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Torque characteristics of high speed steel twist drills

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TORQUE CHARACTERISTICS OF HIGH SPEED STEEL TWIST DRILLS

BY

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INTRODUCTION

The drill is the most efficient tool used by machinists, for in no other tool is the cutting surface as large in proportion to the cross sectional area of the body or part that is its real support.

Drills have shared evolutionary developments from carbon steels to high speed steels and from flat to twist drills. Many investigations have been made on the twist drills, but due to the majority of their work being based on the size of drills from 1/2 to 1-1/2 inches or larger, there is a dearth of published data on the general problem of drills of smaller sizes, such as the diameter of drills smaller than 1/2 inch in diameter.

Therefore, the object of this investigation is to determine the torque characteristics of certain commercial small drills and to evaluate the effect of various factors on the torque.

The importance of this work is quite evident because the result will lead to improved products or better economy in the process of drilling small holes and at the same time the information is useful to the machine tool designers in sizing and proportioning drills, drilling equipment and accessories.

In carrying out this research, drills ranging in diameter from 1/32 to 9/32 inch of the standard high speed steel twist drills were used; and the drilling tests were made on gray cast iron and five kinds of cold rolled steel.

The influence of different values of cutting speeds, materials, lubricants, depth of holes and size of drills on torque is determined.

REVIEW OF LITERATURE

Norris[1] worked on a 4-foot standard radial drill with drills

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(1) H. M. Norris, Power Absorbed in Drilling by Various Metals at Various Speeds and Feeds, American Machinist, Jan. 14, 1904, pp. 52 and 74.

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ranging from 1/2 to 1-1/2 inches. He concluded that:

1. When the speed and feed are constant, the power required to drill cast steel is about 1.10 times, wrought iron about 1.65 times and machinery steel about 1.90 times that required to drill cast iron.

2. When the speeds and feeds remain constant, the power required is approximately proportional to the diameter of the drill.

3. When the diameter of the drill and rate of feed are constant, the power required is approximately proportional to the speed.

4. When the speed and diameter of the drill are constant, the power required is approximately proportional to the feed.

Smith and Poliakoff[2] use the commercial high speed steel twist

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(2) D. Smith and R. Poliakoff, Experiment Upon the Forces Acting on Twist Drills When Operating on Cast Iron and Steel, American Machinist, Vol. 32, 1909, pp. 739-830.

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drills ranging from 3/4 to 1-1/2 inches in diameter on their experiments. The materials tested were medium hardness cast iron and Whitworth's steel (fluid pressed) of medium hardness having 0.29 per cent carbon and 0.625 per cent manganese. The first series of experiments were made on an 18-inch, center screw-cutting lathe, where the work was held in the chuck and rotated with it. They obtained the relation between torque and feed as

$$T = 12(d^2 - .35) + (500 + 1350\ d^2)f$$

on medium cast iron and

$$T = (3200\ f + 20)d^2$$

on steel

where T is the torque in ft-lb

d is the diameter of the drill in inches

and f is the feed in inches per revolution.

They concluded that the torque should be proportional to the square of the drill diameter and approximately proportional to the feed.

The second set of experiments was made in a horizontal milling machine. They obtained the following relations:

$$T = 785\ d^{1.82}\ f^{.72} - .0065d$$

for cast iron and the approximate expression

$$T = 740\ d^{1.8}\ f^{.7}$$

$$T = 2300\ d^{1.28}\ f^{-\frac{1}{8d} + 0.64}$$

for steel and the approximate expression

$$T = 1640\ d^{1.8}\ f^{.7}$$

They concluded from their extensive experiments that for cast iron the torque did not increase as fast as the feed for any given diameter of the drill.

Benedict and Likens[3] worked on the 22-inch all-geared drill press

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(3) Benedict and Likens, Investigation of Twist Drills, University of Illinois Bulletin, 1917, No. 103.

and used a one-inch diameter twist drill. They concluded that:

1. There is no apparent advantage in using a greater helix angle than 35 degrees if the power consumed by the drill is the factor to be considered. The uniform helix angle of 35 degrees, however, appears to be even better than the 32 degree angle. A satisfactory explanation why the torque is greater for the 40 and 45 degree drills is not apparent, though possibly it is due to the flute construction which gives a convex cutting edge, to a rapid dulling of the thin edge which may affect results before the completion of a single hole, or possibly to less effective removal of chips. In general, the results seem to indicate that the larger helix angles give the best performance.

2. The torque for the larger point angle varies only slightly from that of the standard angle for most of the drills. Probably a general average would show the larger point angle to give slightly greater torque, but the torque for the smaller point angle is considerably greater than that for the standard angle. The difference is the most noticeable at heavier feeds.

3. There is no pronounced influence of clearance angle variation. Torque decreases slightly as the clearance angle increases at the heavier feeds, although this variation is not perceptible for the lesser feeds.

4. The torque variation is slight for any variation in the chisel edge angle.

5. The torque of the drill varies with the rate of feed per revolution in a manner which is fairly uniform. The torque decreases as the speed increases for a given feed per revolution, although in most cases no

decrease in torque appears for speeds greater than 400 r.p.m. For speeds less than 150 r.p.m. the results are not uniform.

Boston and Oxford[4] worked on the drill press using drills ranging

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(4) Boston and Oxford, Power Required to Drill Cast Iron and Steel, Transactions ASME, 1930, MSP-52-2.

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from 1/2 to 1-1/2 inches in diameter. They concluded that the torque remains practically constant at speeds ranging from 74 to 441 r.p.m. for both cast iron and steel and for various drills when operating under constant conditions of feeds, lubrication and material. They obtained the following relations among torque, feed, and diameter:

$$T = C\, f^{.6}\, d^{2} \quad \text{for cast iron and}$$

$$T = C\, f^{.78}\, d^{1.8} \quad \text{for steel.}$$

They state that while power increased in direct proportion to the speed, the torque remained constant for a given drill diameter and feed over the whole range of speeds available.

Boston[5] described the method used to determine the emperical

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(5) Boston, Metal Processing, 1st ed., N. Y., John Wiley and Sons, 1941, p. 277.

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formula for the torque of drilling. The formula for the torque was determined from the results of test in which a given diameter drill was operated at various feeds for the first part, and drills of different diameters operated at the same feed for the second part.

Suppose the material to be drilled is steel, then under a certain definite cutting speed the torque values are obtained from a given size of drill operating at different feeds. A straight line is obtained on log-log paper which slopes at an angle from the horizontal whose tangent is .78. The experimental points for torque for different diameter drills operating at constant feed also gives a straight line inclining from the horizontal at an angle whose tangent is 1.8. This gives the relation

$$T = C\ f^{.78}\ d^{1.8}$$

where C is a constant.

Begeman[6] stated, "The drill performance is affected by the helix

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(6) Myron L. Begeman, Manufacturing Processes, 2nd ed., N. Y., John Wiley and Sons, 1947, p. 434.

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angle of the flutes. Although this angle may vary from 0 to 45 degrees, the usual standard for steel and most materials is 30 degrees. The smaller this angle is made, the greater is the torque necessary to operate a given feed. As the angle is increased appreciably, the life of the cutting edge is reduced. Some materials are drilled more efficiently by drills with special helix."

TEST EQUIPMENT

In this test, the selection of the drill press has a decisive factor upon the result. For if a poor machine is used, a correct result cannot be obtained and also no definite relation can be found among the variables which influence the test results. Therefore, it is necessary to have:

1. A drilling machine, the spindle of which is running true,
2. A spindle which remains perpendicular under working stress,
3. The shank of the drill must have the same axis as its fluted portion, and the internal taper of the spindle of the drill press must be concentric with both the axis of the spindle itself, the external taper of the drill chuck, and the shank of the drill.

According to Taylor[7], who is a good authority on the subject of metal cutting, there are twelve things that affect the speed with which

(7) W. E. Splain, Metal Cutting Tools, American Machinist, Vol. 58, 1923, p. 663.

the tool can cut economically. They are as follows:

1. Physical properties of the metal to be cut,
2. Diameter of the drill,
3. Thickness of the shaving,
4. Elasticity of the work and the tool,
5. Shape of the tool,
6. Chemical composition and heat treatment of the tool,
7. Whether or not the tool is cooled with water or other cooling medium,

8. Duration of the cut (the time a tool must last under pressure of the chip without being reground),
9. Pressure of the chip on the tool,
10. Change of feeds and speeds possible on the machine, and
11. Pulling and feeding power of the machine.

From the above points of view, there are so many variables which enter into the performance of a drilling operation that it is extremely difficult to establish anything in the nature of hard and fast rules for the speed and feed that are correct for drilling a hole of specified size in a given class of material.

Norris(8) has made a careful study of the question of drilling

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(8) E. K. Hammond, Feeds and Speeds for Drill, Machinery, Vol. 24, 1918, p. 715.

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speeds and the results of his investigations have lead him to the conclusion that occasionally the drill is found which is capable of standing up satisfactorily at a cutting speed of 150 feet per minute in either cast iron or steel, but it is seldom desirable to drive anything but very small drills at speeds in excess of 100 feet per minute. Under average conditions of operation, the best results will be obtained with the cutting speed of 80 feet per minute in cast iron, while for steel a speed of $12/d + 76$ feet per minute will give satisfactory results.

Selection of the proper speed and feed for a given drilling operation is governed by the diameter of the drill and the kind of material being drilled.

In general, a high speed and light feed is recommended. It is better to err on the side of too much speed than to err on the side of too much feed. The speed can be increased to the point where the outside corners of the drill commence to show signs of wearing away. It can be slightly reduced and maintained at this reduced speed.

Some metals can be cut dry to good advantage, while others require a cutting lubricant in order to obtain the best results.

Lubricants have many functions, several of which are as follows[9]:

1. To cool both the cutting edges of the tool and work being machined. This can best be done by directing as large a volume of the coolant as possible on the cutting edges.
2. To lubricate the chips.
3. To force the chips back from the cutting edges.
4. To improve the finish of the work.

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(9) Handbook for Drillers, The Cleveland Twist Drill Co., p. 19.

During the drilling period, the drill is heated partly by the friction of the chip on the drill and partly by conduction of the heat from the hot chip. The chips are hotter than the drill. If, therefore, a stream of water or other cooling medium is directed against the chips, the chips are cooled and less heat is conducted to the drill. This method permits a higher cutting speed. In lathe tool experiments F. W. Taylor[10] found that the use of a heavy stream of soda water on

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(10) F. W. Taylor, On the Art of Cutting Metals, Folder 15, N. Y., 1906.

the chip at the tool point permitted an increase in cutting speed in steel of about forty per cent. When cutting hard cast iron the increase in speed through the use of water was sixteen per cent.

In the case of cast iron, the chips break off so short that very few hot chips are in contact with the drill, hence there is a relatively small amount of heat conducted to the drill when cutting cast iron so it is often cut dry.

Twist drills must be properly ground and run at a suitable speed and feed in order to do their work efficiently. When grinding the drill points, the following rules should be observed:

1. Both cutting lips must be inclined at the same angle with the axis of the drill and must be of equal length.
2. The drill point must have the proper clearance or contour of surface back of the cutting edges and this clearance must be identical on both sides.

Some of the undesirable conditions resulting from drill points improperly ground are as follows:

1. If both lips are not ground at the same angle with the axis, one lip will fail to counteract the tendency of the other to spring away from the cut; consequently, one lip will do more work than the other, which will result in its becoming dull more rapidly than if both lips were cutting equally, and it will be subjected to an abnormal torsional strain.
2. When the cutting lips of a drill have the same point angle, but are of different lengths, the point of the drill will be off center or eccentric. As a result, the hole will be oversize to

an extent equal to double the amount of this eccentricity.

3. If the drill point is ground with lips at different angles and of different lengths there will be a combination of the undesirable results described in the two proceeding paragraphs.

SCOPE OF TEST

The torque required during the drilling process depends upon a number of variables. The following paragraphs establish the limitations of these studies in terms of important variables.

Materials drilled: The metals drilled in these studies included cold rolled S.A.E. 1015, 1025, 1040, 1112, 2340 steel and gray cast iron. These materials are generally used in the machine shops. The hardness of these materials are shown in Table I.

Table I. Hardness of Metals

Metals	Cast Iron	1015	1025	1040	1112	2340
BHN	126	116	241	197	163	255

Drills ranging in diameter from 1/32 to 9/32 inch were used as shown in Table II.

Depth of drilling: This depends upon the diameter of the drill.

Speed of drill: Spindle speeds of from 630 to 2600 r.p.m. were used in these tests. This range includes the speeds commonly used, although commercial drilling is not limited to these speeds.

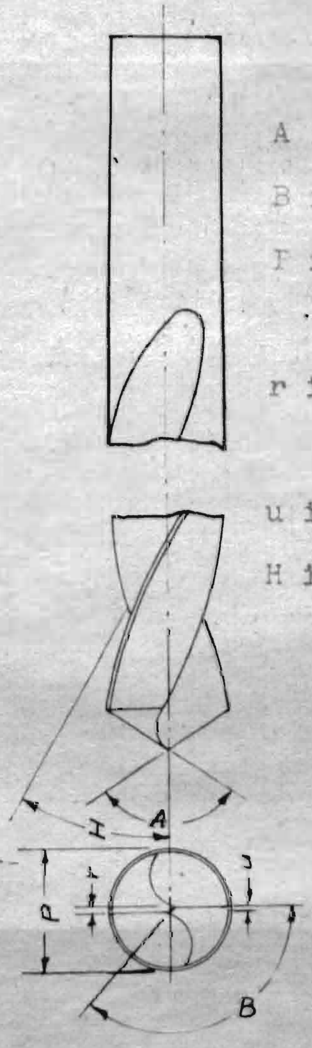
Cutting fluid: Soluble oil was used. The coolant consisted of one part soluble oil and 15 parts of water and one part soluble oil and 50 parts of water.

EQUIPMENT USED IN THE TEST

The drills used are the high speed steel twist drills which have two flutes and cutting edges. The drill is held in the Jacob drill chuck which in turn is held in the socket of the drilling machine spindle by means of the tapered shank.

To obtain good service from a drill, it must be properly ground. All drills were carefully ground so that their form could be duplicated by successive grindings. It was inspected by the use of a protractor. Table II contains a list of the drills used in the tests and gives the values of various measurements, such as the outside diameter, the web thickness at the point, the chisel edge-angle or the angle the chisel edge makes with the cutting edge, the helix angle, the included point angle between the two cutting edges and clearance angle ground back of the cutting edges at the periphery. The drill is shown in Fig. 1.

The drilling machine used was a high precision small radial drill. The power feed of the drill press was constant and equal to 0.00335 inches per revolution of the spindle. The highest speed of this machine was 3600 r.p.m. and the lowest was 630 r.p.m. Due to the special design, theoretically, there are infinite numbers of speed between 3600 and 630 r.p.m., so that any speed between these two limits is possible. The motor used for driving the drill press was a 1/3 horsepower alternating current, single phase, 115 volt General Electric motor running at 3450 r.p.m. The power was transmitted through the V-belt to the drill press. The machine is shown in Fig. 2.



A is the point angle.

B is the edge angle.

D is the diameter at the point.

r is the web thickness at point.

u is the land width.

H is the helix angle.

Fig. 1 Twist drill nomenclature

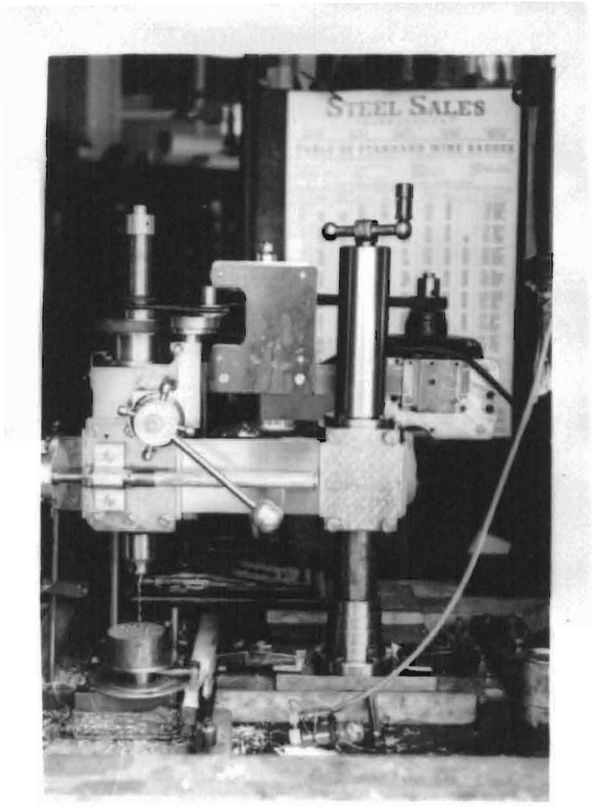


Fig. 2 The radial drill used in the test

TABLE II. LIST OF THE DRILLS USED IN THE TESTS, WITH MEASUREMENTS

Drill size in.	Outside diameter in.	Web thick-ness at point, in.	Helix angle in.	Point angle deg.	Lip angle deg.	Chisel edge angle deg.
1/32	0.031	0.006	22	120	6	120
3/64	0.046	0.016	22	120	6	120
1/16	0.623	0.018	22	120	6	120
5/64	0.078	0.022	22	120	6	120
3/32	0.0833	0.023	22	120	6	120
7/64	0.109	0.025	26	120	6	122
1/8	0.125	0.026	26	120	6	122
9/64	0.1305	0.030	26	120	6	122
5/32	0.1563	0.033	26	120	6	122
11/64	0.172	0.036	26	120	6	122
3/16	0.187	0.036	30	120	6	122
13/64	0.2028	0.036	30	120	6	123
7/32	0.2183	0.036	30	120	6	123

TABLE II cont.

Drill size in.	Outside diameter in.	Web thickness at point, in.	Helix angle deg.	Point angle deg.	Lip angle deg.	Chisel edge angle deg.
15/64	0.234	0.037	30	118	6	123
1/4	0.250	0.039	30	118	6	123
9/32	0.281	0.048	30	118	6	126

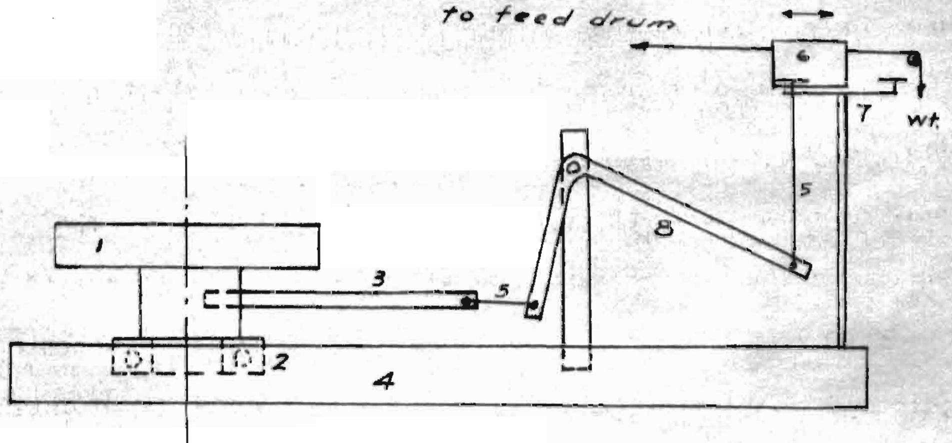


Fig. 3 Measuring apparatus

1 Face plate on which specimens to be drilled are fastened

2 Ball bearing mounting for 1

3 Torque arm attached to the shaft of the face plate

4 Base which is bolted to the table of drill press

5 String which connect the torque arm to the link and connect link to the balance

6 plate on which the paper is clamped, is slided by a cord. The cord is connected to a portion of the drill press on one end and a certain weight on the other end.

7 Balance

8 Link

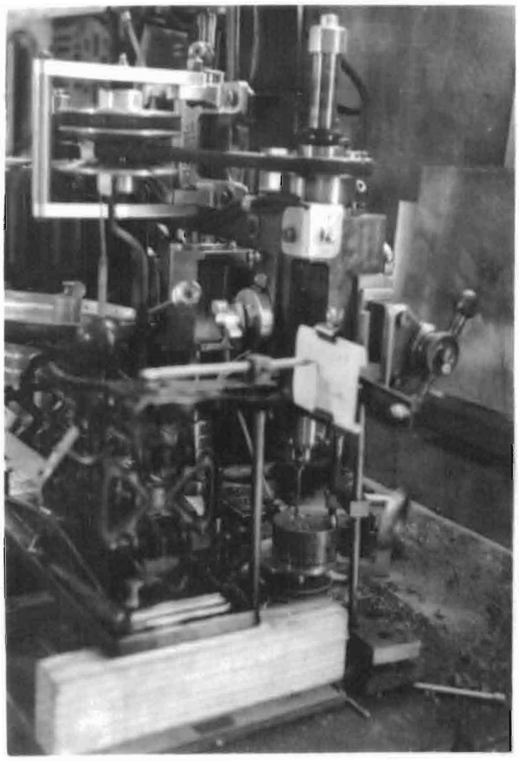


Fig. 4. The measuring apparatus set up on the drill press.

Fig. 5. The balance used in the test.

The measuring apparatus consisted essentially of a base, a ball bearing, face plate, torque arm, link, balance and recording device. Details of the measuring apparatus are shown in Fig. 3, while Fig. 4 is a view of the apparatus set up on the drill press. Fig. 5 is the view of the balance.

The measuring instrument was mounted rigidly on the table and the test material was clamped to the face plate by the use of C clamps. The shaft of the face plate,which was mounted on a ball bearing, was free to rotate except for the torque arm extending to the side. The torque arm was connected to the balance through a link.

During drilling, the plate was slid in synchronism with the drill advance or drill withdrawal by means of a cord which passed from the plate to a point on the drill press spindle feed drum.

While using the measuring apparatus, the specimen was clamped to the face plate by C clamps. Care was taken to make sure the drill came down in the center of the face plate. The cord that controlls the plate is secured to a part on the drill press spindle feed drum. As the drill feeds down into the work, the plate moves and at the same time the torque arm moves the link and the balance. A diagram something like this results

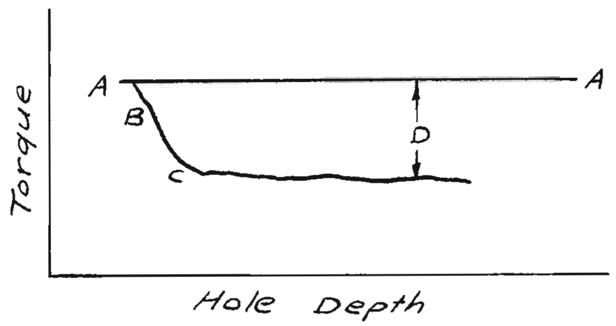


Fig. 6. Torque-depth diagram.

A-A zero starting line.

B point of drill entering work.

C full diameter hole being drilled.

D the dimension indicating the acting force.

The revolution per minute of the spindle of the drill press is determined by the use of the Hasler speed indicator. A rubber tip was first fitted over the spindle of the indicator and then the tip was brought in contact with the center of the spindle of the drill press. The spindle of the speed indicator ran freely without operating any other part of the instrument until the operator gently pressed and released the starting button located on top of the instrument. At the precise moment the release of the starting button set in motion the timing element, the spindle was then automatically thrown into gear. Both large and small indicating hands then moved for a period of exactly three seconds, at which time the spindle was automatically disengaged and the hands stopped, indicating a positive result which was read immediately.

The cutting fluid system of the press was a gravity feed system so that a 1/8-inch stream of an emulsion made of assigned proportion of a soluble oil and water was directed on the top of the work about the drill. The discharge head was 17 inches.

TEST PROCEDURE

1. All drills were sharpened before each test so that the shape could be reproduced in subsequent sharpenings. Before running any tests, each newly ground drill was used to drill one hole to remove any "feather" edge. All holes were drilled to a predetermined depth and all holes drilled were dead end, rather than being drilled through the work. No drill bushings were used in the tests, as it was found they were not needed and might influence the values because of chip interference.

2. The test materials were prepared in a sawing machine with a proper length.

3. The surfaces of the test materials were filed smooth, after which hardness tests were made on them as shown in Table I.

4. Measuring apparatus was set up.

5. The drill was placed in the drill chuck and checked for trueness.

6. The test material was firmly clamped on the face plate.

7. The drill press was started.

8. The control lever was used to bring the machine to the desired speed. This speed was checked by the speed indicator.

9. When the lubricant was used the cutting fluid system was put into action.

The following tests were run and data taken:

A. A series of experiments to determine the torque or twisting moment on twist drills of varying diameters when operating with constant feed on gray cast iron. No lubricant used.

B. A set of experiments similar to the afore mentioned when operating on steels. Lubricant used.

C. A set of experiments on soft cast iron to determine the variation of torque with different cutting speeds. No lubricant used.

D. A set of experiments on steels to determine the variation of torque with different cutting speeds. Lubricant used.

E. A set of experiments on steels to determine the variations of torque with different coolants.

F. A set of experiments to find the effect produced by varying the depth of the hole to be drilled.

DISCUSSION

For convenience in drawing, the numbers are used to replace the sizes of the drills as shown in Table III.

TABLE III. DESIGNATION OF DRILL SIZE

Drill size in inches	Drill number
1/32	2
1/16	4
5/64	5
3/32	6
7/64	7
1/8	8
9/64	9
5/32	10
11/64	11
3/16	12
13/64	13
7/32	14
15/64	15
1/4	16
9/32	18

The length of the torque arm was 2.81 inches.

The unit of torque is in the ft-lb system. The forces applied in the tests are in grams. In order to change the force into pounds it must be multipled by 0.0022. The torque is then obtained by the force in pounds times the length of the torque arm.

TABLE IV. VARIABLE DIAMETERS TESTS, SERIES A, FOR CAST IRON WITH THE SPEED AT 1100 R.P.M.

Drill number	Force		Torque
	g.	lb.	ft-lb
2	13	.0286	.0804
4	25	.055	.154
5	25	.055	.154
6	20	.044	.123
7	24	.0528	.149
8	30	.066	.185
9	32	.0703	.198
10	38	.0835	.234
11	70	.154	.433
12	90	.198	.556
13	95	.209	.587
14	95	.209	.587
15	100	.22	.619
16	107	.23	.646
18	115	.253	.72

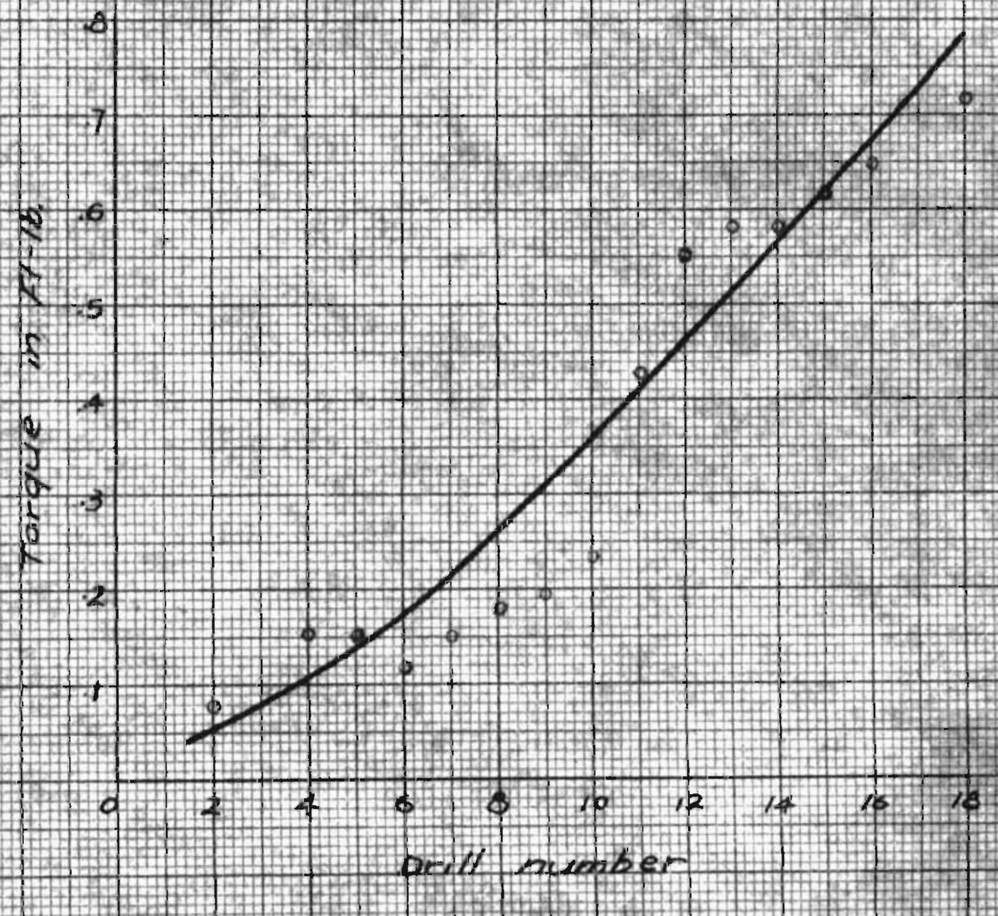


Fig. 7 Variable diameters tests showing torque for cast iron at constant speed of 1100 r.p.m. and constant feed. Series A.

TABLE V. VARIABLE DIAMETERS TESTS, SERIES B, FOR S.A.E. 1015 STEEL WITH SPEED AT 1090 R.P.M.

Drill number	Force		Torque
	g.	lb.	ft-lb
2	3	.006	.0168
4	5	.011	.031
5	10	.022	.0618
6	25	.055	.155
7	28	.061	.171
8	30	.066	.185
9	40	.088	.248
10	47	.103	.290
11	50	.110	.309
12	63	.139	.390
13	80	.176	.495
14	125	.275	.774
15	135	.297	.835
16	155	.341	.958
18	180	.396	1.110

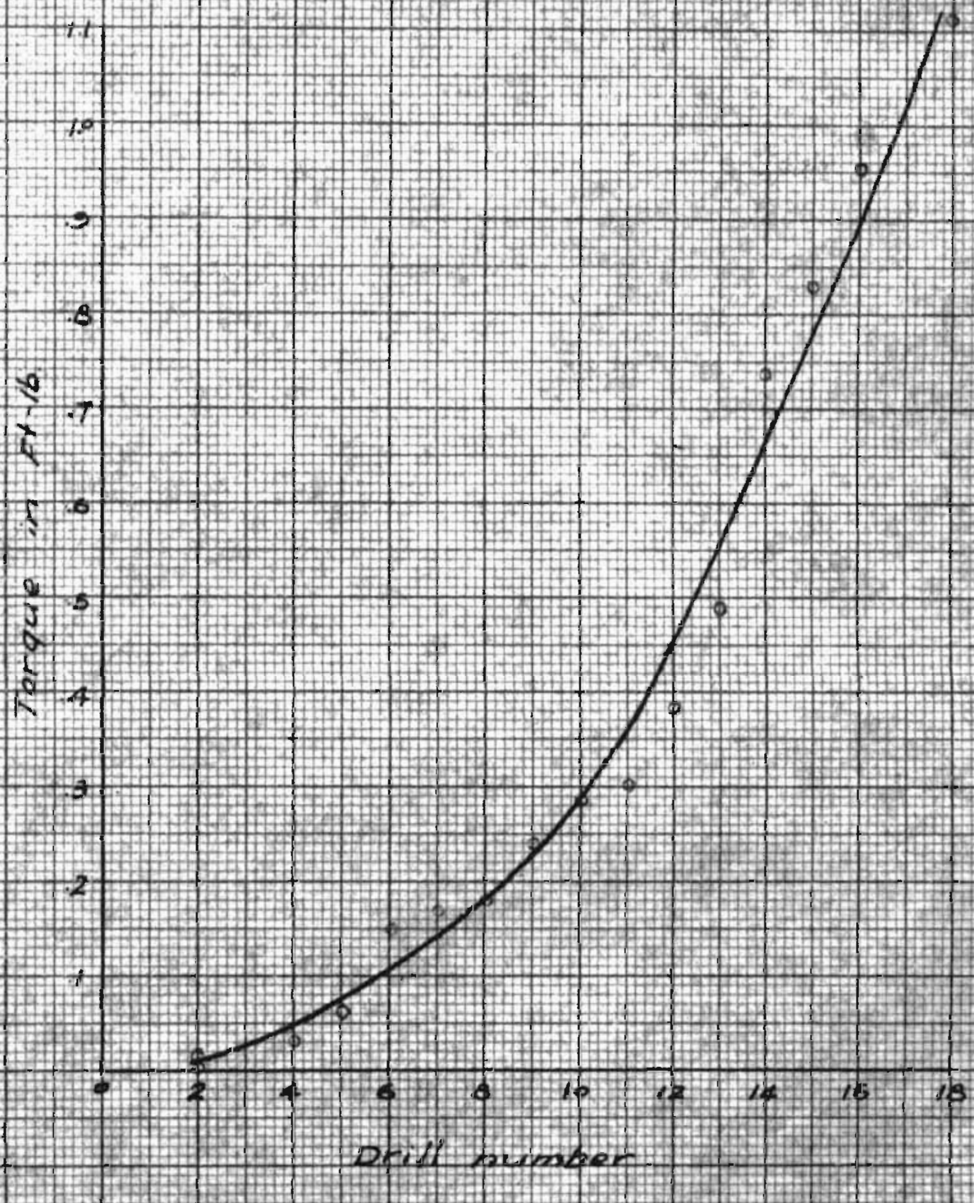


Fig. 8 Variable diameters tests showing torque for S.A.E. 1015 steel at constant speed of 1090 r.p.m. and constant feed. Series 3.

TABLE VI. VARIABLE DIAMETERS TESTS, SERIES B, FOR S.A.E. 1112 STEEL WITH SPEED AT 680 R.P.M.

Drill number	Force		Torque
	g.	lb.	ft-lb
2	3	.006	.0168
4	5	.011	.031
5	10	.022	.0618
6	5	.033	.0928
7	25	.055	.1545
8	35	.077	.216
9	30	.066	.185
10	45	.099	.278
11	55	.121	.340
12	75	.165	.464
13	75	.165	.464
14	90	.188	.527
15	103	.226	.635
16	130	.286	.805
18	150	.330	.929

TABLE VII. VARIABLE DIAMETERS TESTS, SERIES B, FOR S.A.E. 1025 STEEL WITH SPEED AT 680 R.P.M.

Drill number	Force		Torque
	g.	lb.	ft-lb
2	3	.006	.0168
4	12	.0264	.074
5	20	.044	.123
6	18	.0396	.111
7	30	.066	.185
8	30	.066	.185
9	30	.066	.185
10	41	.090	.253
11	50	.110	.309
12	60	.132	.371
13	70	.154	.433
14	80	.176	.495
15	95	.209	.588
16	110	.242	.680
18	153	.336	.945

TABLE VIII. VARIABLE DIAMETERS TESTS, SERIES B, FOR S.A.E. 1040 STEEL WITH SPEED AT 680 R.P.M.

Drill number	Force		Torque
	g.	lb.	ft-lb
2	2	,0044	.0124
4	5	.011	.031
5	18	.0396	.111
6	20	.044	.124
7	35	.077	.216
8	35	.077	.216
9	40	.088	.248
10	47	.103	.290
11	50	.110	.309
12	55	.121	.440
13	70	.154	.432
14	78	.171	.480
15	89	.196	.550
16	104	.229	.644
18	142	.312	.876

TABLE IX. VARIABLE DIAMETERS TESTS, SERIES B, FOR S.A.E. 2340 STEEL WITH SPEED AT 680 R.P.M.

Drill number	Force		Torque
	g.	lb.	ft-lb
2			
4	5	.011	.031
5	16	.035	.0985
6	20	.057	.160
7	32	.0705	.188
8	35	.077	.216
9	40	.088	.248
10	43	.0945	.266
11	45	.099	.278
12	50	.110	.309
13	67	.147	.414
14	78	.171	.480
15	85	.187	.525
16	102	.224	.630
18	140	.308	.665

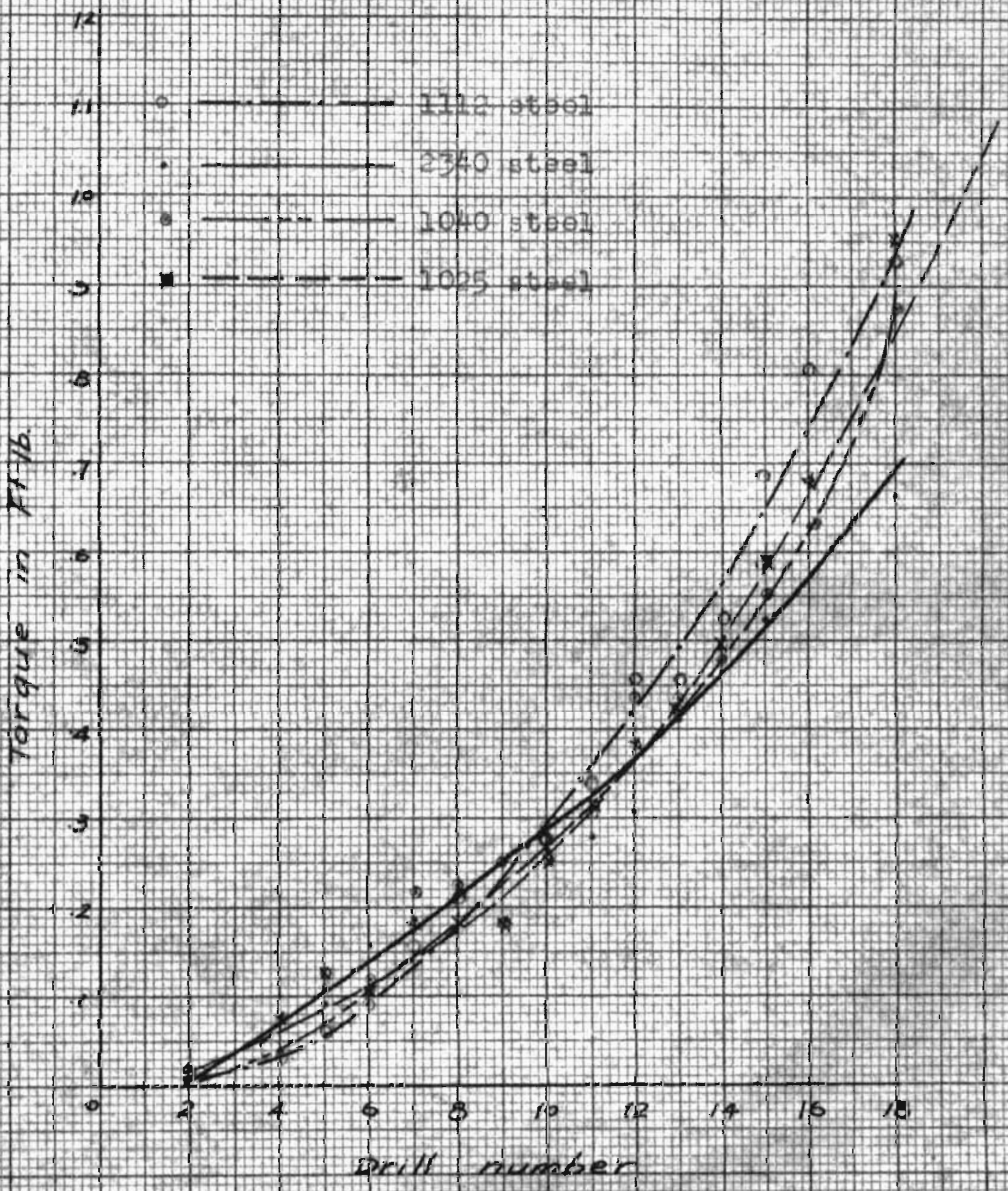


Fig. 9 Variable diameters tests showing torque for S.A.E. 1025, 1040, 1112 and 2340 steel at constant speed of 680 r.p.m. and constant feed. Series [illegible].

TABLE X. VARIABLE SPEEDS TESTS FOR CAST IRON
SERIES C

Drill size inches	R.P.M.	Force g.	Force lb.	Torque ft-lb
1/8	670	22	.048	.135
1/8	900	25	.055	.154
1/8	1300	20	.044	.123
1/8	1755	20	.044	.123
11/64	580	30	.066	.185
11/64	710	50	.110	.309
11/64	915	55	.121	.340
11/64	1100	50	.110	.309
11/64	1900	35	.079	.216

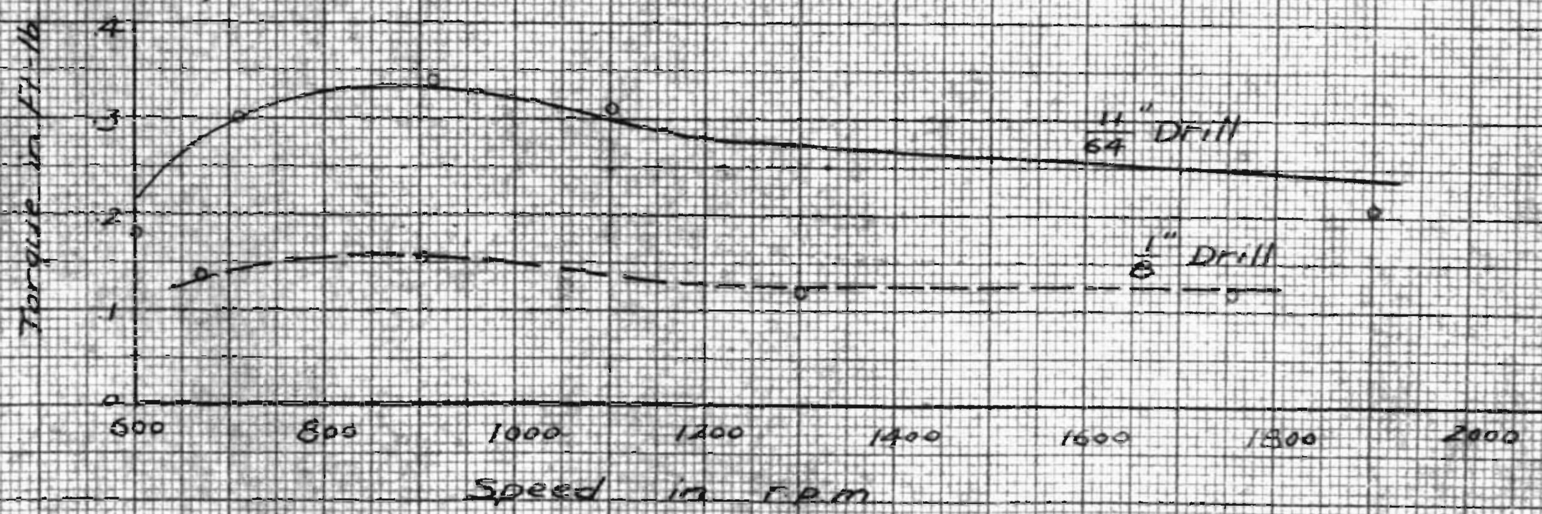


Fig. 10 Variable speed tests showing torque for cast iron with constant feed. No lubricant used. Series C.

TABLE XI. VARIABLE SPEEDS TESTS FOR S.A.E. 1025 STEEL, SERIES D

Drill size	R.P.M.	Force		Torque
inches		g.	lb.	ft-lb
7/64	900	15	.033	.093
7/64	1155	18	.036	.101
7/64	1330	12	.026	.074
7/64	1680	18	.036	.101
1/8	1100	30	.066	.185
1/8	1540	25	.055	.154
1/8	1770	27	.060	.167
1/8	1965	29	.064	.179
9/64	750	39	.085	.238
9/64	860	35	.077	.216
9/64	960	40	.088	.247
9/64	1080	40	.088	.247
9/64	1210	45	.099	.278
9/64	1680	40	.088	.247

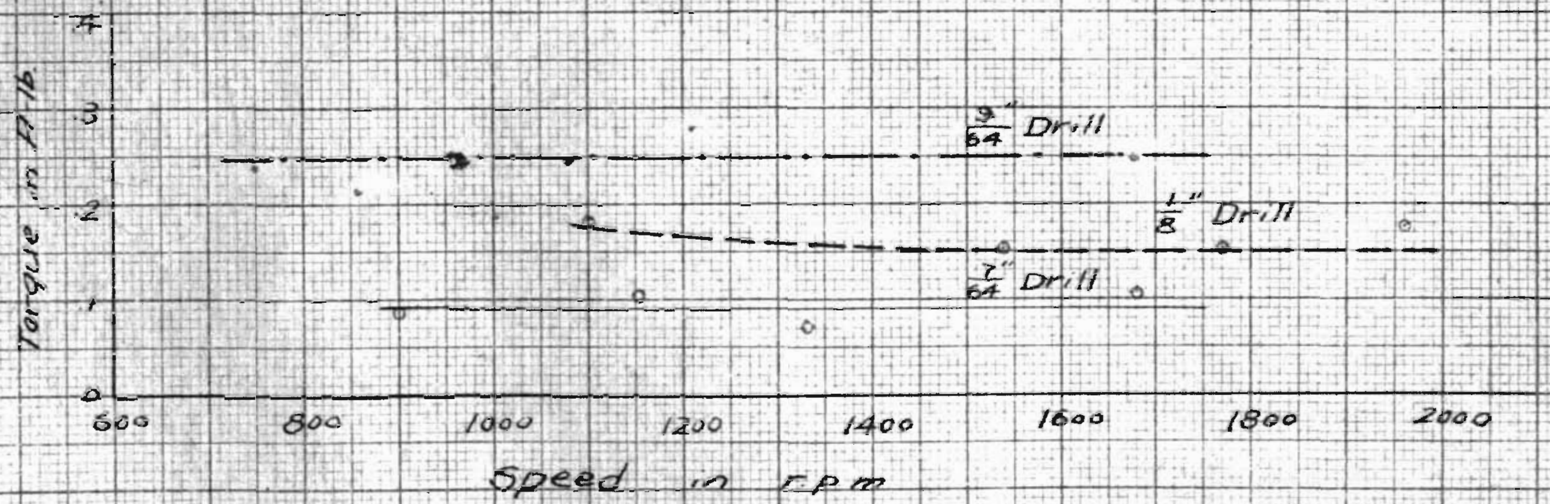


Fig. 11 Variable speed tests showing torque for S.A.E. 1025 steel with constant feed. Series D.

TABLE XII. VARIABLE SPEEDS TESTS FOR S.A.E. 1040 STEEL, SERIES D

Drill size inches	R.P.M.	Force g.	Force lb.	Torque ft-lb
13/64	600	70	.154	.432
13/64	975	75	.165	.465
13/64	1060	75	.165	.465
13/64	1295	60	.132	.371
7/64	680	35	.077	.216
7/64	970	37	.081	.228
7/64	1320	38	.083	.233
7/64	2000	30	.066	.185

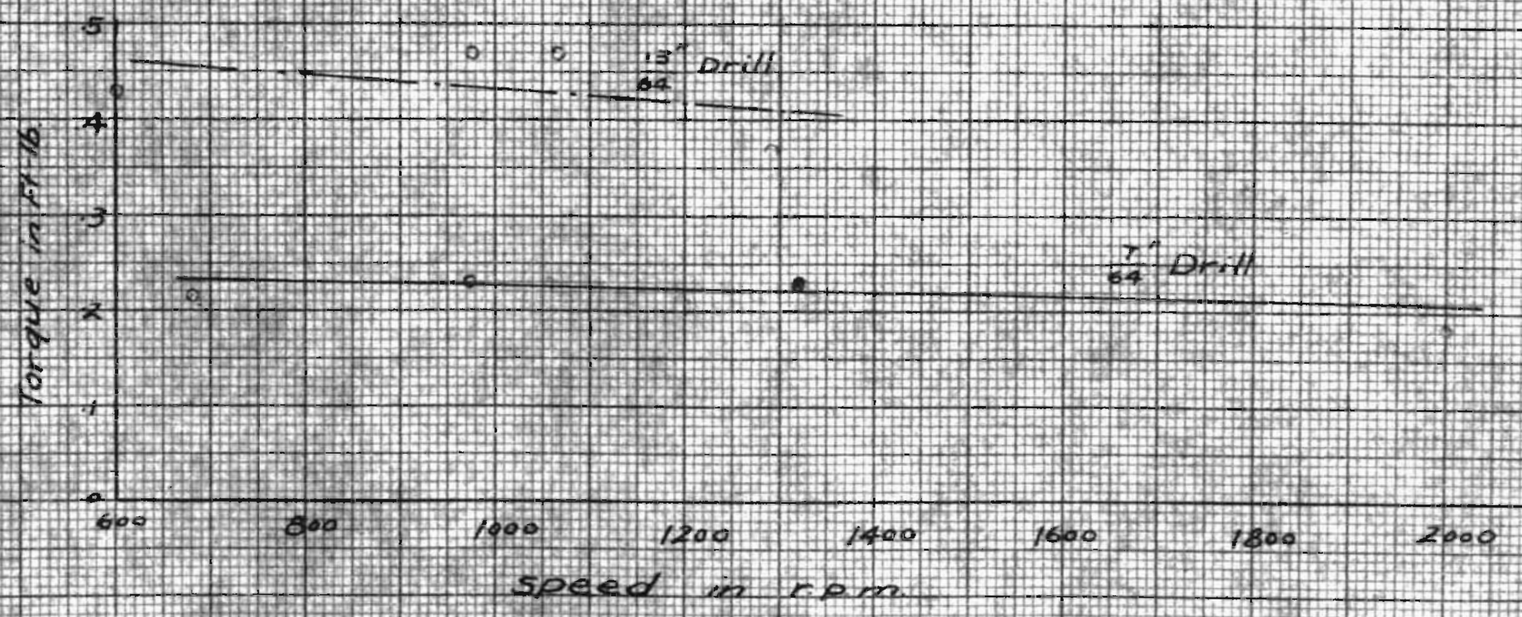


Fig. 12 Variable speed tests showing torque for S.A.E. 1040 steel with constant feed, Series D.

TABLE XIII. VARIABLE SPEEDS TESTS FOR S.A.E. 2340 STEEL, SERIES D

Drill size	R.P.M.	Force		Torque
inches		g.	lb.	ft-lb
1/8	680	35	.077	.216
1/8	1030	30	.066	.185
1/8	1405	30	.066	.185
1/8	1960	15	.033	.093
1/8	2600	20	.044	.123
5/64	700	20	.044	.123
5/64	1010	25	.055	.155
5/64	1310	22	.048	.136
5/64	2600	20	.044	.123

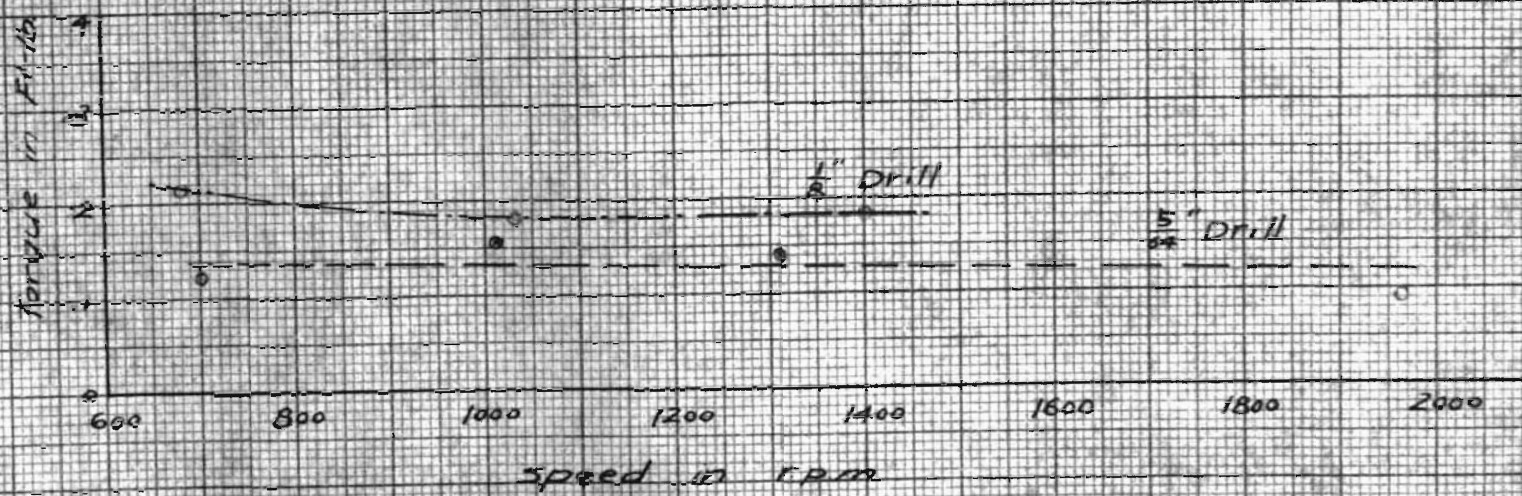


Fig. 13 Variable speed tests showing torque for S.A.E. 2340 steel with constant feed. Series D.

TABLE XIV. VARIABLE SPEEDS TESTS FOR S.A.E. 1112 STEEL, SERIES D

Drill size	R.P.M.	Force		Torque
inches		g.	lb.	ft-lb
1/8	680	35	.077	.216
1/8	1100	25	.055	.155
1/8	1370	25	.055	.155
1/8	1765	25	.055	.155
5/64	680	10	.022	.062
5/64	970	10	.022	.062
5/64	1320	5	.011	.031
5/64	1765	8	.018	.060

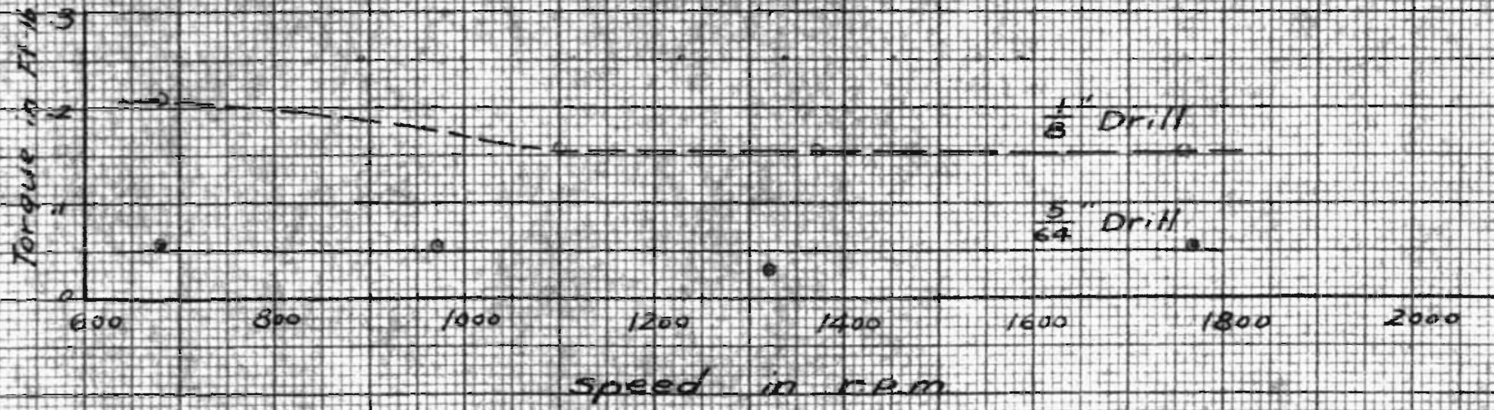


Fig. 14 Variable speed tests showing torque for S.A.E. 1112 steel with constant feed. Series D.

TABLE XV. VARIABLE SPEEDS TESTS FOR S.A.E. 1015 STEEL, SERIES D

Drill size	R.P.M.	Force		Torque
inches		g.	lb.	ft-lb
1/8	670	30	.066	.185
1/8	880	38	.083	.233
1/8	1230	38	.083	.233
1/8	1720	25	.055	.154
1/8	2025	26	.057	.160
11/64	660	30	.066	.185
11/64	890	45	.095	.268
11/64	1255	50	.110	.309
11/64	1725	52	.114	.320
11/64	2025	50	.110	.309
13/64	600	75	.165	.464
13/64	795	80	.176	.495
13/64	1090	80	.176	.495
13/64	1355	80	.176	.495

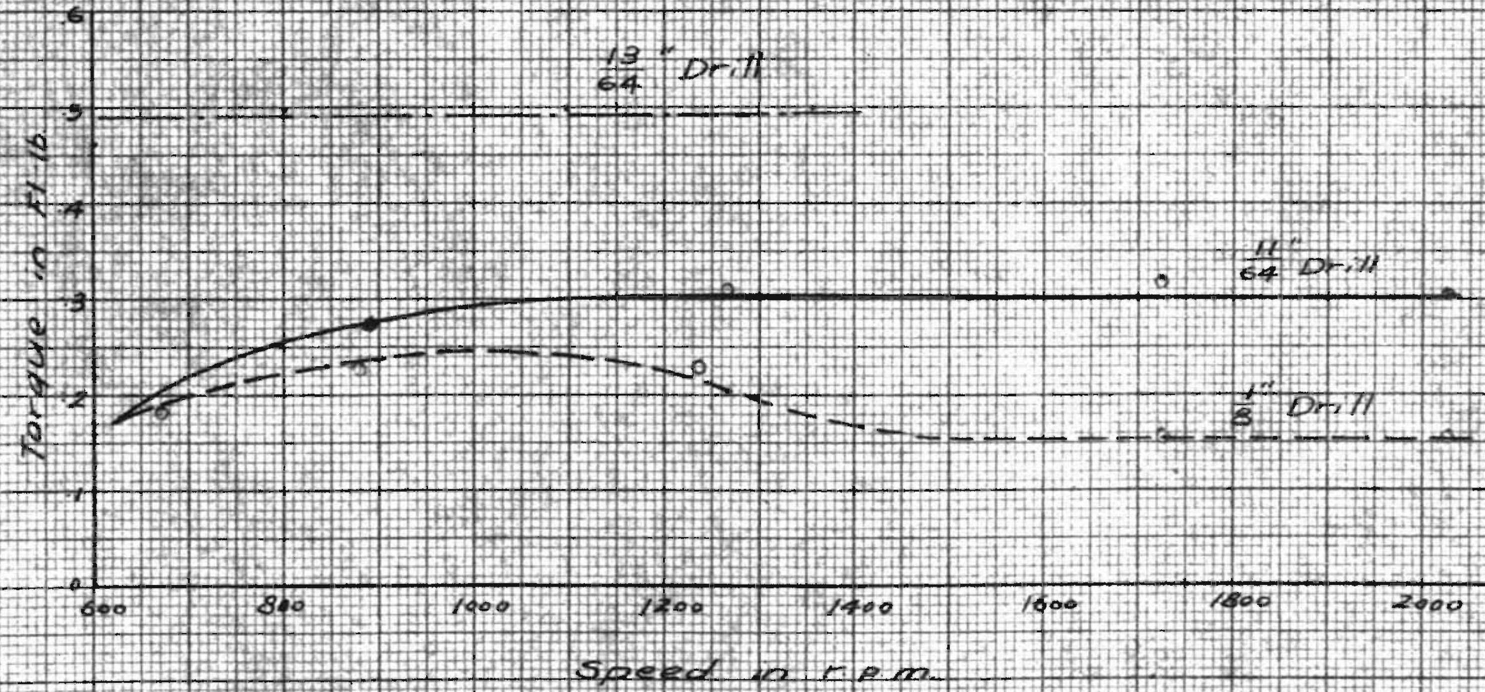


Fig. 15 Variable speed tests showing torque for S.A.E. 1015 steel with constant feed. Series D.

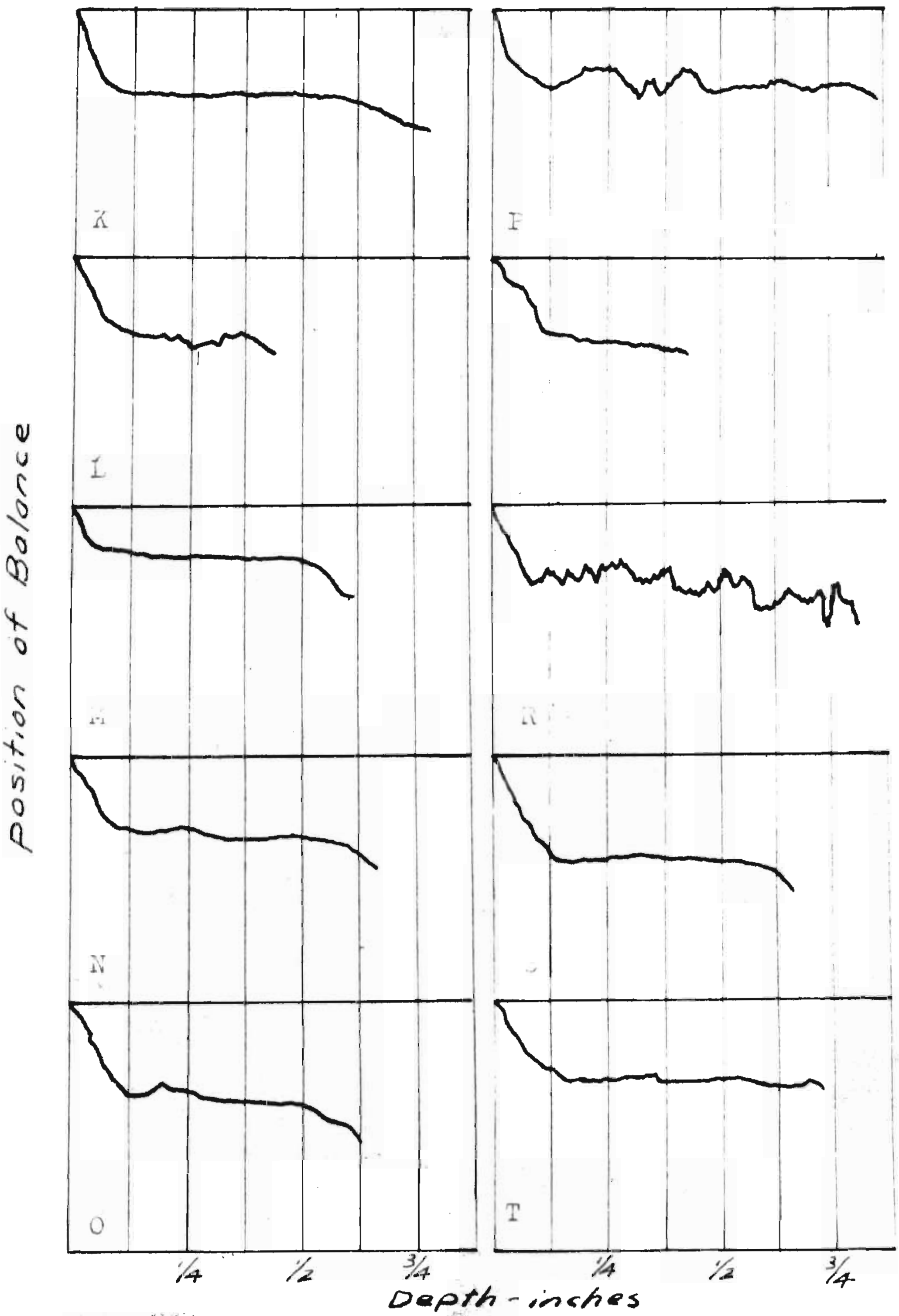


Fig. 16 Test cards showing corresponding force with the depth of hole

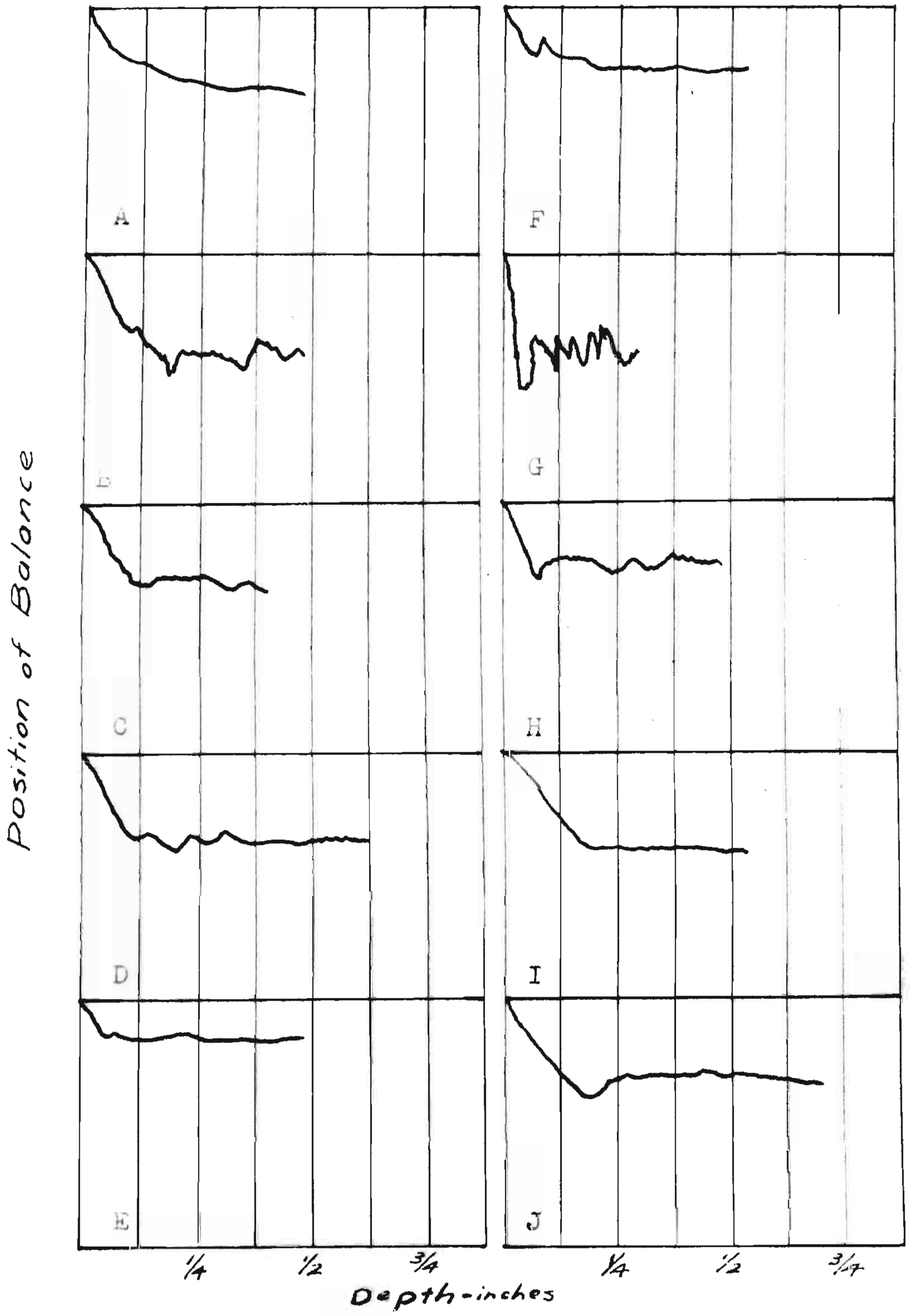


Fig.16 continued

TABLE XVI. TEST DATA

Curve	Drill size	Material to be drilled	R.P.M.
A	1/8 in.	1025	1680
B	1/8	1025	1155
C	9/64	1025	580
D	9/64	1025	1080
E	7/64	1015	680
F	9/64	2340	680
G	7/32	1112	680
H	9/64	1025	680
I	1/8	1040	680
J	3/32	1040	680
K	7/64	1112	680
L	1/8	cast iron	1070
M	3/32	1025	680
N	1/8	2340	680
O	1/8	1025	680
P	13/64	1015	600
Q	3/32	1040	680
R	13/64	1040	1295
S	1/8	1112	680
T	1/8	2340	680

Curve L was cut dry, curves I, J, N, O and S were cut with 1:50 cutting fluid. The rest of the curves are cut with 1:15 cutting fluid.

TABLE XVII. VARIABLE CUTTING FLUIDS TESTS

The cutting speeds are 680 r.p.m.

Drill size	Material	Torque in ft-lb	
inches	S.A.E.	1:15 fluid	1:50 fluid
1/8	2340	.216	.309
1/8	1015	.185	.247
1/8	1025	.185	.272
1/8	1040	.216	.290
1/8	1112	.216	.233
3/32	2340	.123	.198
3/32	1015	.123	.204
3/32	1025	.111	.136
3/32	1040	.123	.167
3/32	1112	.093	.117

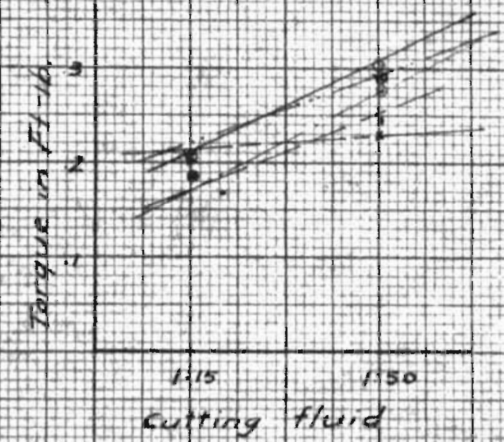
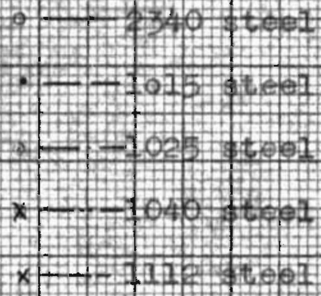


Fig. 17 A



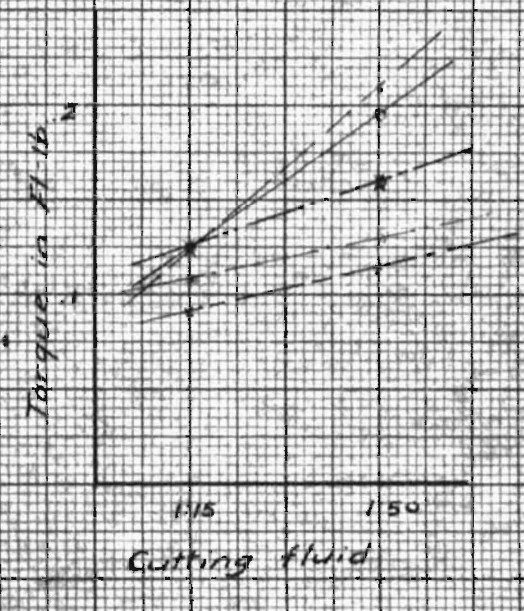


Fig. 17 B

Fig. 17 A and 17 B showing the effects of various soluble cutting oils on torque when cutting different materials. Fig. 17 A for 1/8 in. diameter drill, while 17 B for 5/32 in. diameter. The speeds are 680 r.p.m. in both cases.

Tables 4, 5, 6, 7, 8 and 9 give the data for drilling the holes on cast iron, S.A.E. 1015, 1112, 1025, 1040 and 2340 steels respectively. It is made with different diameters of drills. The cast iron was cut dry and the cutting fluids used for all five kinds of steels were one part soluble oil to 15 parts water. The drill sizes were from 1/32 to 9/32 inch in diameter. The diameter increment was 1/64 inch.

The cutting speeds for cast iron was 1100 r.p.m., 1090 r.p.m. for S.A.E. 1015 steel, and 680 r.p.m. for the other four kinds of steels.

The results of these tests showing the influence of the diameters on the torque are shown in figures 7, 8, and 9. The general characteristics of the curves are similar to each other. From these curves it is seen that under a certain speed the torque required to cut the material increases as the diameter of the drill increases. The rate of the increase of the torque is not the same for the equal increment of the drill size. At the very beginning the rate of the torque increase is slow. As the drill size becomes larger and larger the former increases more rapidly since the slope of the curve is larger than before. The curves for S.A.E. 1040 and 1025 steel are quite close.

Under the same conditions of cutting, the torque required to drive small drills is about the same in all materials, but there is a noticeable difference in torque requirements for larger drills in the various materials.

Tables 10, 11, 12, 13, 14, and 15 give the data for drilling holes on various materials with various sizes of drills. The cast iron was cut dry and the cutting fluid of one part soluble oil to 15 parts water was used for all five kinds of steels. The results of tests to show the influence of speed on torque are shown in Figures 10, 11, 12, 13, 14, and 15.

Figure 10 shows the results on cast iron. The speeds used were 580, 710, 915, 1100, and 1900 r.p.m. for a 11/64 inch diameter drill. The torque increases at first as the speed increases and reaches a maximum, then decreases and remains approximately constant over a wide range of higher speeds. The same shape of curve was obtained when the 1/8 inch diameter drill was used with the speeds of 670, 900, 1300, and 1755 r.p.m.

Figure 11 shows the result of tests on S.A.E. 1025 steel with 7/64, 1/8, and 9/64 inch drills. Figure 12 gives the results of tests on 1040 steel with 7/64 and 13/64 inch diameter drills. Figure 13 gives the results of tests on 2340 steel with 5/64 and 1/8 inch diameter drills. Figure 14 gives the results of tests on 1112 steel with 5/64 and 1/8 inch diameter drills. Figure 15 gives the results of tests on 1015 steel with 1/8, 11/64, and 13/64 inch diameter drills. The cutting speed range in these tests was from 600 to 2000 r.p.m.

From these curves it is seen that the torque decreases as the speed increases. But in most cases there is no decrease in torque as the speeds increase over a certain value. This is represented by the approximately horizontal line in the figure.

The results of tests to show the influence of the depth of holes to be drilled for various materials and drill sizes are shown in Figure 16.

From these curves it is seen that the increase in torque as the depth increases is pronounced. The fact that holes were run at high speed seems to have been a factor affecting chip disposal, and the tests show a much more rapid increase in torque as depth increases. So the readings taken at relatively shallow depth are considered more reliable than those obtained for the holes with greater depth.

The influence of the depth of the hole to be drilled on the torque depends upon many variables, such as the diameter of the drill, sharpness of the drill, the material to be drilled and the quality of the cutting fluid. There is no definite rule to determine it.

In practice, torque readings are taken at a depth of 3/8 inch and they are correct and reliable.

The results of tests on all five kinds of steels to show the influence of the effect of varying the proportion of the soluble oil to water on the torque are shown in Figure 17A and 17B. The drill sizes are 1/8 and 3/32 inch in diameter respectively. The cutting speed is 680 r.p.m. in both cases.

From these curves, it is seen that as the proportion of the soluble oil to a given amount of water is increased, the torque is decreased and the rate of change is different for different materials. S.A.E. 1112 steel has no pronounced change.

CONCLUSIONS

1. When the speed of the drill and rate of feed are constant, the torque required to cut a given material with a given cutting fluid is proportional to the diameter of the drill.

2. When the diameter of the drill and rate of feed are constant under higher speed, the torque required to cut a given material with a given cutting fluid is approximately constant. Generally speaking, as the cutting speed increases the torque decreases, but over a certain range the torque remains constant.

3. When drilling with smaller drills the value of the torque was influenced appreciably many times by chips forming in the flutes. The readings taken at relatively shallow depths were considered more reliable than those obtained for the greater depth.

4. When the diameter of the drill, rate of feed and speed, and the proportion of soluble oil to water for forming the cutting fluid are constant, the torque required to cut the different materials is not the same. It is affected by the composition of the material, the manufacturing process and the heat treatment followed.

5. As the proportion of the soluble oil to form the cutting fluid is increased the torque required to cut a given material is decreased.

SUMMARY

This paper presents the results of drilling tests on cast iron, S.A.E. 1015, 1025, 1040, 1112, and 2340 steels. Drill sizes from 1/32 to 9/32 inch diameter of the commercial high speed steel twist drills were used. The increment of the drill size was 1/64 inch. A small radial drill was used. The feed of the drill press was constant. The measuring apparatus consisted of a balance, recording device, work holding fixture and a link to transmit the forces. The speed of the drill press was determined by the use of a speed indicator in each test.

The materials were prepared to predetermine the thickness, filed smooth and a hardness test followed. A gravity feed system was used for the cutting fluid. The cutting fluid consisted of one part soluble oil to 15 parts water and one part soluble oil to 50 parts water.

Data for torques required for drilling were taken on the various diameters of the drills under different speeds and different materials, on the varying speed of cutting under different drills and different materials, and on the different proportion of the soluble oil to water with different drill sizes and different materials. Cast iron was cut dry. The curves were taken from the recording device and examined for the effect of the depth of the hole to be drilled on the torque required for cutting.

Various curves were drawn from the test data. The torque, with variation of drill diameters, cutting speeds, cutting fluids and depth of holes, was then determined for various materials.

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