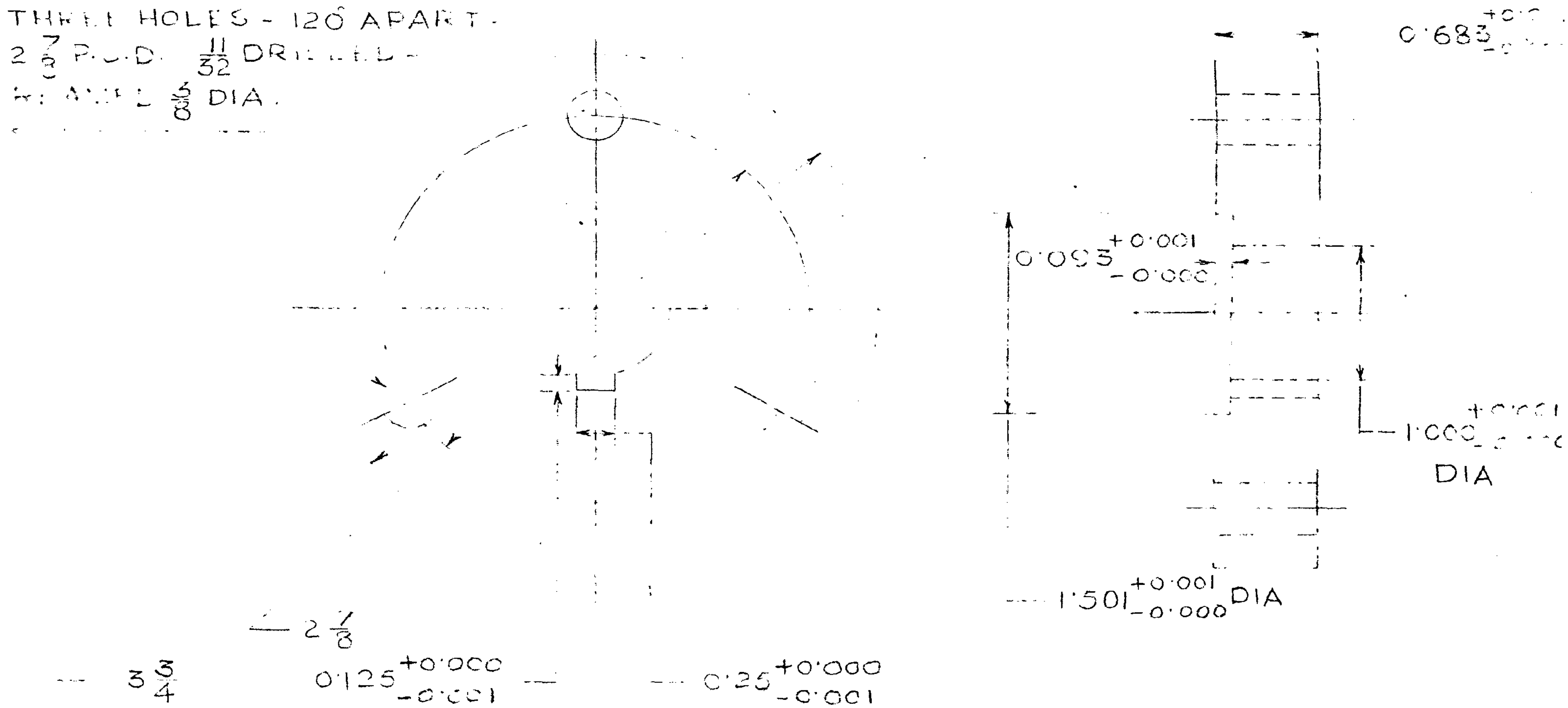
9 MATERIAL – C.I. [illegible]
PROCESS – CAST AND MACHINED
NO. REQD. – 1

UNIVERSITY OF ROORKEE
DEPT. OF MECH. ENGG.

M.E. DISSERTATION ON
"STRENGTH OF SQUARE KEY"
TEST PART HUB

FULL SCALE | 14-6-[illegible] | S D

A 5



10 MATERIAL - C.I. CLOSE GRAINED
PROCESS - CAST AND MACHINED
NO. REQD. - 1

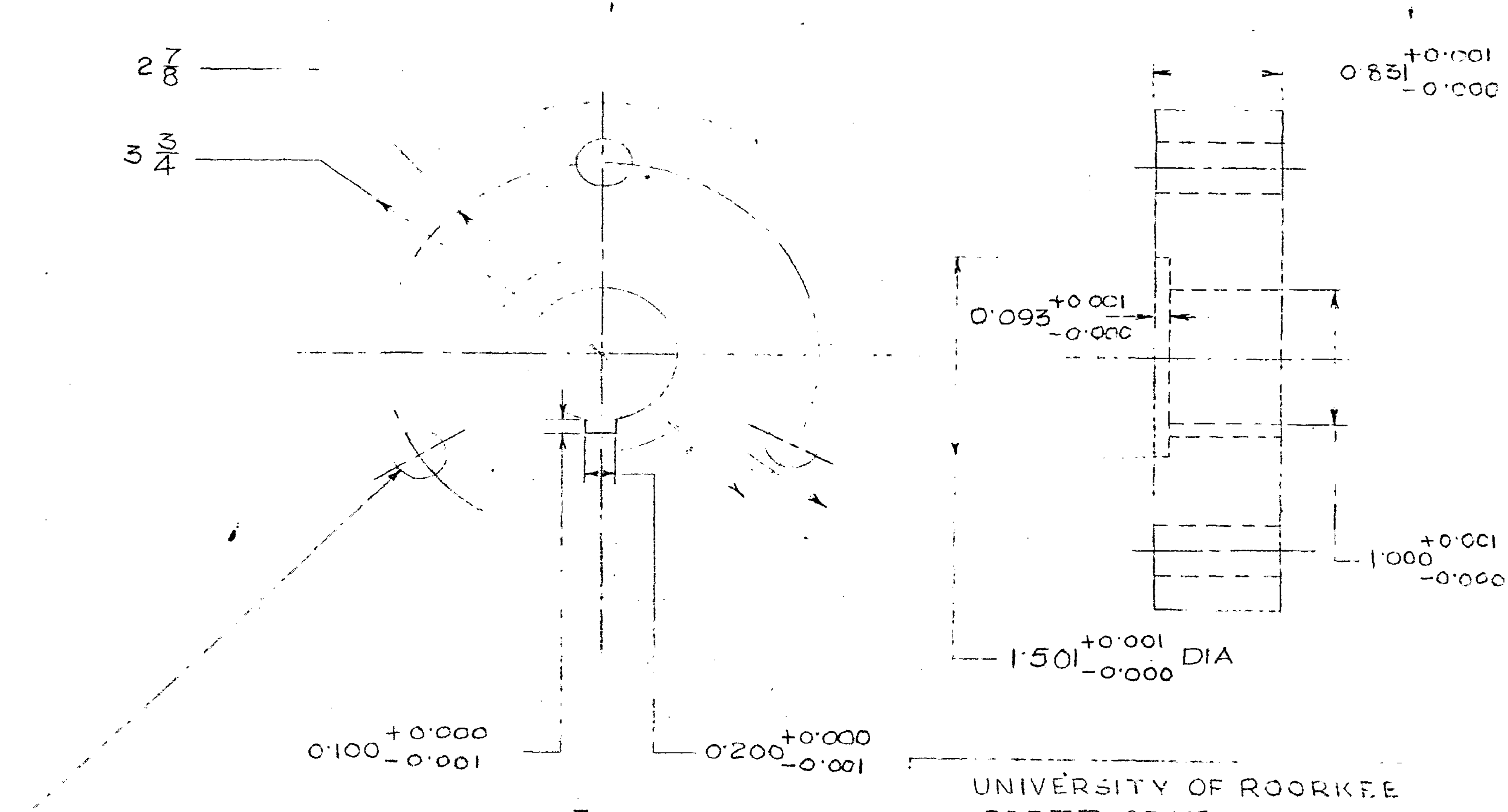
FURTHER INSTRUCTIONS - KEYWAY SHOWN IS MEANT FOR THE TEST OF KEY. TWO MORE KEYWAYS TO BE MADE 120° APART ... CLEARANCE ... KEY.

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART - HUB

FULL SCALE	14 - 5 - 68	S.D.

A - 6



THREE HOLES - 120° APART - $2\frac{7}{8}$ P.C.D.
$\frac{11}{32}$ DRILLED - REAMED $\frac{3}{8}$ DIA

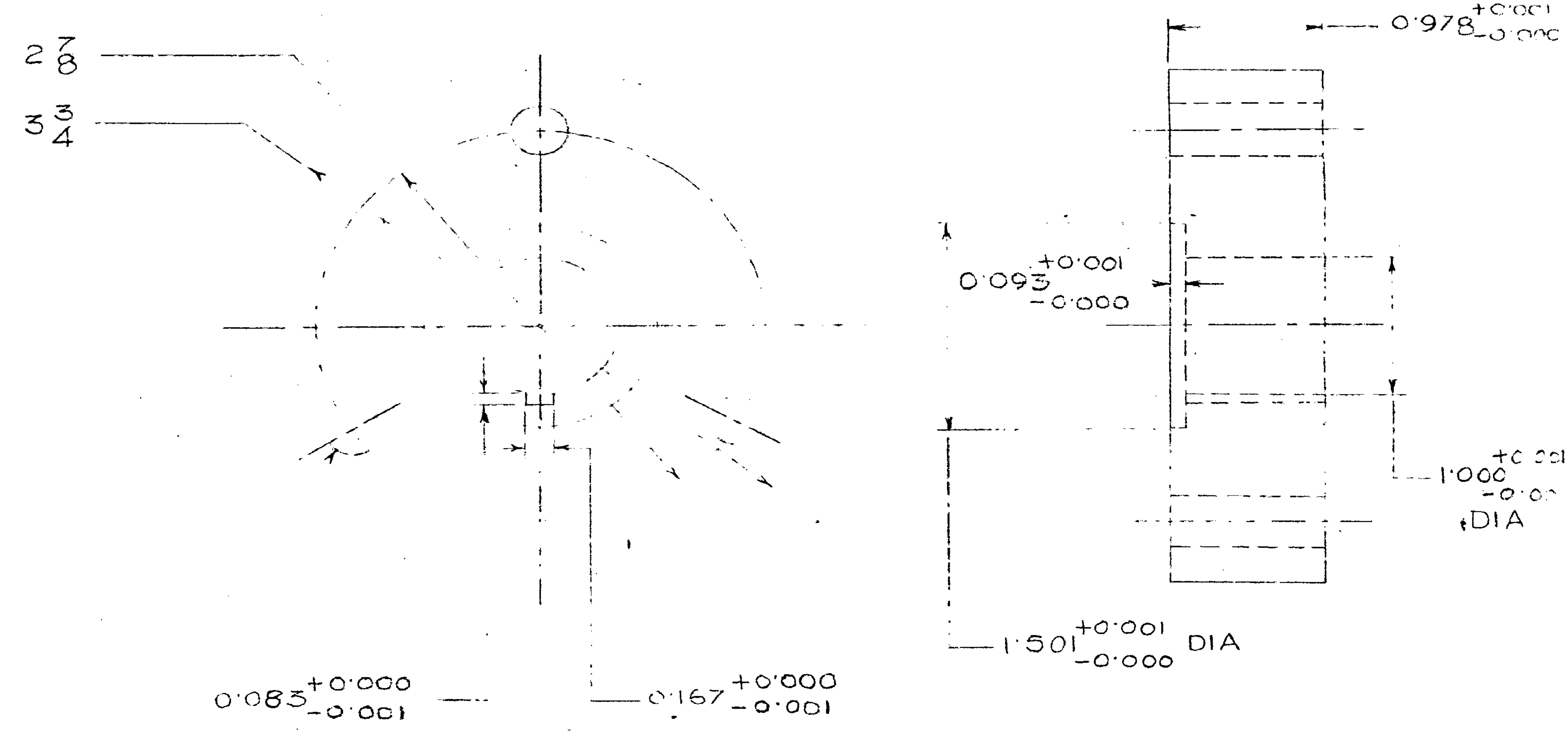
(11) MATERIAL – C.I. CLOSE GRAINED
PROCESS – CAST AND MACHINED
No REQD. – 1

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART - HUB

FULL SCALE	14-6-63	S. D.

A-7

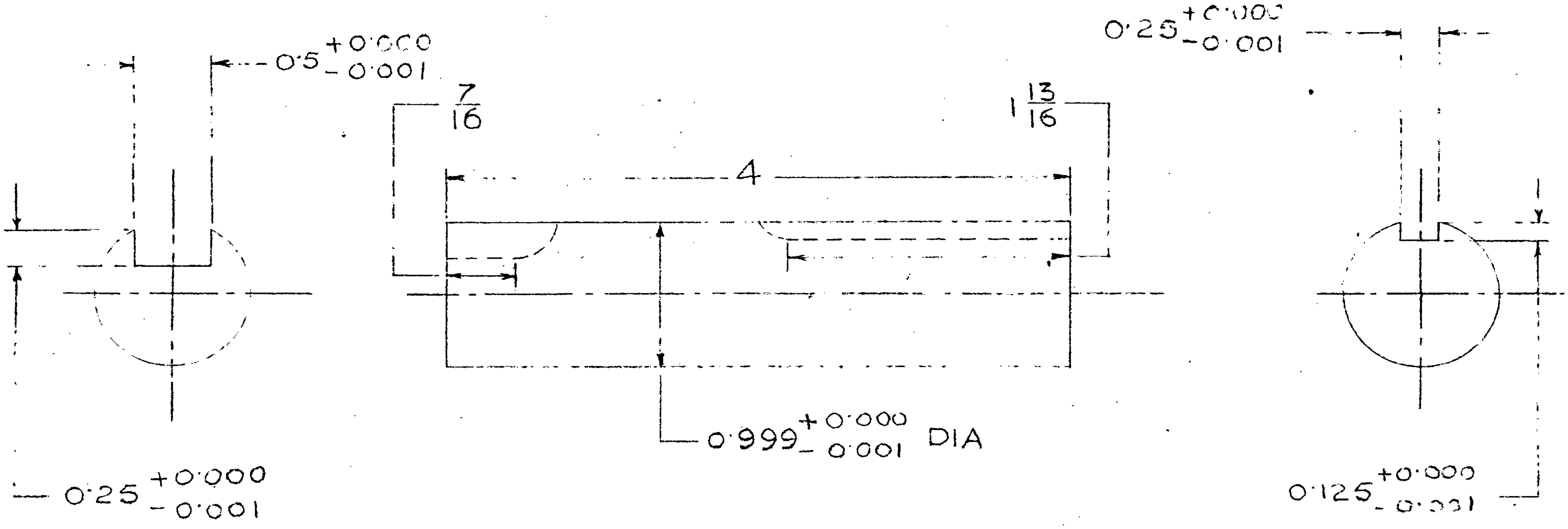


THREE HOLES - 120° APART - $2\frac{7}{8}$ P.C.D.
$\frac{11}{32}$ DRILLED · REAMED $\frac{3}{8}$ DIA

(12) MATERIAL - C.I. CLOSE GRAINED
PROCESS - CAST AND MACHINED
No. REQD - 1

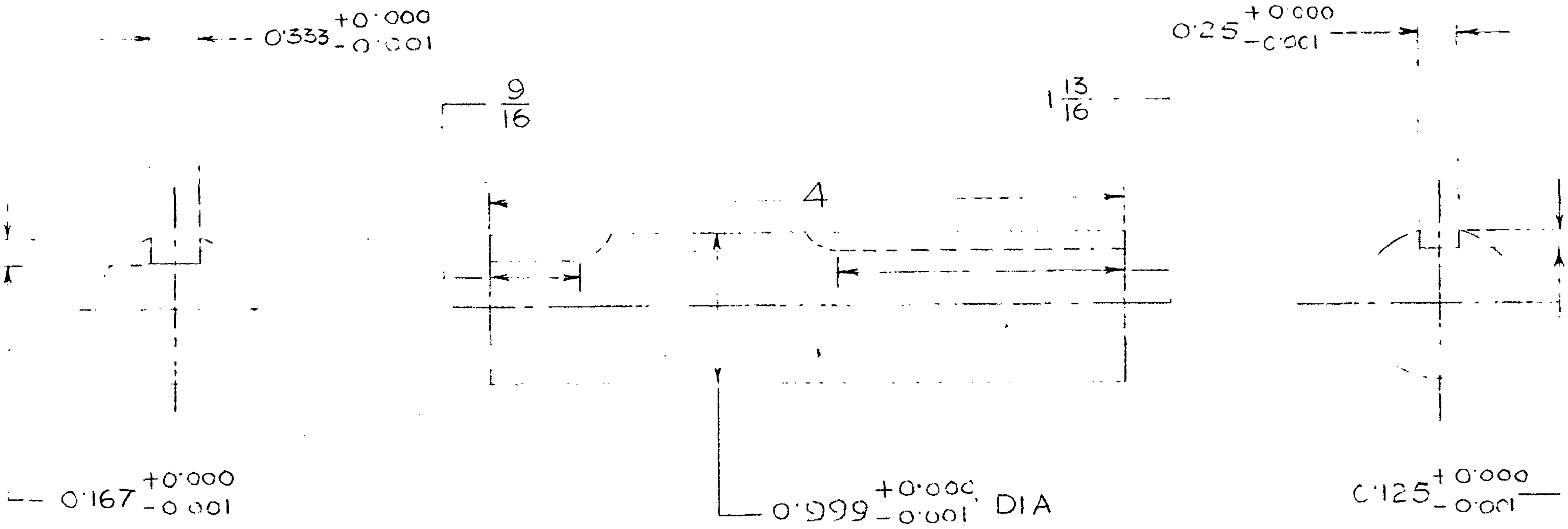
UNIVERSITY OF ROORKEE DEPTT. OF MECH. ENGG.		
.M.E. DISSERTATION "STRENGTH OF SQUARE KEY" TEST PART - HUB		
FULL SCALE	14-6-63	S.D

A-8



(13) MATERIAL – M.S. ROLLED STOCK
PROCESS – MACHINING
No. REQD. – 3

UNIVERSITY OF ROORKEE DEPTT. OF MECH. ENGG.		
M.E. DISSERTATION "STRENGTH OF SQUARE KEY" TEST PART- SHAFT		
FULL SCALE	15-6-63	S.D
A-9		



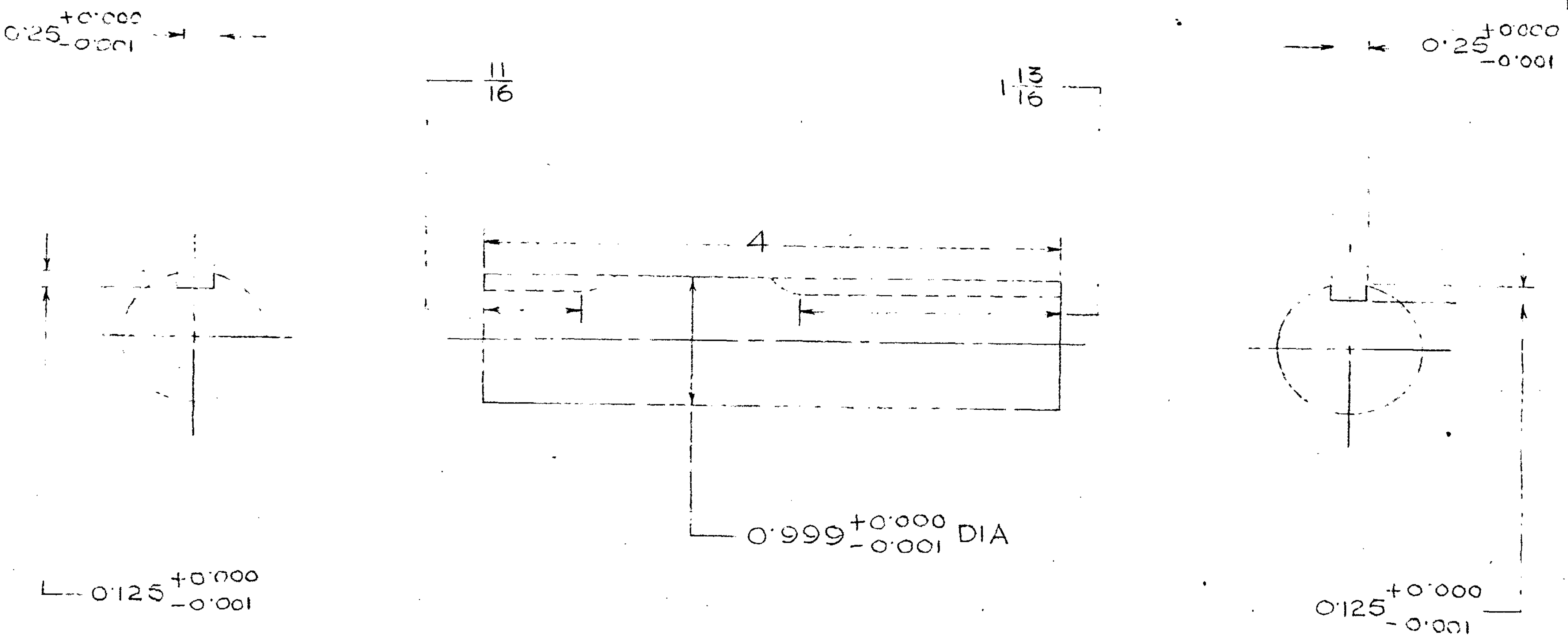
(14) MATERIAL – M.S. ROLLED STOCK
PROCESS – MACHINING
No. REQD. – 3

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – SHAFT

FULL SCALE	17-6-63	S.D.

A-10



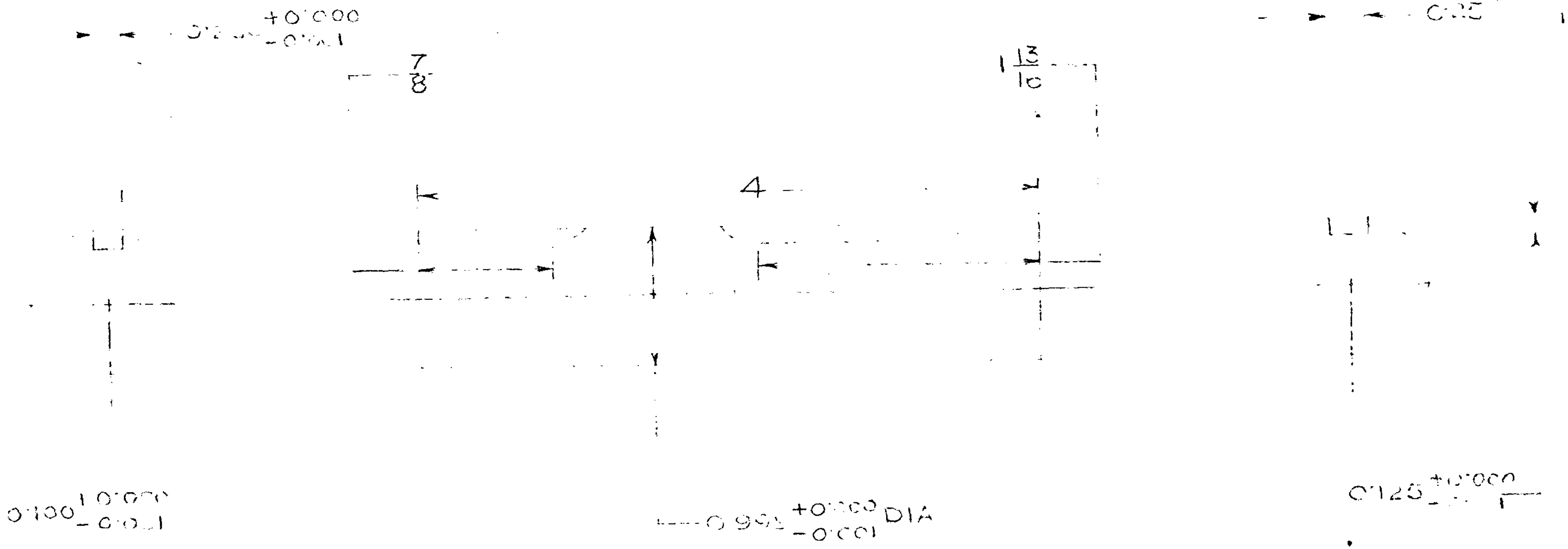
15, MATERIAL _ M.S. ROLLED STOCK
PROCESS _ MACHINING
No. REQD. _ 3

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY
TEST PART - SHAFT

FULL SCALE	17-6-63	S.D.

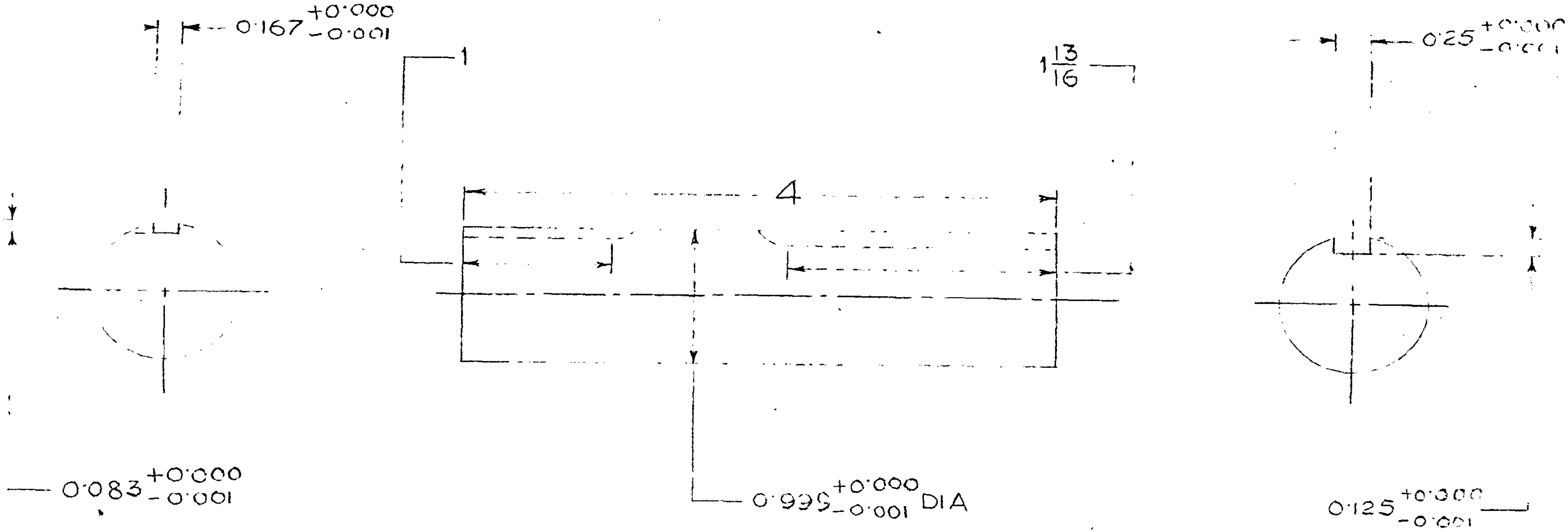
A-11



16 MATERIAL – M.S. ROLLED STOCK
PROCESS – MACHINING
NO. REQD. – 3

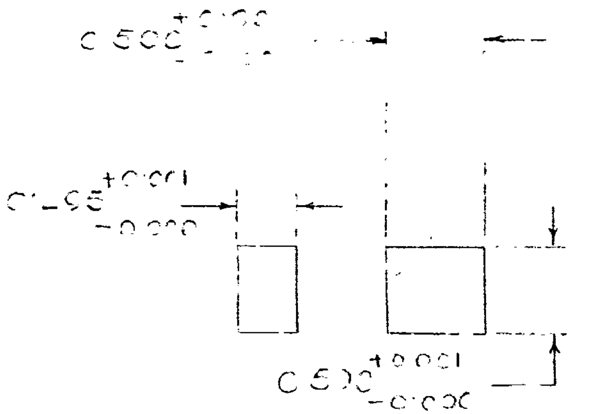
M.E. DISSERTATION

A 12

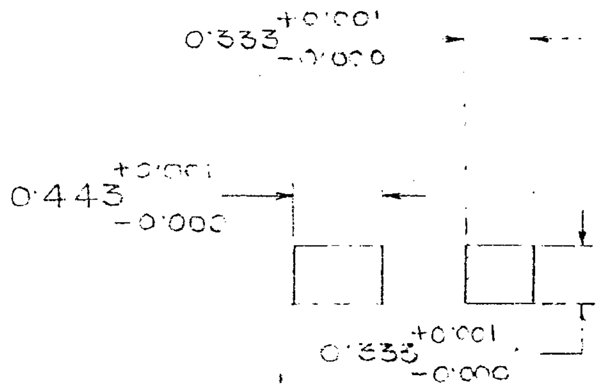


(17) MATERIAL _ M.S. ROLLED STOCK
PROCESS _ MACHINING
No. REQD. _ 3

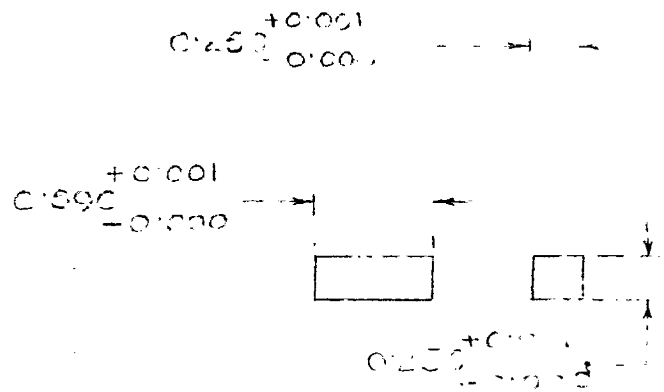
UNIVERSITY OF ROORKEE DEPTT. OF MECH. ENGG.		
M.E. DISSERTATION "STRENGTH OF SQUARE KEY" TEST PART - SHAFT		
FULL SCALE	17-6-63	S. D.
	A 13	



18 MATERIAL – M.S.
PROCESS – MACHINING
NO. REQD. – 3

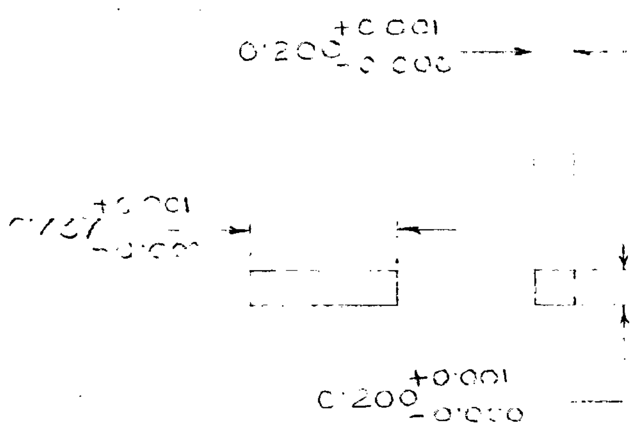


19 MATERIAL – M.S.
PROCESS – MACHINING
NO. REQD – 3

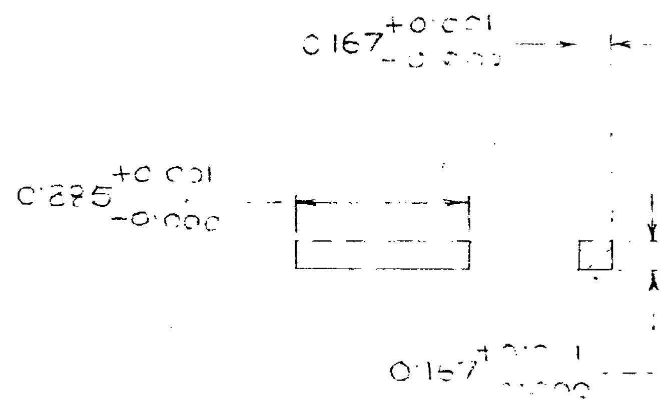


20 MATERIAL – M.S.
PROCESS – MACHINING
NO. REQD. – 3

NOTE: ALL KEYS TO BE MACHINED OUT OF SAME LENGTH OF STOCK AS USED FOR MAKING SHAFT.



21 MATERIAL – M.S
PROCESS – MACHINING
NO. REQD. – 3



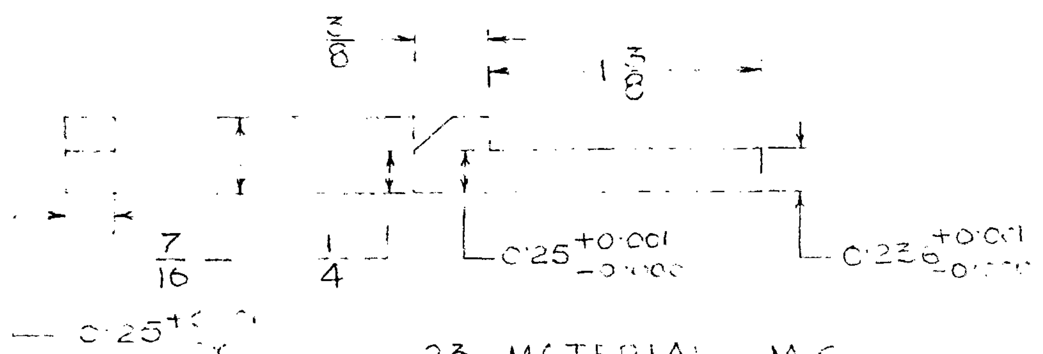
22 MATERIAL – M.S.
PROCESS – MACHINING
NO. REQD – 3

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

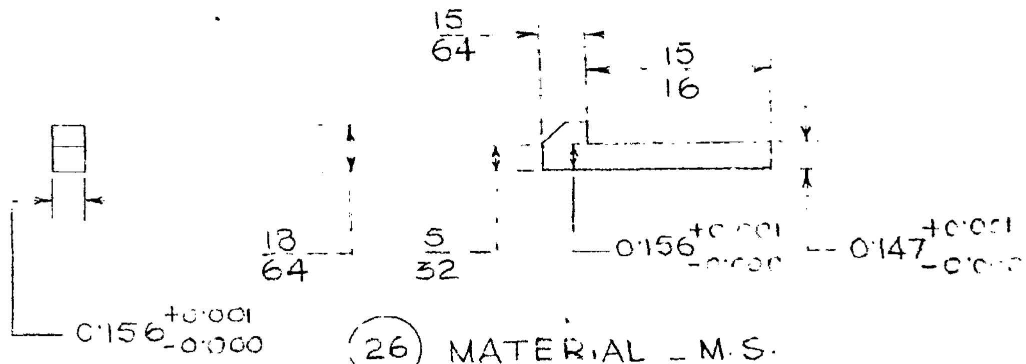
M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – KEYS

FULL SCALE	19-6-65	S.D.

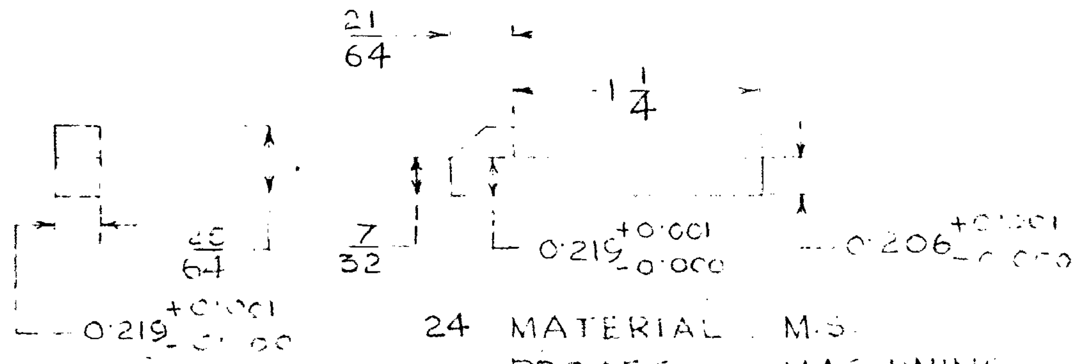
A-14



23 MATERIAL – M.S.
PROCESS – MACHINING
No. REQD. – 1

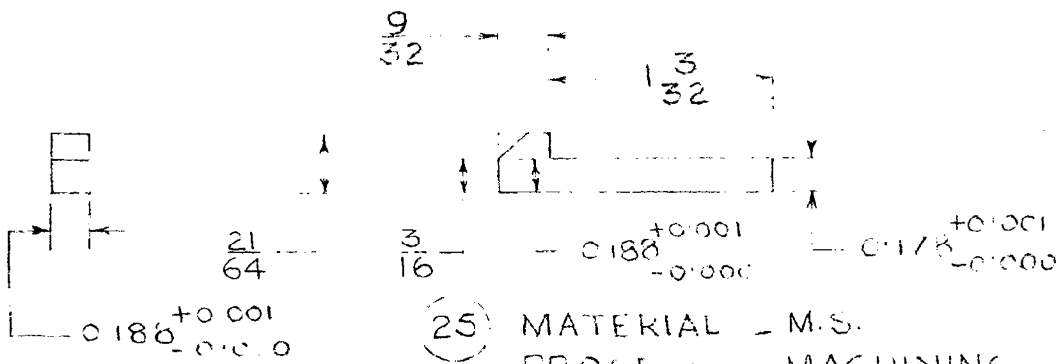


26 MATERIAL – M.S.
PROCESS – MACHINING
No. REQD. – 1



24 MATERIAL – M.S.
PROCESS – MACHINING
No. REQD – 1

NOTE: TAPER ON ALL KEYS – 1 IN 100
ACTUAL SIZE REQD. SHOWN
ON DRAWINGS.



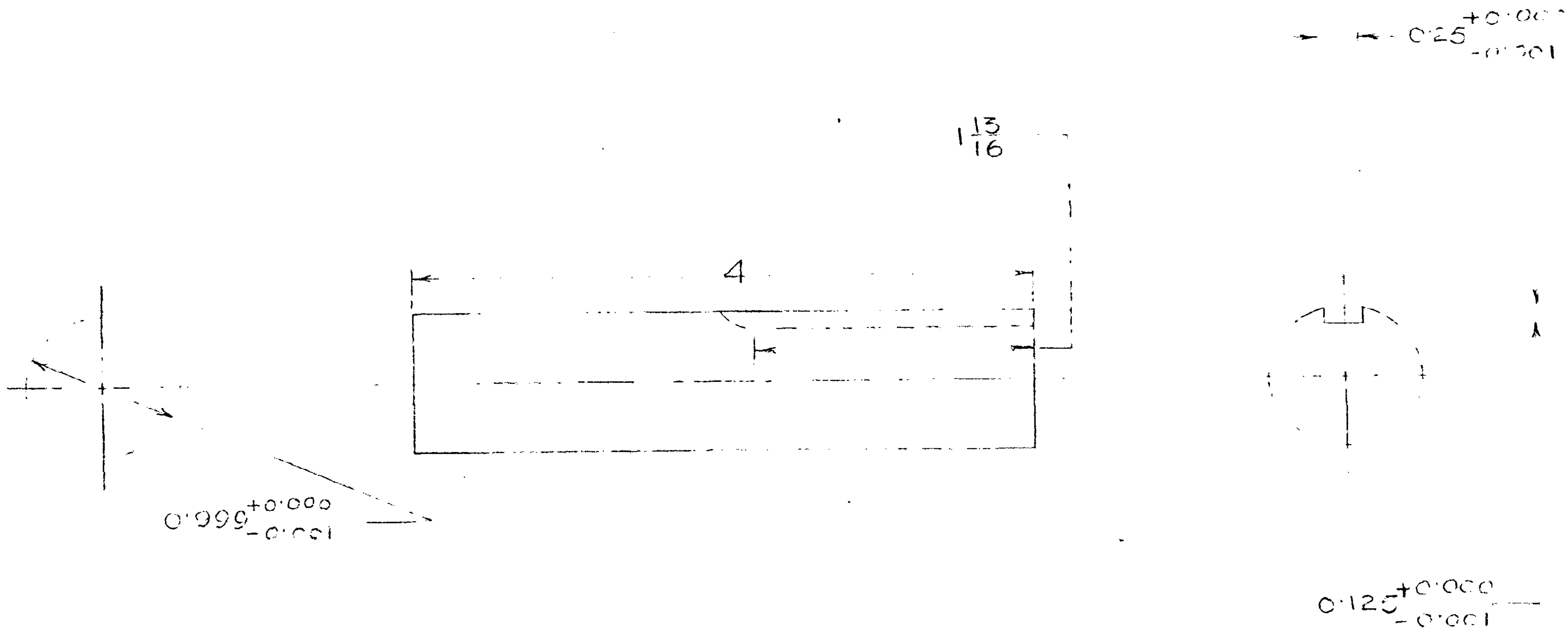
25 MATERIAL – M.S.
PROCESS – MACHINING
No. REQD. – 1

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – KEYS

FULL SCALE | 20-6-03 |

A-15

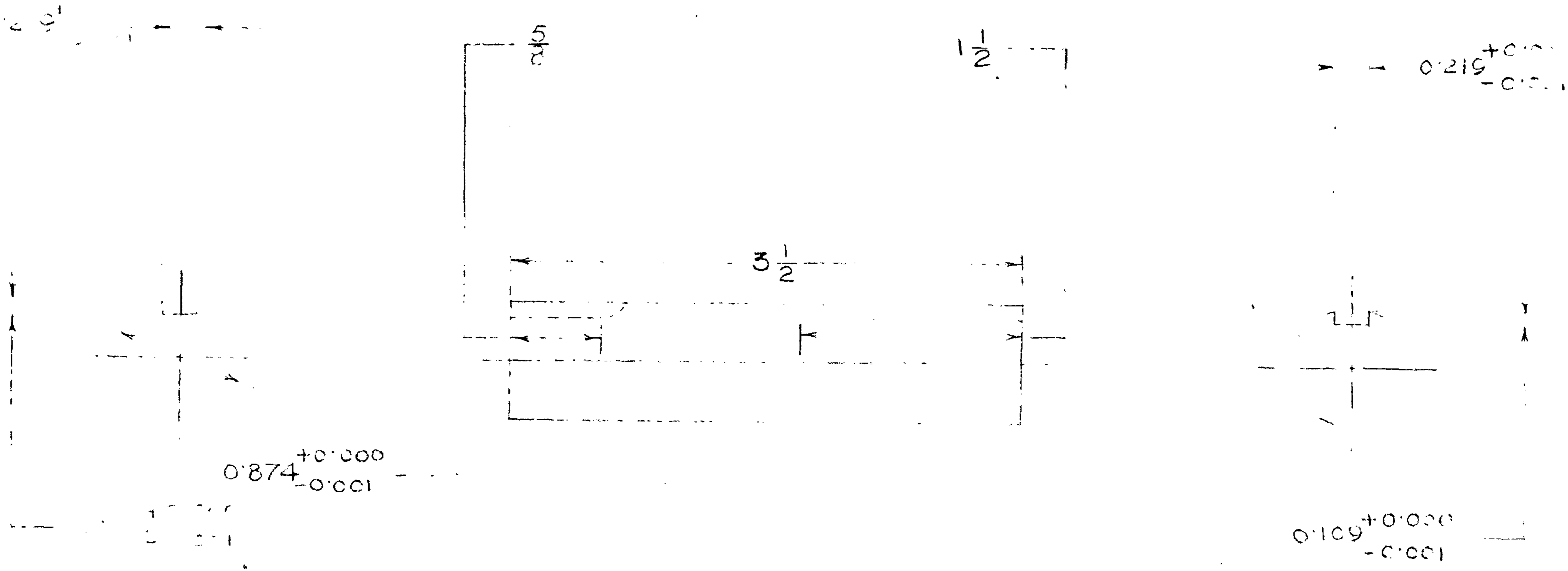


(27) MATERIAL – M.S. ROLLED STOCK
PROCESS – MACHINING.
NO. REQD. – 6

FURTHER INSTR[illegible]TION –
KEYWAY [illegible] SIDE ON ALL SHAFTS TO BE CUT
EXA[illegible]Y AS IN DRG. A-11

UNIVERSITY OF ROORKEE DEPTT. OF MECH ENGG.		
M.E. DISSERTATION "STRENGTH OF SQUARE KEY" TEST PART- SHAFT		
FULL SCALE	21-6-63	S D

A-16



(28) MATERIAL _ M.S. ROLLED STOCK
PROCESS _ MACHINING
No. REQD. _ 9

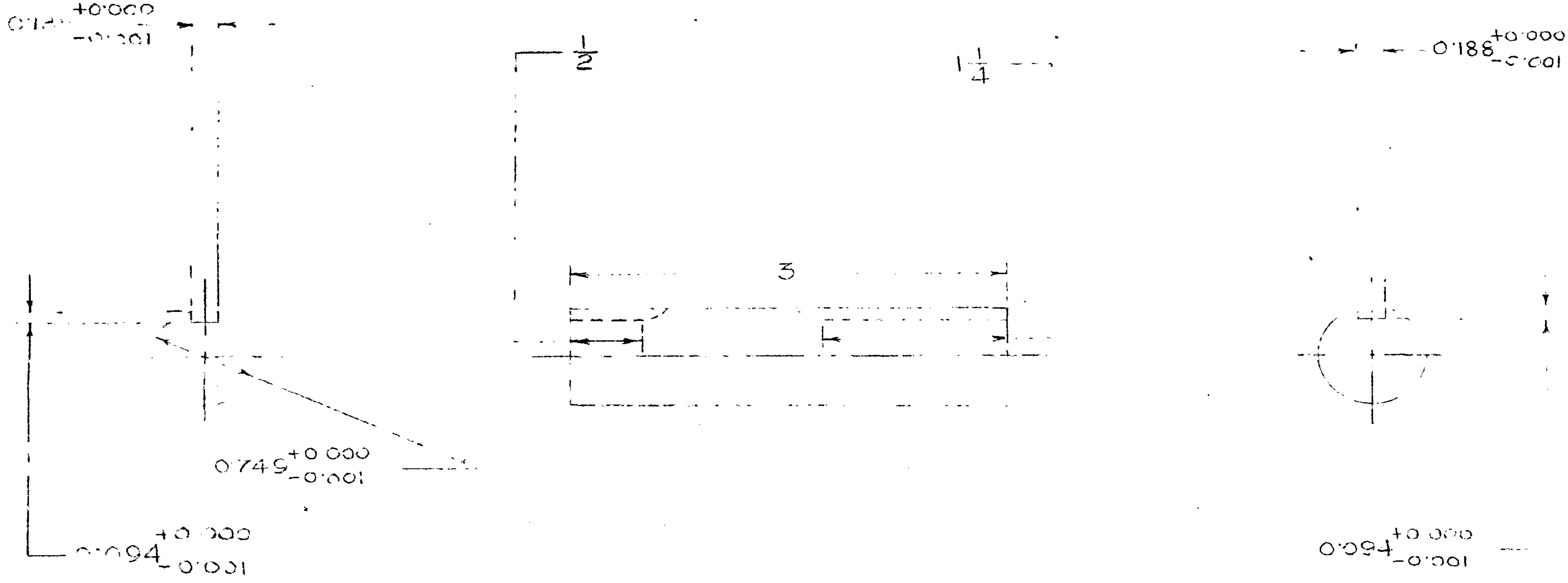
FURTHER INSTRUCTION _
KEY WAY ON LEFT SIDE IN ALL SHAFTS AS SHOWN

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART - SHAFT

FULL SCALE	21-6-63	S.D.

A-17



(29) MATERIAL – M.S. ROLLED STOCK
PROCESS – MACHINING
No. REQD. – 9

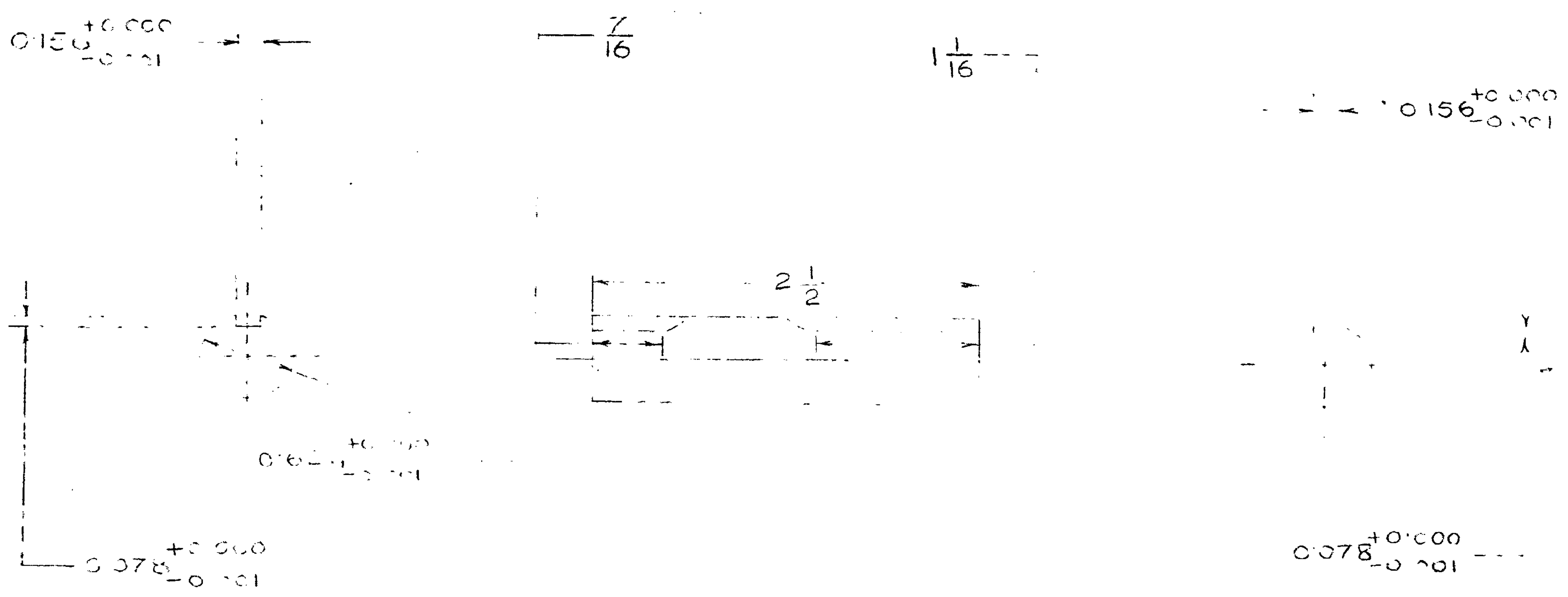
FURTHER INSTRUCTION –
KEYWAY ON LEFT SIDE ON ALL SHAFTS AS SHOWN

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – SHAFT

FULL SCALE	21-6-63	S.D.

A-18



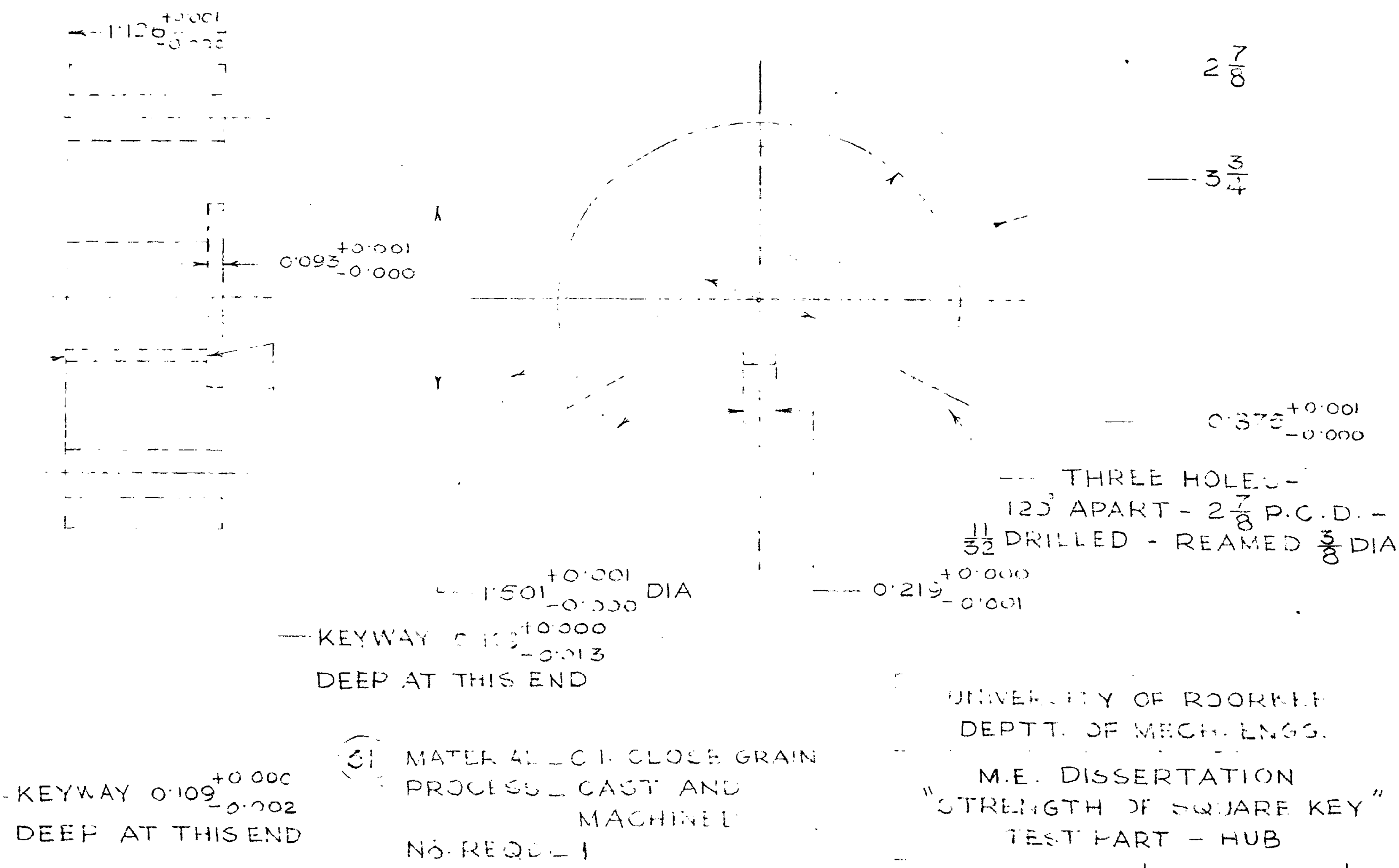
MATERIAL – M.S. ROLLED STOCK
PROCESS – MACHINING
NO. REQD. – 9

FURTHER INSTRUCTION.
KEYWAY ON LEFT SIDE ON ALL SHAFTS AS SHOWN

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.
M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – SHAFT

FULL SCALE	21-6-63	S.D.

A-19



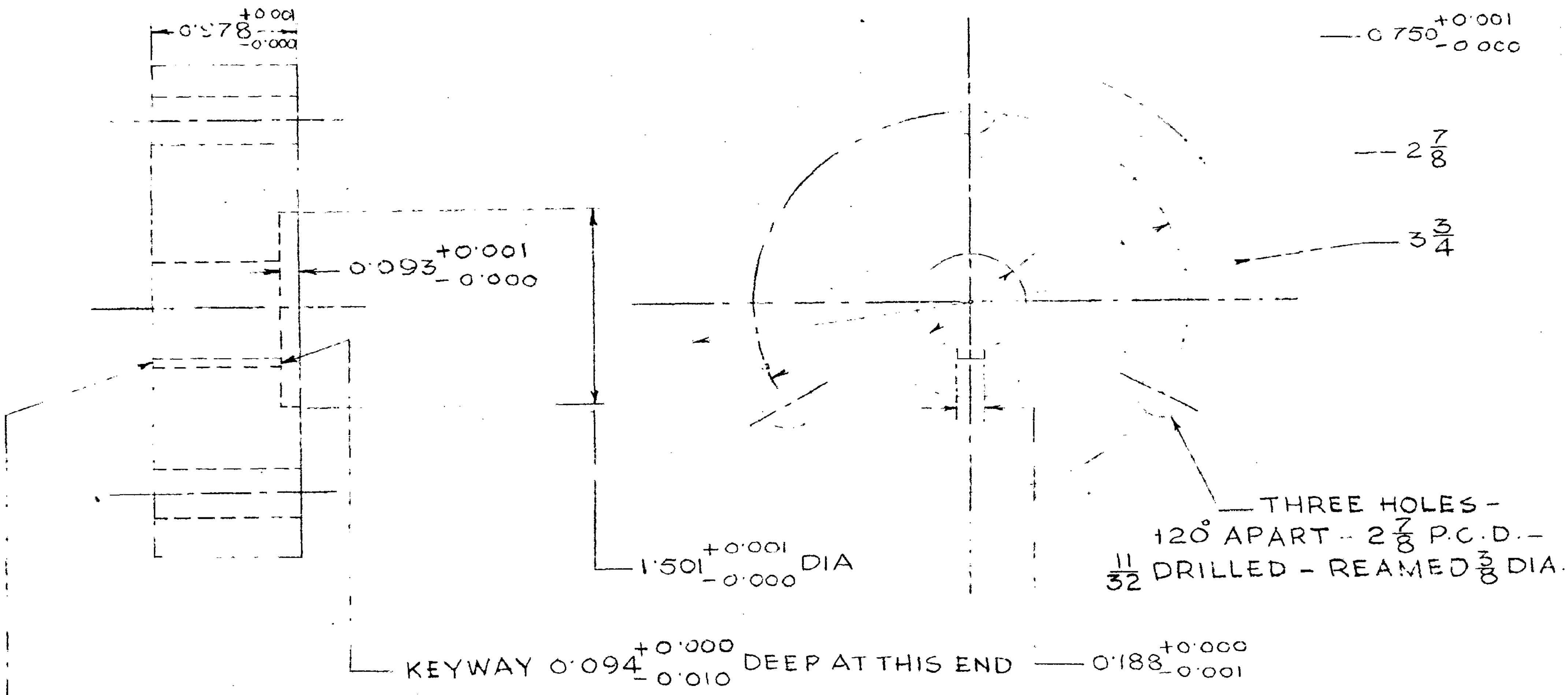
UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – HUB

FULL SCALE	25-6-63	S.D.

A-20

112



KEYWAY 0·094 $^{+0\cdot000}_{-0\cdot002}$
DEEP AT THIS END

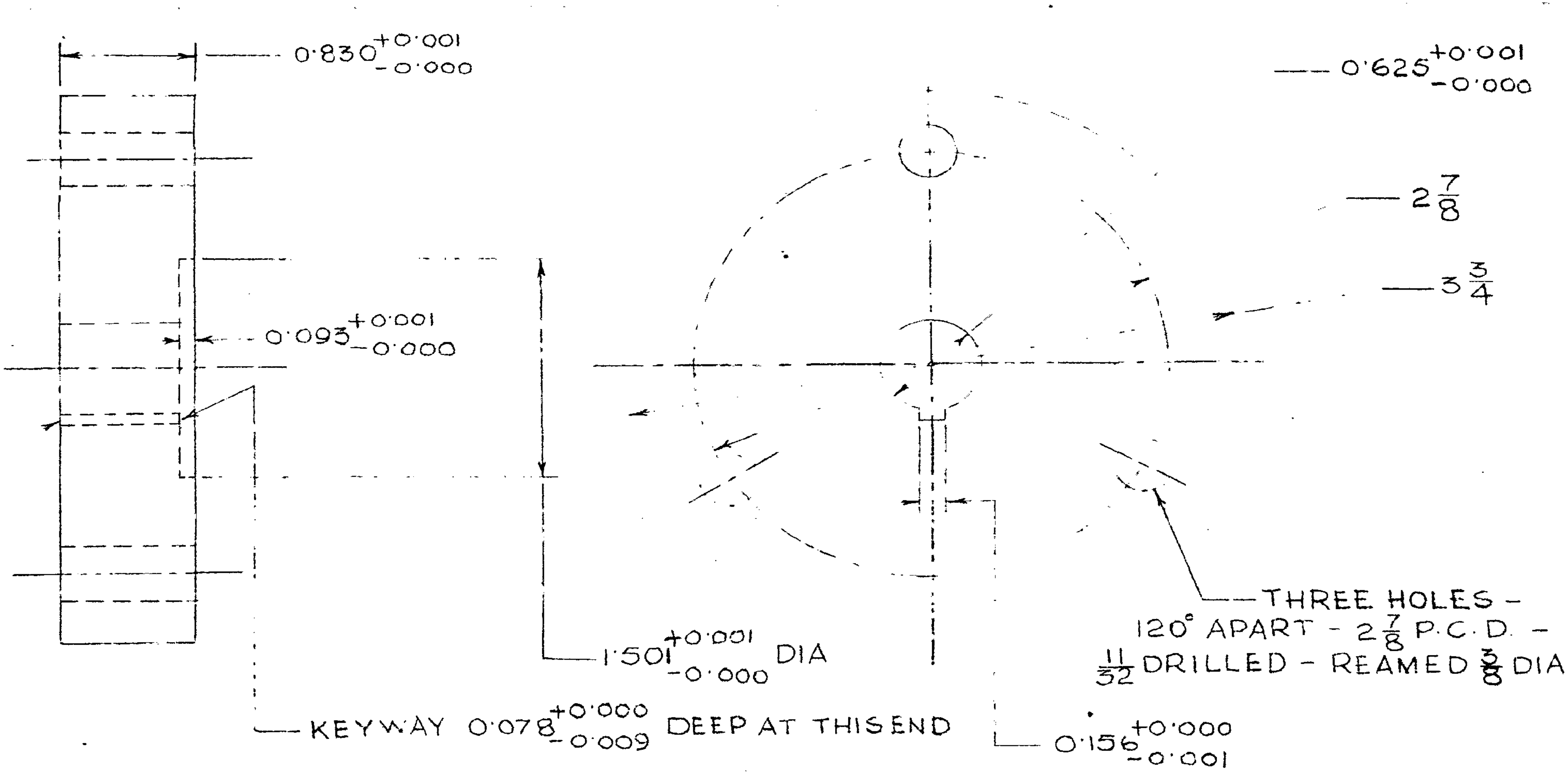
(32) MATERIAL – C.I. CLOSE GRAIN
PROCESS – CAST AND MACHINED
No. REQD. – 1

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – HUB

FULL SCALE	25-6-63	S.D.

A-21



KEYWAY 0·078 $^{+0.000}_{-0.002}$
DEEP AT THIS END

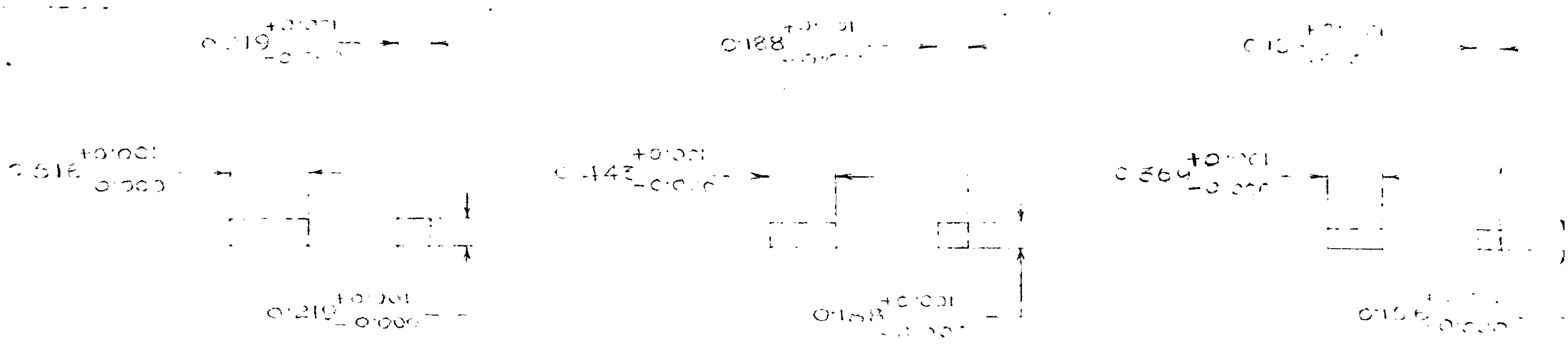
(33) MATERIAL – C.I. CLOSE GRAIN
PROCESS – CAST AND MACHINED
No. REQD. – 1

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – HUB

FULL SCALE	25-6-63	S D.

A-22



(34) MATERIAL – M.S.
PROCESS – MACHINING
NO. REQD. – 9

(35) MATERIAL – M.S.
PROCESS – MACHINING
NO. REQD. – 9

(36) MATERIAL – M.S.
PROCESS – MACHINING
NO. REQD. –

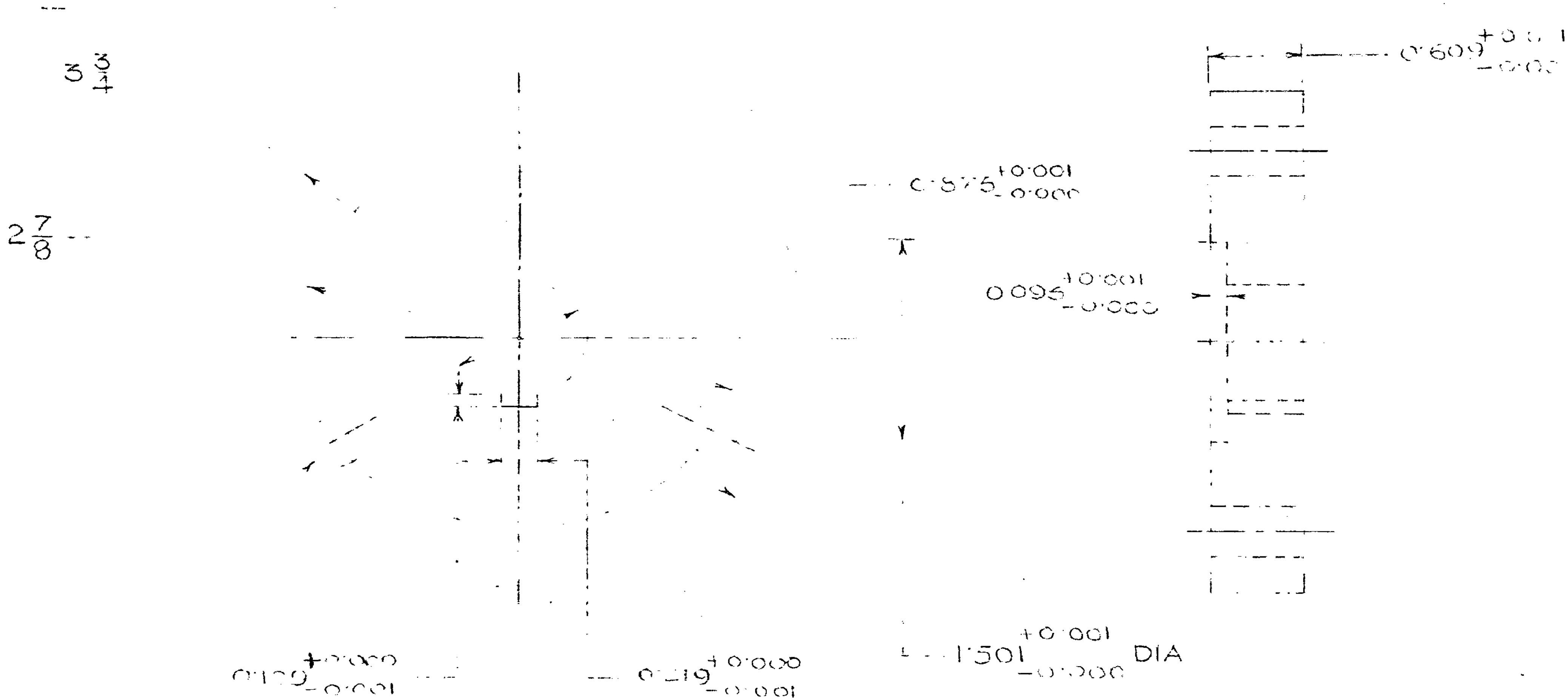
NOTE. ALL KEYS TO BE MACHINED OUT OF SAME LENGTH OF STOCK AS USED FOR MAKING SHAFTS.

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART – KEYS

FULL SCALE | 22-7-63 | S.D.

A



THREE HOLES - 120° APART - $2\frac{7}{8}$ P.C.D.
$\frac{11}{32}$ DRILLED REAMED $\frac{3}{8}$ DIA

(37) MATERIAL _ C.I. CLOSE GRAINED
PROCESS _ CAST AND MACHINED
NO. REQD. _ 1

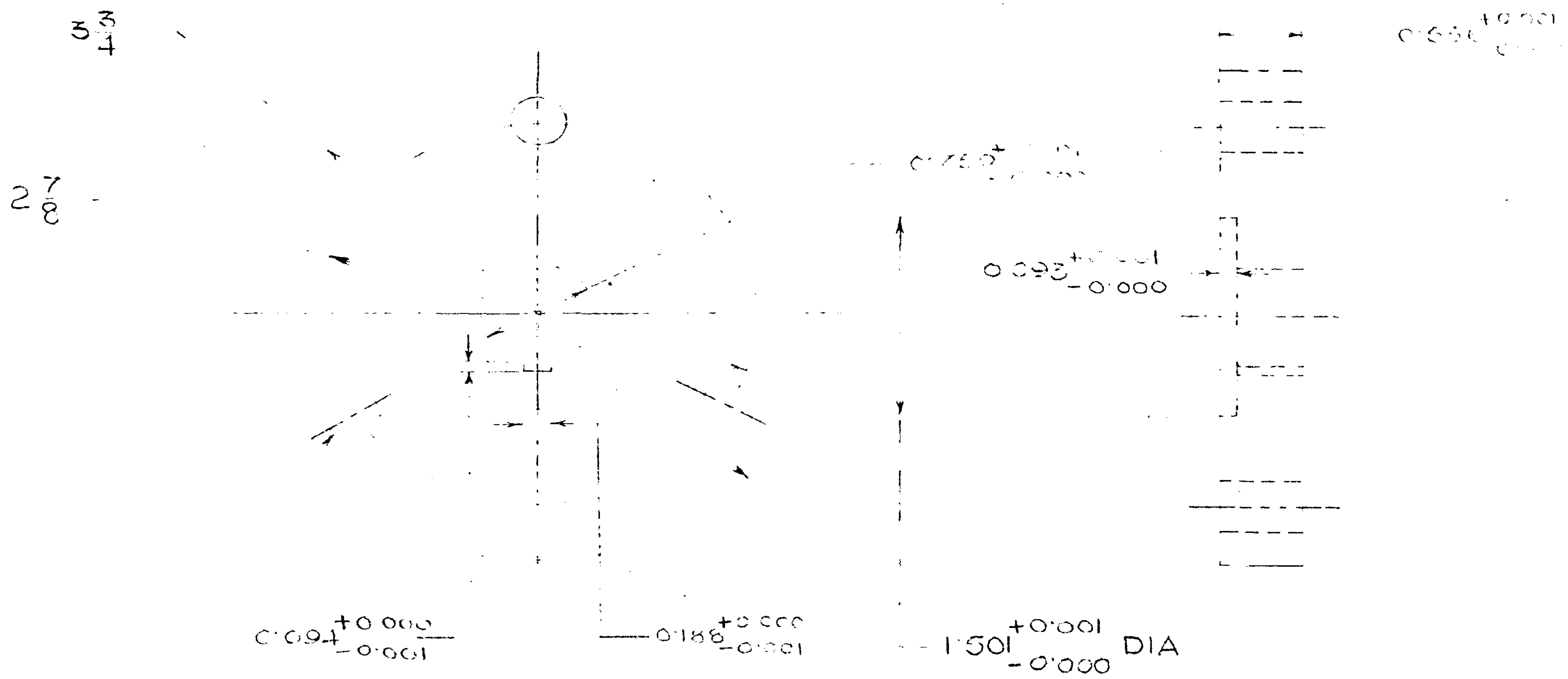
FURTHER INSTRUCTION _ KEYWAY SHOWN IS MEANT FOR TIGHT FIT OF KEY. TWO MORE KEYWAYS TO BE MADE 120° APART TO GIVE 0.003 AND 0.006 CLEARANCE AROUND KEY.

UNIVERSITY OF ROORKEE
DEPT. OF MECH. ENGG.

M.E. DISSERTATION ON
"STRENGTH OF SQUARE KEY"
TEST PART HUB

FULL SCALE	24-7-63	S.D

A-4



THREE HOLES - 120° APART $2\frac{7}{8}$ P.C.D.
$\frac{11}{32}$ DRILLED - REAMED $\frac{3}{8}$ DIA

(38) MATERIAL – C.I. CLOSE [illegible]
PROCESS – CAST AND MACHINED
NO. REQD – 1

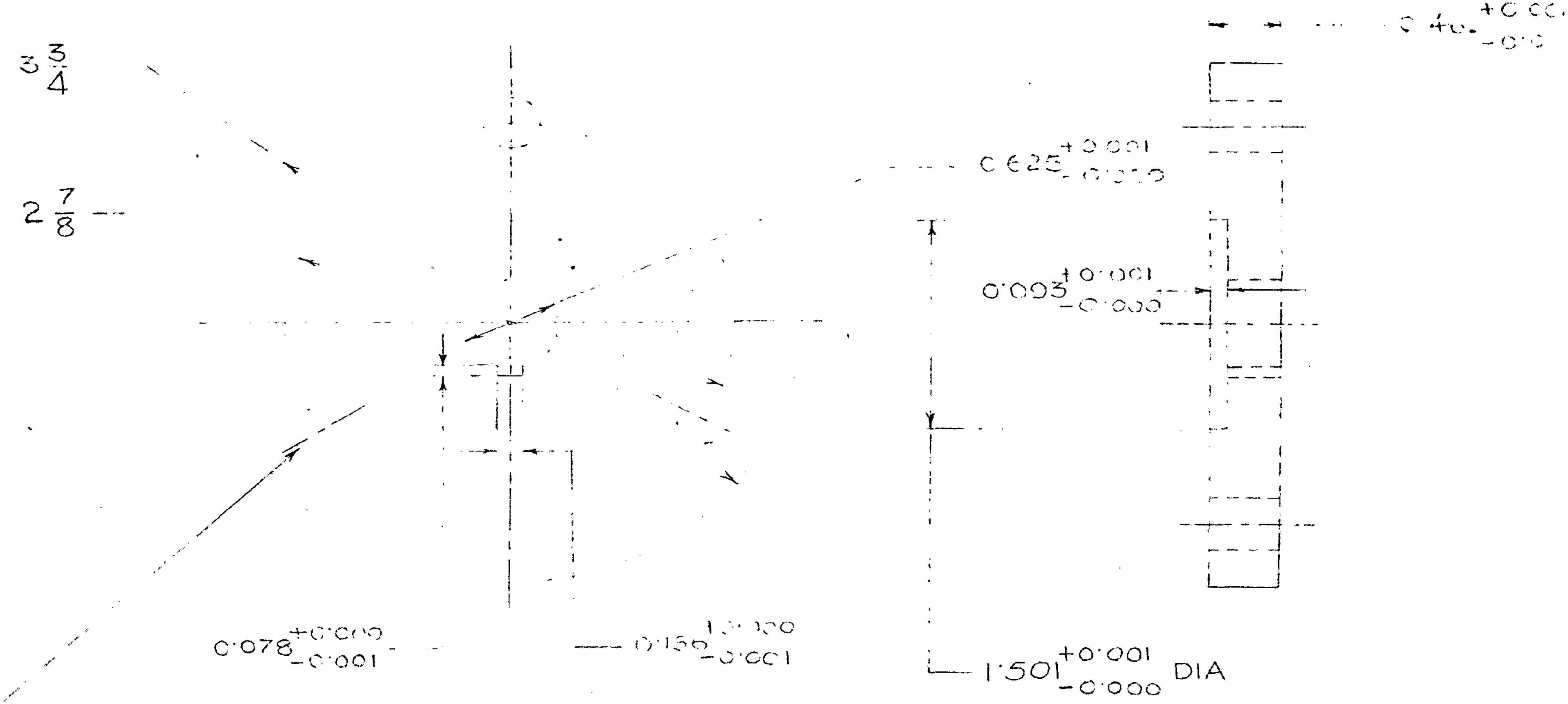
FURTHER INSTRUCTION – KEYWAY SHOWN IS MEANT FOR TIGHT FIT OF KEY. TWO MORE KEYWAYS TO BE MADE 120° APART TO GIVE [illegible] AND [illegible] CLEARANCE AROUND KEY.

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. [illegible]
"STRENGTH OF SQUARE KEY"
TEST PART – HUB

FULL SCALE 24-[illegible]-63 S.D.

A 25



THREE HOLES - 120° APART - 2 7/8 P.C.D.
11/32 DRILLED - REAMED 3/8 DIA

39 MATERIAL — C.I. CLOSE GRAINED
PROCESS — CAST AND MACHD.
No. REQD. — 1

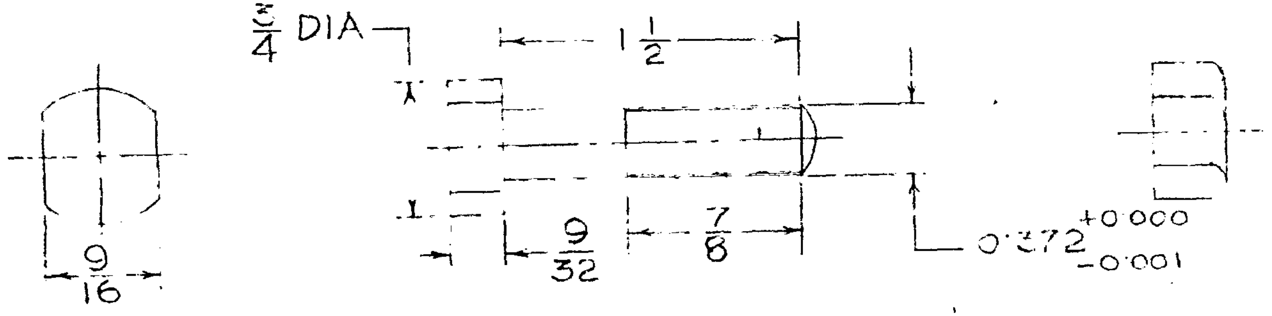
FURTHER INSTRUCTI[illegible] KEYWAY SHOWN IS MEANT FOR TIGHT FIT OF KEY. TWO MORE KEYWAYS TO BE MADE [illegible] TO GIVE 0.003 AND 0.006 CLEARA[illegible] [illegible] KEY.

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

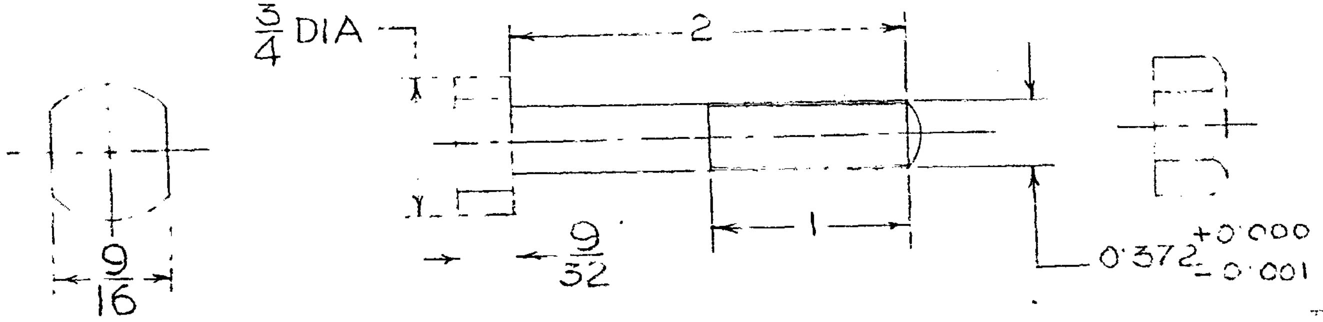
M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
TEST PART - HUB

FULL SCALE 24-7-65 S.D.

A-26



(40) M.S. BOLTS - RT. HAND B.S.W. - 16 T.P.I. - WITH NUTS
No. REQD. - 3



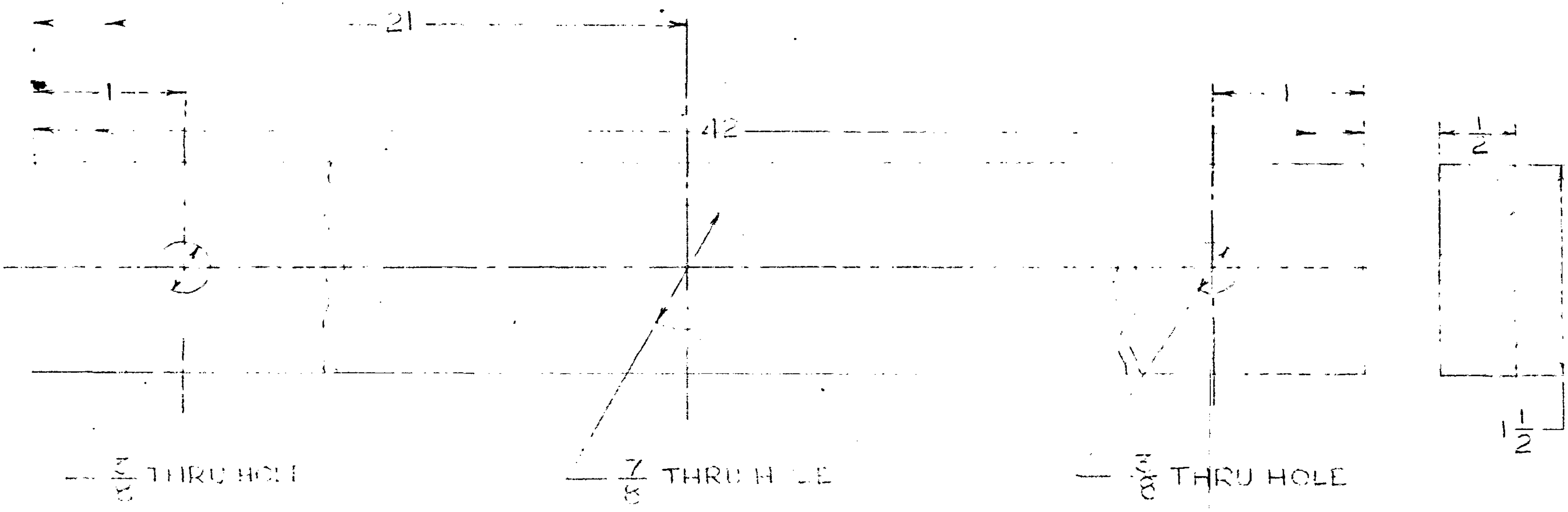
(41) M.S. BOLTS - RT. HAND B.S.W. - 16 T.P.I. - WITH NUTS
No. REQD. - 3

UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
FIXTURE

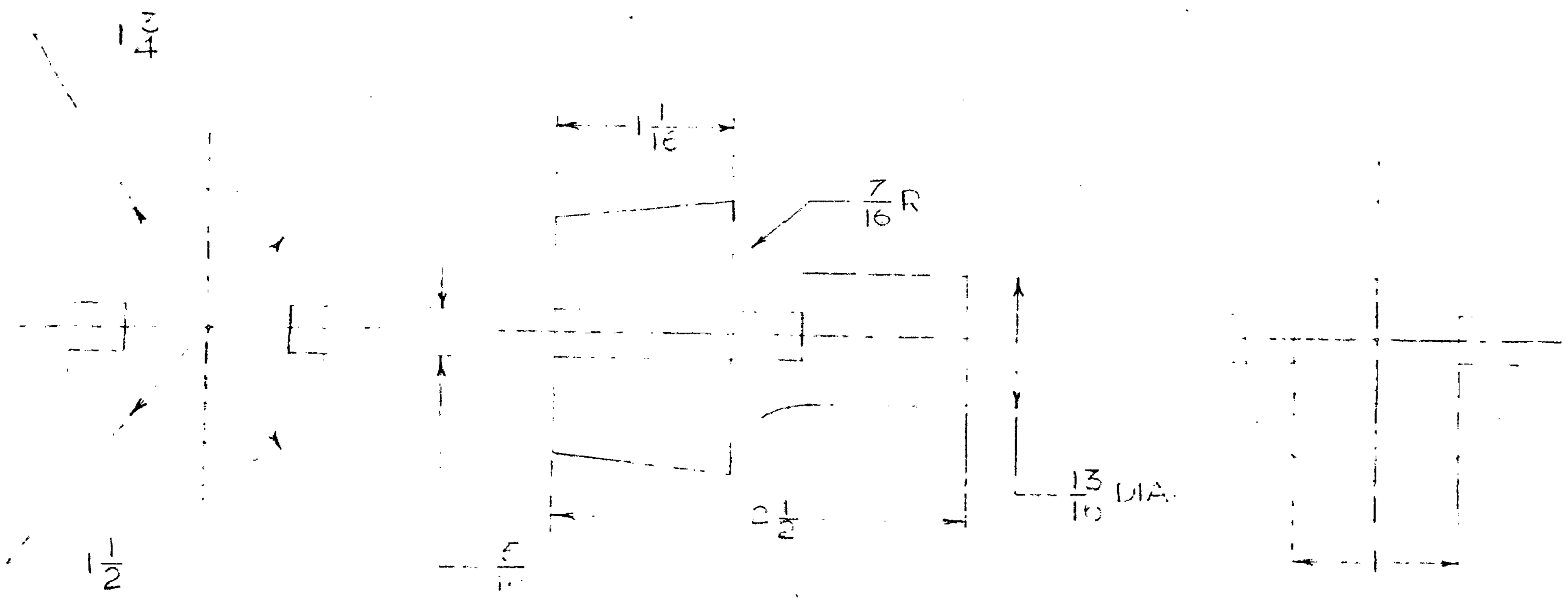
FULL SCALE	24-7-63	S.D

A-27



(12) M.S. BEAM
NO. REQD. 1

UNIVERSITY OF ROORKEE DEPTT. OF MECH. ENGG.
M.E. DISSERTATION "STRENGTH OF SQUARE KEY CALIBRATION [illegible]
FULL SCALE 5-8-[illegible]
A-28



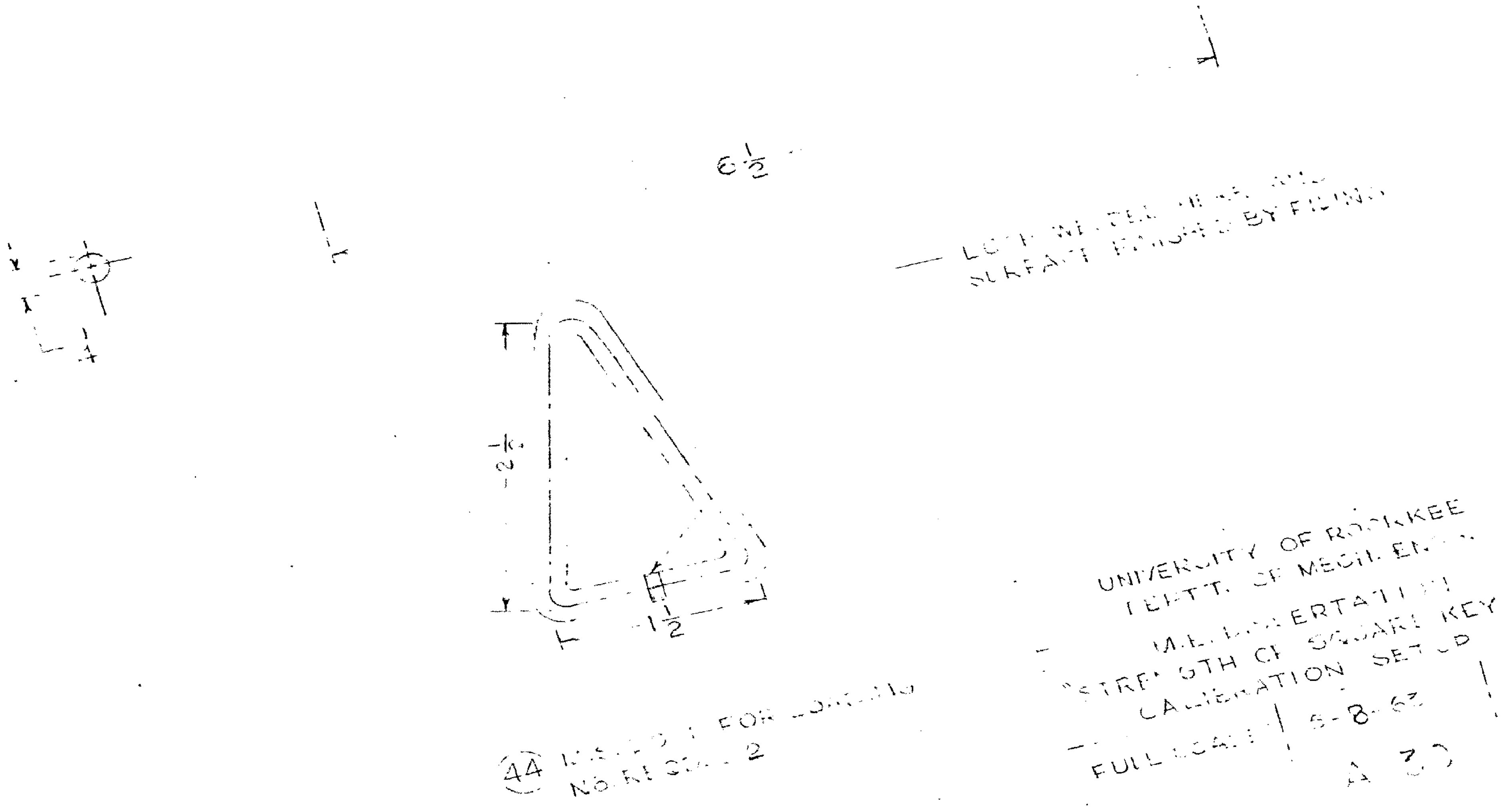
(13) M.S. TORSION PIECE
NO REQD. 1

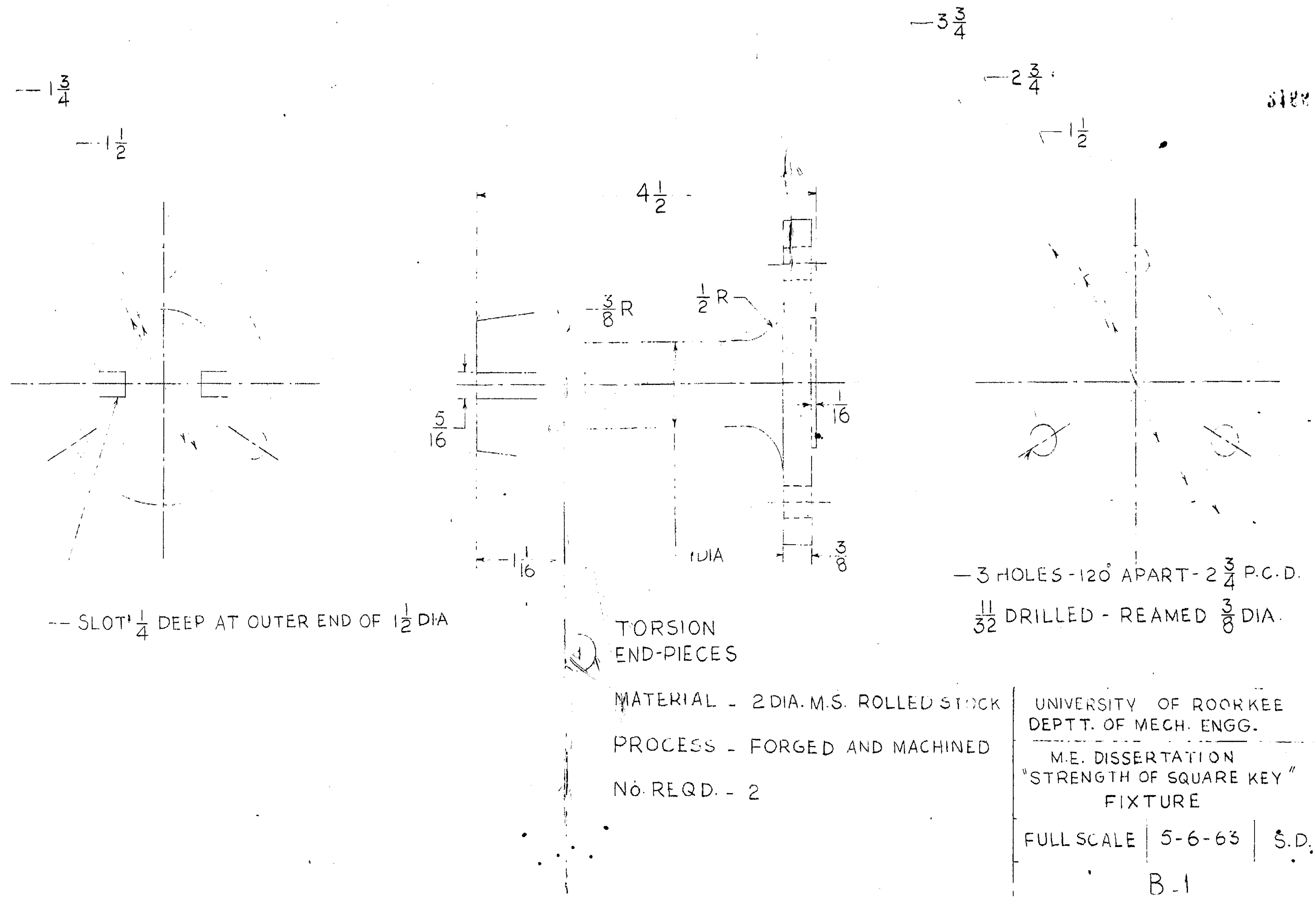
UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.

M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
CALIBRATION SETUP

FULL SCALE	5-8-63	S.C

A 29


6 1/2
1 1/2
44
FOR
CALIBRATION SET UP
FULL



1 3/4
1 1/2
SLOT 1/4 DEEP AT OUTER END OF 1 1/2 DIA
4 1/2
3/8 R
1/2 R
5/16
1/16
1 1/16
1 DIA
3/8
3 3/4
2 3/4
1 1/2
3 HOLES - 120° APART - 2 3/4 P.C.D.
11/32 DRILLED - REAMED 3/8 DIA.
TORSION
END-PIECES
MATERIAL - 2 DIA. M.S. ROLLED STOCK
PROCESS - FORGED AND MACHINED
No. REQD. - 2
UNIVERSITY OF ROORKEE
DEPTT. OF MECH. ENGG.
M.E. DISSERTATION
"STRENGTH OF SQUARE KEY"
FIXTURE
FULL SCALE
5-6-63
S.D.
B-1

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