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The Use of Quartz in the Manufacture of Small Diameter Pitot Tubes

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The use of quartz in the manufacture of small diameter pitot tubes

by

J.R. Cooke, N.A.E.

SUMMARY

This note describes the method of manufacture of small quartz-tipped pitot tubes (down to 0.005 in. outside tip diameter) which have been used successfully for boundary layer measurements on small models in a supersonic wind tunnel.

Tests have been made (a) of the effects of taper and end finish on the accuracy of measurement and (b) of the effect of the inside diameter of the tip (for a standard taper) on response rate. For a given inside tip diameter the tapered quartz tubes gave a faster response rate than the stainless steel hypodermic tubes previously used.

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1 Introduction

The relatively thin boundary layers encountered in wind tunnel tests at supersonic speeds necessitate the development of pitot tubes of extremely small dimensions. The most common method of doing this has been to flatten small stainless steel hypodermic tubing (original outside diameter = 0.020") and then to hone this to an overall height of approximately 0.010" or less if desired.

Now as Bradfield and Yale[1] have stated, the optimum shape at the entry to a pitot tube for a fast response rate is obtained if the bore expands immediately behind the mouth. The reason for this is that such a shape keeps the length of the smallest diameter passageway to a minimum. (In this passageway the Reynolds number will be small because of its small height and the friction coefficient will be correspondingly high). Unfortunately the process of flattening tubes tends to produce a fairly long passageway with little expansion which together with the small inside diameter of the tubing used (usually about 0.010" for 0.020" outside diameter tubing) causes a considerable restriction.

On the other hand the technique of drawing down quartz tube described in this report gives a pitot head with an entry much closer to the optimum shape and with a much improved response rate for a given tip diameter.

Acknowledgement

The author would like to acknowledge the help given by Mr. M.W. Walkden in the manufacture and testing of the tubes described in this report.

2 Method of manufacture

The method of manufacture of quartz pitot tubes (shown in step by step stages in Fig.1) is briefly as follows.

The centre portion of a piece of quartz* tubing approximately 3" to 4" long × 0.050" O.D.** (0.030" I.D.) is heated in an oxygen-coal gas flame. By pulling at each end the quartz flows and the centre portion of the tube is drawn down to the required diameter. The tube is removed from the flame and bent between the fingers, being brittle it breaks and two heads in the rough state are obtained. As in drawing glass, care must be taken to avoid a very fierce flame or the quartz will flow too easily and break off in the flame. In the early stages of development an air-gas flame was used but the heat was hardly sufficient to make the quartz flow.

By adjustment of flame, care in drawing down and in breaking, the heads can be made to any required diameter and degree of taper. Tubes drawn out in a straight line retain a perfectly round and true bore even when drawn down to 0.001" O.D.

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* Quartz is used in preference to glass as it is considerably stronger and was found to be easier to work with.

** Tubes of these dimensions may be obtained from the Thermal Syndicate, Wallsend-on-Tyne.

The heads are now polished to obtain a smooth end surface in the plane normal to the axis (as in Fig.3b). Care must be taken at this stage as the quartz chips easily (cf. Fig.3c). Smooth gentle sweeps over a fine hone holding the head between the thumb and forefinger have yielded the best results and by this method the proportion of rejected tubes has been kept down to about 50%.

After polishing the head is gently heated in an air gas flame and bent through 90° (Fig.1) to form a total head probe. It is then inserted in a piece of 2 m.m. stainless steel hypodermic tubing (I.D. = 0.053") and an air tight seal is made between the quartz and the steel. As shown in Fig.1 two methods have been used. The original method was to coat the quartz with platinum (liquid platinum process see Ref.2), copper plate the platinum and solder into the 2 m.m. stainless steel tube. This method was discontinued when it was found that the platinum was tending to peel off the quartz (probably due to dirty quartz). The tubes are now sealed with a cold setting araldite. No trouble has been experienced with this seal but it requires 24 hours for setting* (liquid platinum process gives an immediate seal).

A completed pitot tube is shown as the final stage in Fig.1.

Checks are made during manufacture for trueness of bore, and before each test run, for smoothness of end surface. Fig.2 shows a comparison of bore between two quartz tubes, a 0.020" O.D. hypodermic tube and a 0.020" O.D. hypodermic tube flattened to 0.010" overall height. (The flattened tube is a very good example of its type).

3 Tests carried out with quartz pitot tubes

3.1 Effects of end finish and degree of taper on accuracy of measurement

Boundary layer traverses on a flat plate were made with 4 tubes of varying end finish and degree of taper. The tips of these tubes are shown in Fig.3.

(1) Fig.3a Steep tapered tube with a good polished end surface.

(2) Fig.3b Short tube with normal taper and a highly polished end surface.

(3) Fig.3c Normal length tube with normal taper but with a bad chip on the under side of the end surface. No attempt was made to polish this tube.

(4) Fig.3d Normal length tube with small amount of taper. The polishing is left unfinished and some chipping remains.

Fig.4 shows some pitot pressure profiles obtained with these tubes in a turbulent boundary layer on a flat plate.

From this test it can be concluded that (a) taper has a negligible effect as shown by comparing tubes 1 and 2. (b) end finish is important (tubes 1 and 2 compared with tubes 3 and 4), but provided that tubes are polished to a reasonable degree they will show good agreement.

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* Araldite with a shorter setting time (1 hour) is now available and would most likely be suitable for this process.

3.2 Response rates for tubes of varying diameter

3.21 Test rig

The response rates of a number of pitot tubes (quartz and hypodermic) were obtained using the test rig shown in Fig.5. The pitot tube under test was inserted in one side of the test chamber and connected via an isolation valve and a T piece to a mercury manometer. By closing the isolation valve and opening valve A (pressure) or B (vacuum) the pitot side could be set at any desired pressure. The test chamber was evacuated to a required pressure by a vacuum pump and maintained at this pressure by using the bleed valve. When conditions in the chamber and on the pitot side were steady, valve A (or B) was closed and the isolation valve opened. With a stop watch the rate at which the pitot manometer was brought to the test chamber pressure was noted. The chamber was set at a low pressure as this simulated the actual tunnel running conditions.

3.22 Response rates

Five quartz pitot tubes of inside tip diameters ranging from 0.004" to 0.013", but of approximately constant taper and length, and two hypodermic tubes (one a standard 0.020" O.D. tube and the other a flattened version) were tested. Table I gives the main dimensions of each tube. The length of connecting tube to the pitot manometer was fairly typical of that used in wind tunnel tests and was kept constant.

Fig.6 gives plots of the time which the pitot manometer took to reach within 5% and 1% of the test chamber pressure. In Fig.6a the pressure was rising inside the pitot tube from 173 m.m. Hg Abs. to a test chamber pressure of 381 m.m. Hg Abs., while in Fig.6b the pressure was falling from atmospheric to a test chamber pressure of 36.5 m.m. Hg Abs.

In both cases the quartz tubes show a marked superiority over the hypodermic tubes, for which the main explanation is probably the differences in diameter of the two types of tubes following the entry (see Table I). It is also likely that the quartz tubes possess cleaner bores.

The smallest quartz tip tested had an I.D. of 0.0042" and an O.D. of 0.0078" and took 100 secs (for 1% accuracy) to fall from atmospheric to 36.5 m.m. Hg Abs. (Fig.6b). This is regarded therefore as the limiting size for a tube of the geometry detailed in Table I if a reasonable response rate is desired. The response rate could be improved if there was a steeper taper on the tip.

The response rate is also affected by the volume of the system, bore of connecting tubing etc., so that improvements could be obtained by adjustment of these parameters. This was outside the scope of the present tests but a method for finding the optimum length and inside diameter of connecting tubing is given in Ref.3.

Another possibility for improving the response rate (for a given tube size) might be to flatten the tips in addition to drawing them down. (Note that in Fig.6 the reduction in response rate in going from a circular to a flattened hypodermic tube is not as great as that experienced by the quartz tips over the same range of inside diameters since the cross section area at the mouth of a flattened tube is considerably greater than that of one of circular section of the same height.)

4 Additional comments and conclusions

It has been shown that very small pitot heads can be made by drawing down quartz tubing and the examples considered have shown very satisfactory response rates. Because of their taper and smooth finish the quartz tips gave faster response rates than those obtained with hypodermic tubes of the same orifice height.

A quartz tip cannot be as robust as a steel tip and more care is required when handling them but they have stood up to quite arduous conditions inside a wind tunnel and their ease of manufacture compensates for any fragility. (More breakages have occurred outside than inside the wind tunnel). Finally, any blockage by foreign matter is easily detected since the tube is transparent.

REFERENCES

No.	Author	Title, etc.
1	W.S. Bradfield and G.E. Yale	Small pitot tubes with fast pressure response time Journal of Aeronautical Sciences Vol.18 No.10 pp.697 October, 1951
2	R.J. Monaghan and J.R. Cooke	The measurement of heat transfer and skin friction at supersonic speeds. Part III Measurement of overall heat transfer and of the associated boundary layers on a flat plate at M = 2.43 CP. 139 December, 1951
3	A.R. Sinclair and A.W. Robins	A method for the determination of the time lag in pressure measuring systems incorporating capillaries NACA T.N.2793 September, 1952

TABLE I

Dimensions of tubes used in response rate tests

Type	O.Dia Ins.	I.Dia Ins.	Taper (Total Angle)	Bore and Length of Connecting Tubing Ins.	Bore of * Manometer Tube Ins.	I.Dia and Length of Fine Bore Tubing Ins.
Quartz	0.0078	0.0042	5° 50'	0.125 x 110.0	0.28	0.030 x 1.2
"	0.009	0.006	5° 40'	" "	"	" "
"	0.014	0.0072	5° 14'	" "	"	" "
"	0.0168	0.0108	5° 42'	" "	"	" "
"	0.0204	0.0126	6° 20'	" "	"	" "
Hypodermic	0.020	0.012	None	" "	"	0.012 x 1.0
Hypodermic⌿ Flattened	0.006 x 0.0234	0.0032 x 0.0137		" "	"	0.012 x 1.0

* For length of manometer tube in system see Fig.5.

⌿ This tube is similar to that shown in Fig.2.

FIG. I

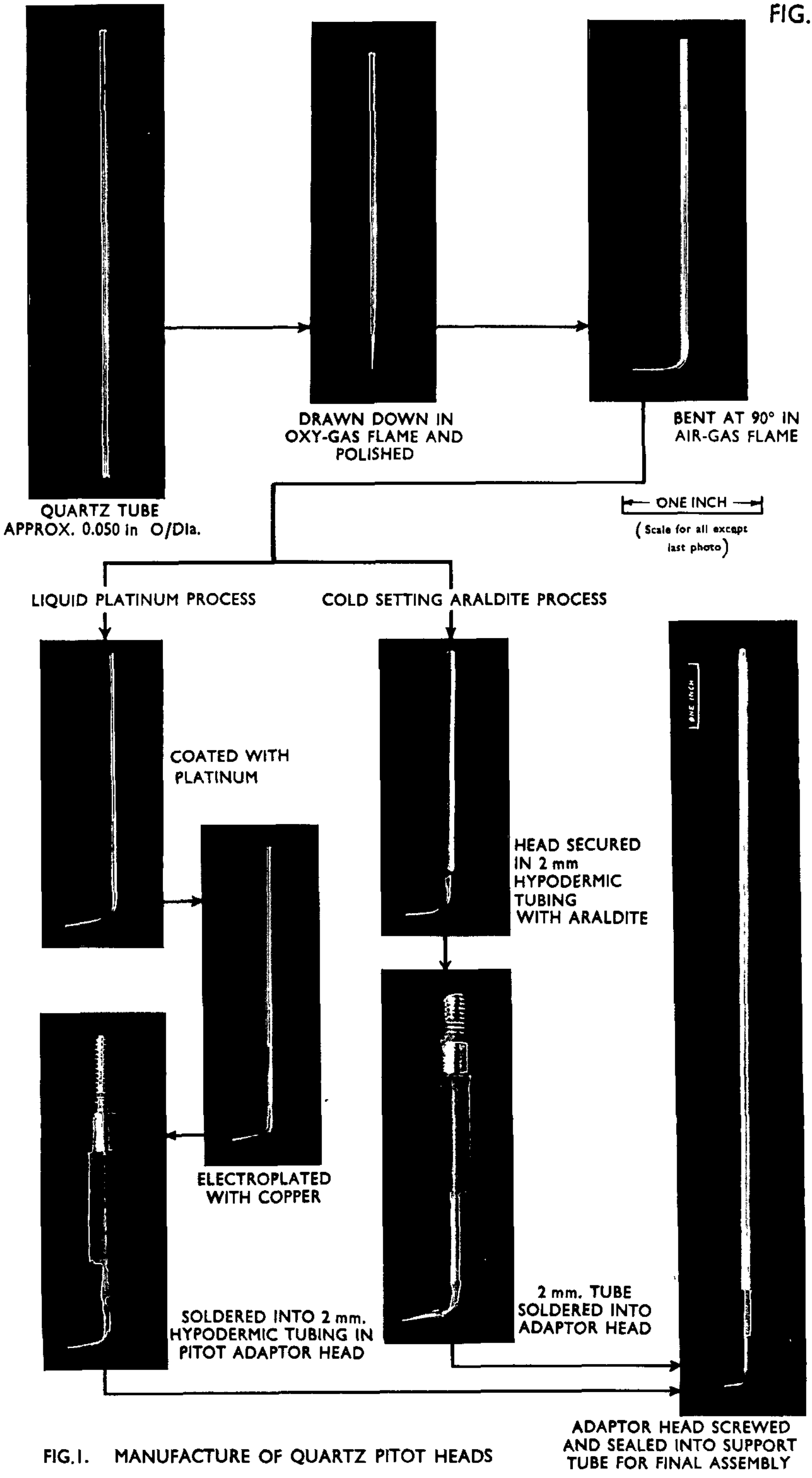
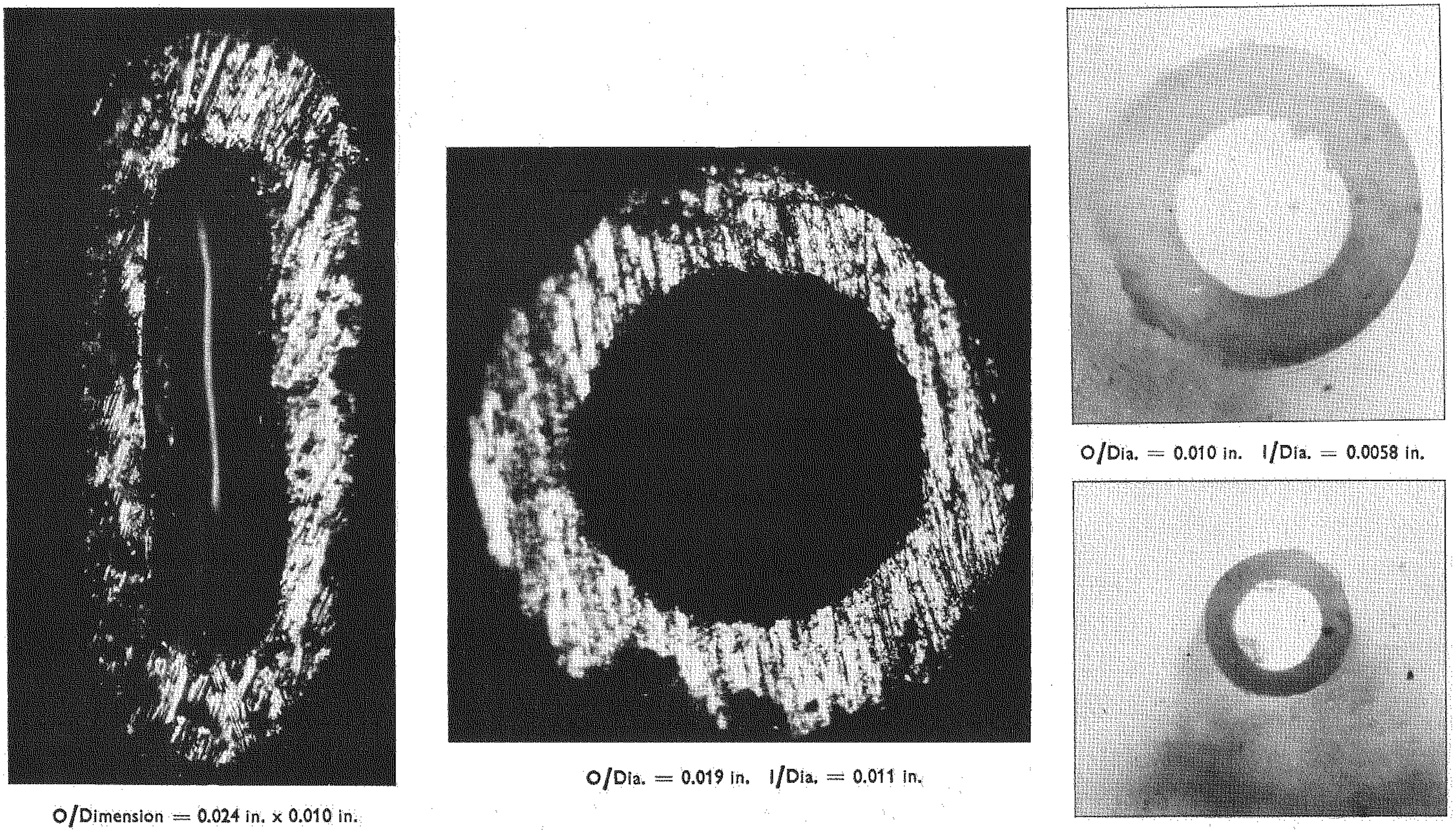


FIG. I. MANUFACTURE OF QUARTZ PITOT HEADS

FIG.2



O/Dimension = 0.024 in. x 0.010 in.
I/Dimension = 0.016 in. x 0.003 in.

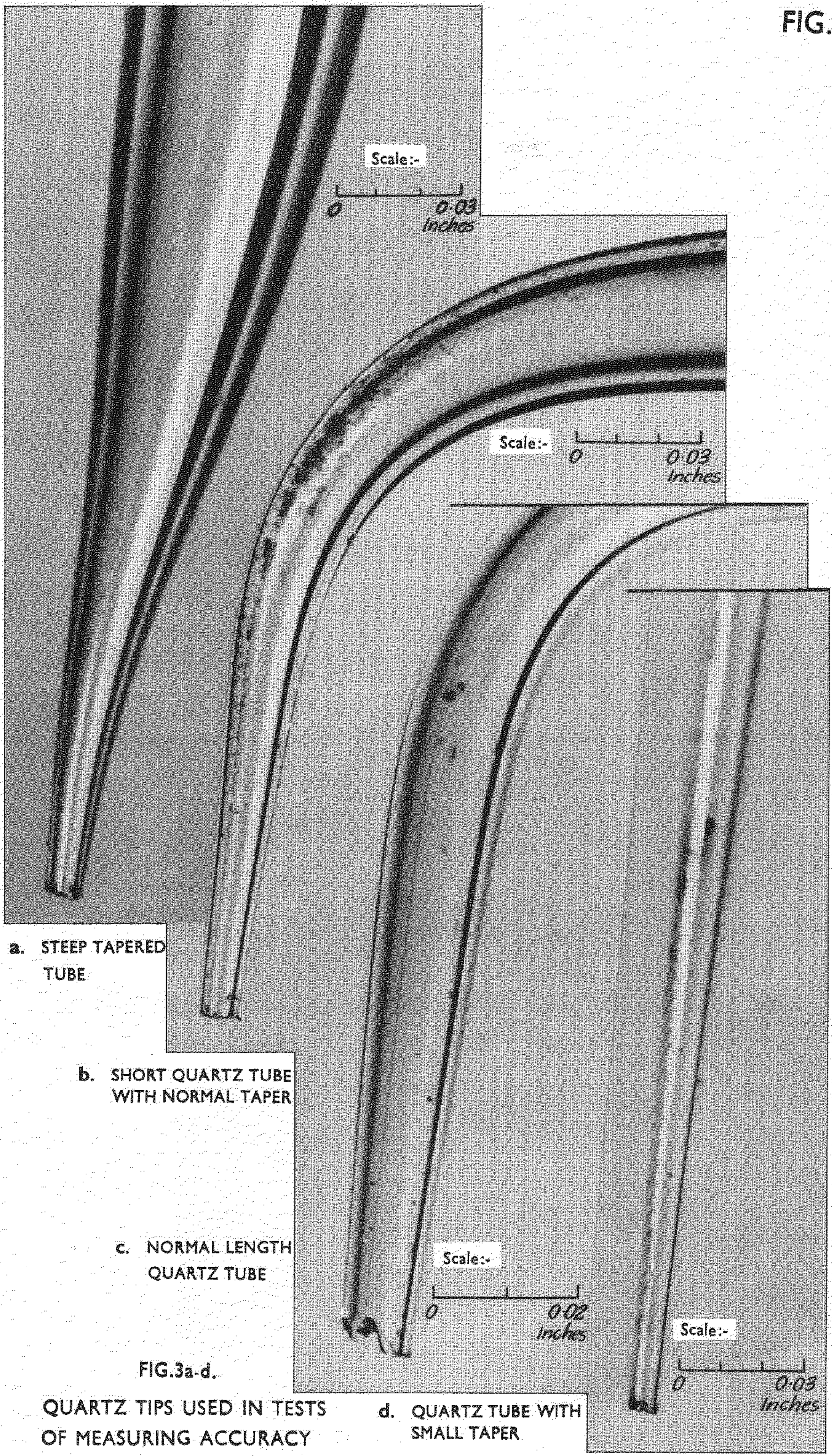
O/Dia. = 0.019 in. I/Dia. = 0.011 in.

O/Dia. = 0.010 in. I/Dia. = 0.0058 in.

O/Dia. = 0.0025 in. I/Dia. = 0.0013 in.

FIG.2. END ON VIEWS OF QUARTZ AND STAINLESS STEEL TUBES OF COMPARABLE DIMENSIONS

FIG.3



a. STEEP TAPERED TUBE

b. SHORT QUARTZ TUBE WITH NORMAL TAPER

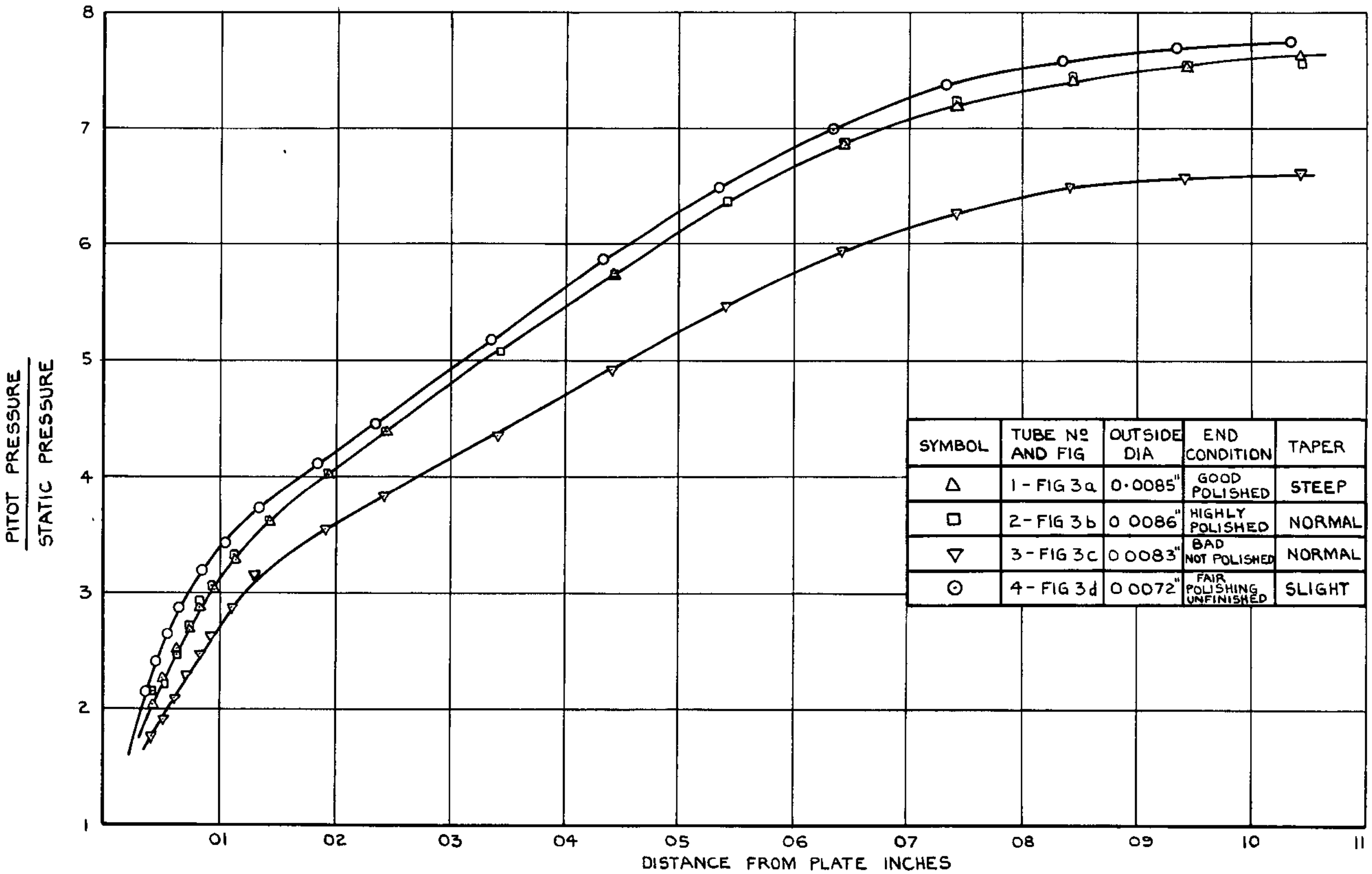
c. NORMAL LENGTH QUARTZ TUBE

d. QUARTZ TUBE WITH SMALL TAPER

FIG.3a-d.

QUARTZ TIPS USED IN TESTS OF MEASURING ACCURACY

FIG.4



SYMBOL	TUBE Nº AND FIG	OUTSIDE DIA	END CONDITION	TAPER
△	1 - FIG 3a	0·0085"	GOOD POLISHED	STEEP
□	2 - FIG 3b	0 0086"	HIGHLY POLISHED	NORMAL
▽	3 - FIG 3c	0 0083"	BAD NOT POLISHED	NORMAL
⊙	4 - FIG 3d	0 0072"	FAIR POLISHING UNFINISHED	SLIGHT

FIG.4. PITOT PRESSURE PROFILES OBTAINED IN BOUNDARY LAYER TRAVERSES ON A FLAT PLATE. USING THE 4 TUBES SHOWN IN FIG. 3.

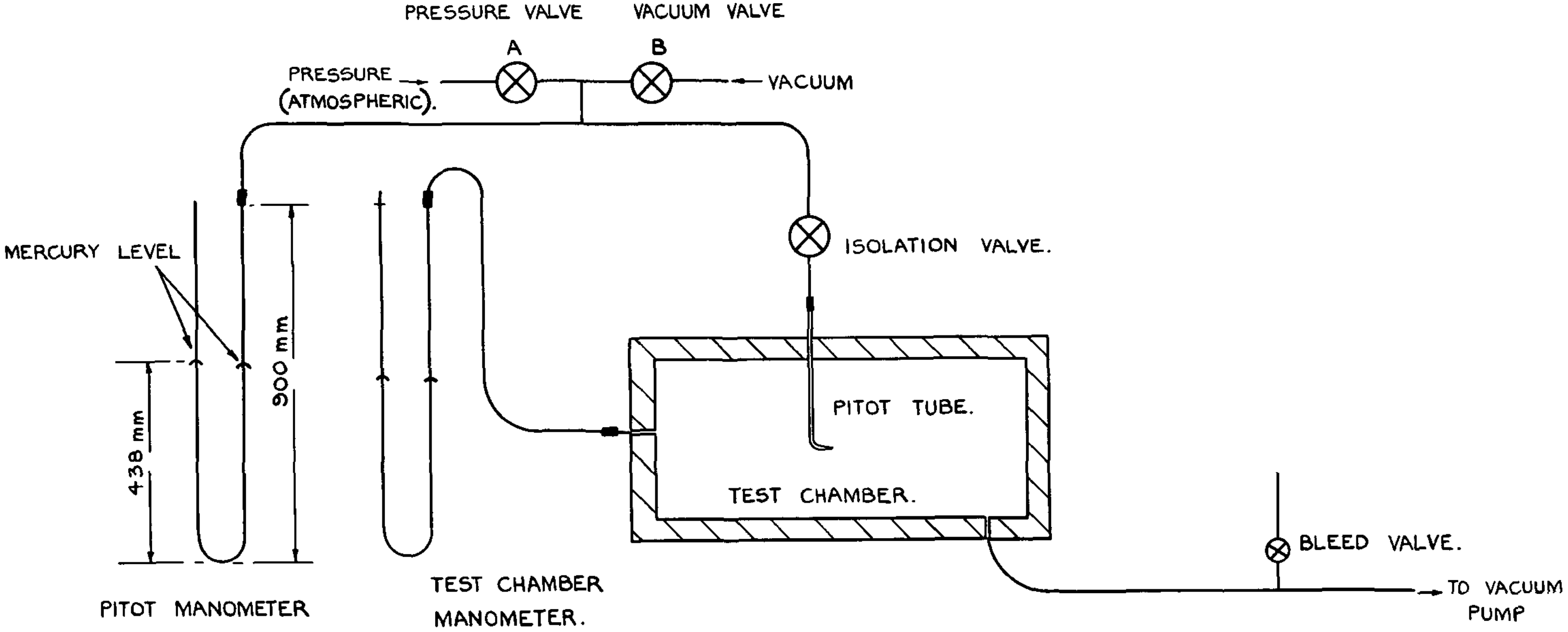
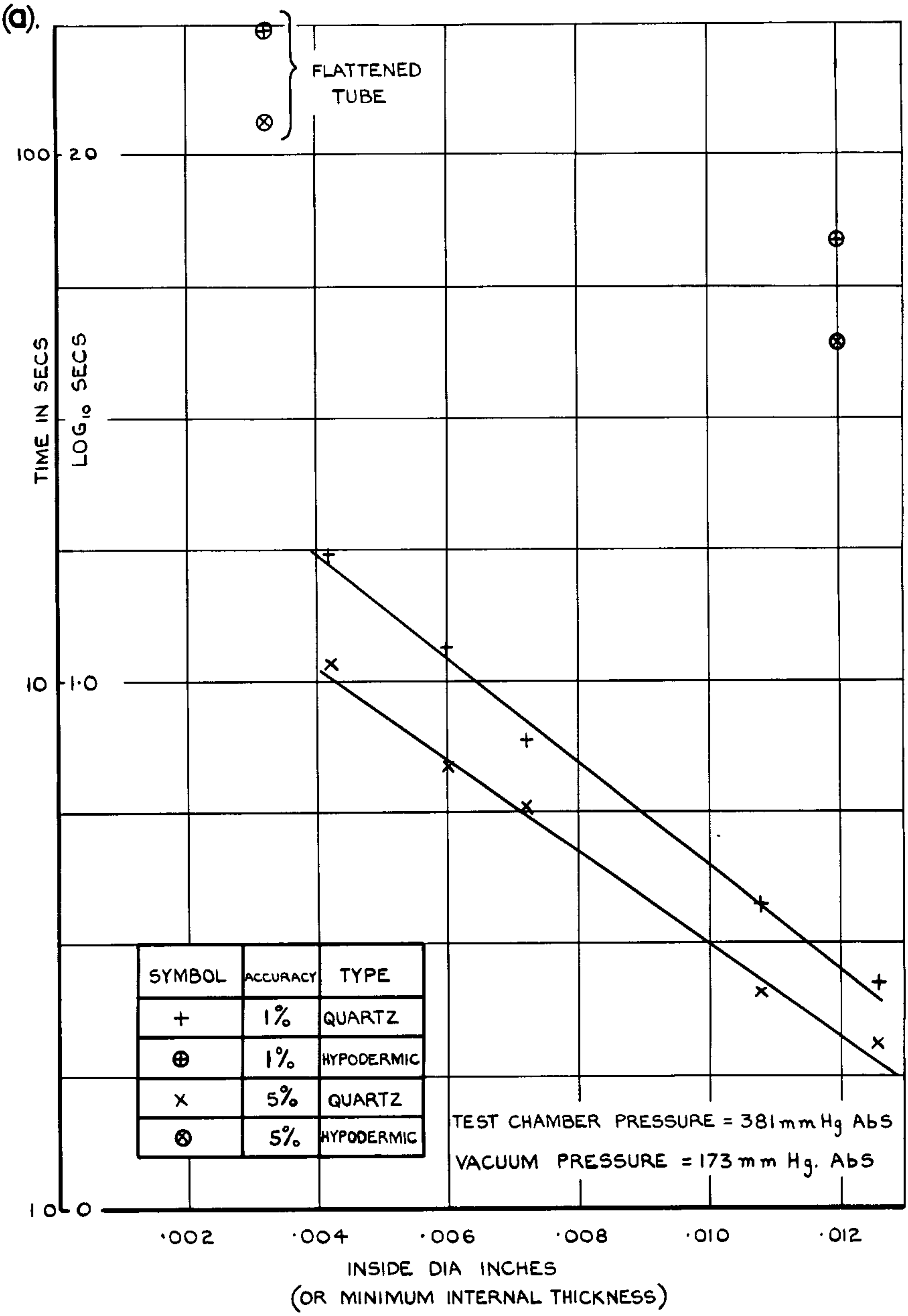


FIG. 5. TEST RIG FOR PITOT RESPONSE RATE (LINE DRAWING).

FIG. 6 (a).

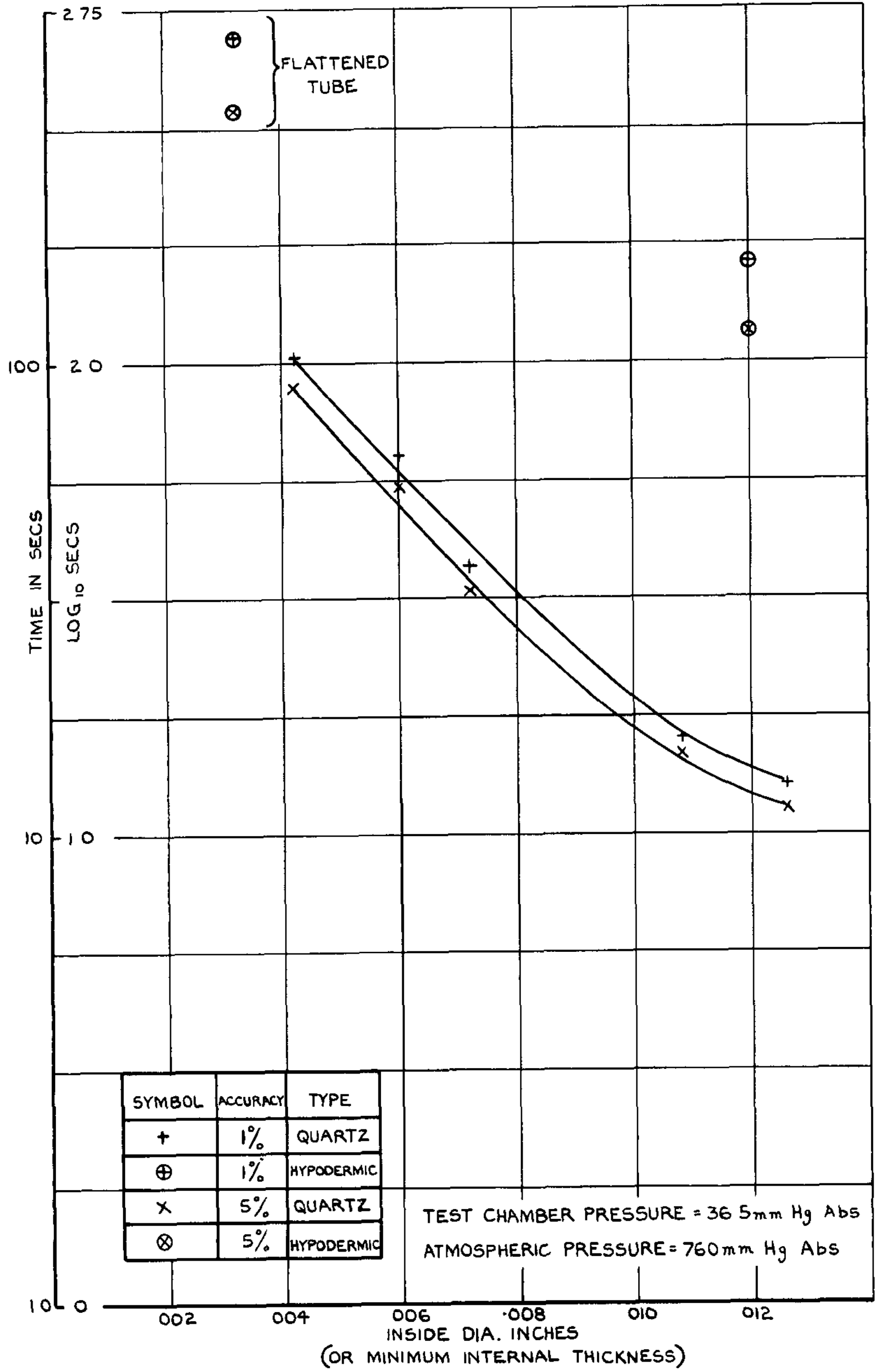


(a) FROM A VACUUM TO TEST CHAMBER PRESSURE.

FIG. 6. RESPONSE RATES FOR QUARTZ AND HYPODERMIC TUBES.

(TIMES REQUIRED TO REACH WITHIN 5% AND 1% OF TEST CHAMBER PRESSURE)

FIG. 6 (b).



(b) FROM ATMOSPHERIC PRESSURE TO TEST CHAMBER PRESSURE

FIG. 6 (CONTD.) RESPONSE RATES FOR QUARTZ AND HYPODERMIC TESTS.

(TIMES REQUIRED TO REACH WITHIN 5% AND 1% OF TEST CHAMBER PRESSURE)

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