

## EXPERIMENTS WITH A LATHE-TOOL DYNAMOMETER.

---

BY MR. J. T. NICOLSON, D.Sc.,

PROFESSOR OF MECHANICAL ENGINEERING AT THE MUNICIPAL SCHOOL OF  
TECHNOLOGY, MANCHESTER.

SOMETIME PROFESSOR AT MCGILL UNIVERSITY, MONTREAL.

---

In the Tool-Steel Trials made by the Manchester Committee in 1902-03 (the report upon which was published by the Manchester Association of Engineers in their Transactions for 1903), there appeared an entire lack of uniformity in the shapes and angles of the tools submitted by the eight competing firms. There was also no obvious connection between the shapes and angles of the tools and the cutting forces upon these tools deduced in the report from the electrical power measurements made by the Committee. Neither did the shape or angle supply a clue to the causes of success and failure in the various trials with different tools.

On the other hand, the necessary reconsideration of the design of lathes for the rapid and heavy cutting rendered possible by the new steels introduced by Taylor and White, and now everywhere adopted, calls for a thorough and systematic investigation of the forces acting upon a cutting tool. If a standard area of cut can be agreed upon for the various sizes of lathe, a knowledge of the forces to be overcome when taking that cut—not only for turning the work against the tool, but also for moving the slide-rest and saddle in

both the traversing and surfacing directions—will enable the calculation of the stresses in, and the proportioning of, the various parts of the machine to be gone about in a rational and scientific way.

No such knowledge has hitherto been available; and it appeared to the author that the prosecution of a somewhat extensive research into the matter would well repay the time, labour, and expense, which it would necessarily involve.

The present Paper records the results of over 300 serial trials, each requiring the making, recording and reducing of from 50 to 100 observations; but it is only to be looked upon as a first instalment of the work required to be done in order that the action of the tools used in a machine-shop may be thoroughly understood.

The thanks of the author, and, if the results herein contained should prove of value, those of the engineering public, should be given to those whose action alone rendered possible the carrying out of the work. First, to the authorities of the Manchester Municipal School of Technology, who authorised the expenditure incurred for power, light, and mechanical assistance, to a not inconsiderable amount. Second, to the firm of Sir W. G. Armstrong, Whitworth and Co., for the continuance of their loan of the lathe used in the experiments by the Manchester Committee; for the donation of the remainder of the material unoperated upon in those experiments, namely, three steel forgings and three iron castings; and for the gift of large quantities of their AW steel of various sections.

The record of the experimenters in this field is not a very long one. In Hartig's Work "Experiments on the Efficiency of Machine-Tools,"\* the law was enunciated that the cutting force varies in simple proportion to the depth of the shaving. In the "Proceedings of the Royal Society" for December 1881, Mr. A. Mallock published certain observations, and the conclusions he deduced from these, upon lathe turnings, made in the engineering workshop at Cambridge University. He then gave an analysis of the forces acting upon the tool when removing the shaving; and it

---

\* Leipzig, 1873.

will be interesting to compare his results, where possible, with the experimental data given below. Professor R. H. Smith published, in his work on "Cutting Tools" in 1882, a series of diagrams and tables, giving the results of experiments made by him with a lever form of dynamometer for measuring the vertical force only; but the cutting forces he measured never exceeded 1,000 lbs., and the cutting speeds were all below 10 feet per minute.

Professor Smith, in the preface to his book, takes Hartig severely to task for proposing the above-mentioned law of variation of force with depth; but (although the author has not had access to Hartig's work) the results of the present experiments appear to substantiate Hartig's law to, at all events, a first approximation; and, however valuable Professor Smith's work may be, it appears to the author to be open to the criticism of lack of scope and exaggeration of detail. His experimental apparatus, consisting of a Smith and Coventry's tool-holder, with a  $\frac{5}{16}$ -inch steel pin driven through it to act as a fulcrum between the cutting force at the front and the weight scale at the back, was obviously unsuited for heavy cuts, the steel pins having to sustain the sum of both the cutting and weighing forces. In the dynamometers described in this Paper this error has been avoided, and by placing the horizontal and vertical axis about which the tool is free to move at the back, whilst the weighing thrust is applied at the front near the cutting end, and therefore between point and axis, the latter has only the small difference between the cutting and weighing forces to sustain and can be made correspondingly small and frictionless.

Two dynamometers were made and used in these experiments. They were each capable of measuring forces up to 15 tons on the tool point when taking a cut. In the first, means were only provided for measuring the vertical force upon the point of the tool; whilst in the second, not only the vertically directed force, but also that tending to push the tool and saddle backwards, and that tending to oppose the traversing feed were observed.

The second apparatus grew out of the first, and was only constructed after sufficient experience with the simpler form had indicated the feasibility of a still freer suspension of the tool.

The force measurer itself consisted of an hydraulic support and a Bourdon gauge. The author had already had considerable experience with these supports, having constructed small ones for similar work, and a set for use in a rotatory transmission dynamometer, in the laboratory of the McGill University, Montreal. His attention was first attracted to them in connection with the reports on railway brakes presented to this Institution by Captain Galton,\* in which a support designed by Mr. George Westinghouse is figured and described, and was largely used in the experimental van employed by the former. The pressure was, however, recorded by connecting the interior of the support to a steam-engine indicator, and as there was necessarily considerable leakage of the fluid past the piston, an auxiliary fluid-supply device had to be added, which not only disturbed the readings of the pressure, but also made the instrument more complicated.

By reading the pressure on a Bourdon gauge, and taking precautions in making the joints, leakage can however be entirely eliminated; and the author used the instrument in this form in 1894, believing the method to be original. He has since found that many others had adopted the same plan for measuring a transmitted force, notably Napoli, Thomasset, and Maillard.

The principal hydraulic support, used for measuring the vertical force on the tool in both the first and second dynamometers, is shown in sectional elevation in Fig. 4, Plate 123. The compression piece A, when thrust upwards, produces pressure in the fluid, which communicates by means of the small copper pipe B through the make-up plug fitting C with the interior of the gauge tube D. The body of the diaphragm casing E is held down to the lathe saddle by means of two bolts FF, Fig. 3, Plate 122. Care must be taken in filling the diaphragm to remove all air from the contained fluid. Distilled water, which is boiled after filling the casing, makes a satisfactory medium; and a small filling screw fitted in the end of the gauge tube is necessary for ridding it of air.

---

\* Proceedings, 1878, pages 467 and 590, also 1879, page 170.

Turning now to the other end of the dynamometer, the tool was, in the first instance, free to move only about a horizontal axis (parallel to the lathe centre line). This arrangement is shown in Plate 122. The axis is formed by the points of two screws G passing through two massive cast-iron chocks H which rest upon the tool-slide. The points of the screws enter into deep centre pops made on the sides of the tool before hardening. When the tool is resting freely between the two loose chocks, and the screw points are entered into the pops, the tool clamps are tightened down hard upon the former, and when the screws are then advanced up to the tool it has only one degree of freedom to move. Friction between the tool and the cast-iron side-pieces, due to vertical motion of the former, is prevented by interposing greasy plates between them; and the tool is supported near its point by the strut I underneath it. This is of adjustable length, is formed into a knife-edge on top, and rests upon a knife-edge on the cast-steel beam J at bottom.

This strut I is kept in place during the cut by the stirrup-shaped piece K, which is hinged on the tap-bolts L, and retains I by means of two pointed screws M which enter the centres of the tool steel pin N connecting the double and single eye as shown.

The beam is about 2 feet  $4\frac{1}{2}$  inches long, has a fulcrum on the under side, and another knife-edge formed upon its upper side at the opposite end for taking the diaphragm-strut A. The fulcrum is a knife-edge 4 inches long, formed on the beam and resting on a flat steel plate upon the saddle. It is important that the knife-edges should be part of the beam, so that the leverage ratio may remain constantly the same, notwithstanding chatter.

With this arrangement loads of over 10 tons on the point of the tool have been taken when cutting, with but little more vibration than what is felt when the tool is bolted to the tool-slide in the ordinary way. The diaphragm only yields, when the fluid is air-free, by the amount necessary to supply the increased volume of the gauge due to the added pressure, and the spring of the tube is able to bring the arrangement back to zero when the load is removed. In order to assist this action the tool (whose point is set centrally to the work) is adjusted with a considerable droop; so that,

as with a spring tool, the cutting force diminishes when the tool deflects.

In the second form of dynamometer the same large hydraulic support Z, Fig. 4, cast-steel beam J, struts A and I, are used as in the first for measuring the downward force; but three other diaphragms are added to enable the backward and side thrusts to be measured. The side elevation of the whole instrument is shown in Fig. 4, Plate 123, the plan in Fig. 5, and the front and side views in Plate 124. The loose cast-iron cheek-pieces are here replaced by a casting O, Fig. 5, Plate 123, shaped to fit round the tool clamp studs, and recessed to provide for the gimbal tool-holder P. The object of the latter is to allow the tool freedom to move about either a horizontal axis, parallel to the lathe centre line, or a vertical axis intersecting the other. Two pointed screws Q pass through O into centre punch marks in the gimbal piece P; and two other similar screws R pass through the gimbal into pop marks on the top and bottom surfaces of the tool itself. As the tool point can now move horizontally (as well as vertically), the strut I is pointed at the bottom and rests in a recess in the cast-steel beam J, instead of upon a knife-edge formed upon it as before. The stirrup piece K is now only used to retain the strut I in the direction of the depth of the cut; that strut being free to tilt somewhat in the direction of the traverse feed. The two hydraulic supports S and T (with struts U and V of adjustable length) are suitably placed so as to retain the tool in a fixed position, in plan, relatively to the tool slide. When an experiment is about to be made, compression is put on both these supports S and T by screwing and lengthening struts U and V; so that the tool is firmly held sideways by two compressive forces of from 500 to 1,000 lbs. each, acting upon it from the supports. If, then, the tool slide thrusts to the right when traversing, it will increase the pressure on the right-hand support T, and diminish, by the same amount, the pressure on the left-hand support S. If it should thrust to the left, *i.e.* draw into the cut, it will have the reverse effect.

In order to allow of the back thrust of the tool being measured, the pointed screws Q are not tapped through the casting O itself,

but through sliding blocks W fitting in slots therein. An hydraulic support X, with its strut Y, is supplied at the back of the tool; the strut centre line being inclined at the same angle as the tool, which, for the reason above mentioned, droops somewhat towards the work.

The tool projects very little behind the centres of screws Q, and there is thus but little vertical or horizontal motion of the point of strut Y, where it touches the tool, when the latter moves under the deflections of the diaphragms of supports Z, S or T. Before the cut commences, support X is also put under pressure by screwing and lengthening strut Y, so that the tool is kept from running in by being pressed with considerable force through the blocks W, against the front of the slots formed in the casting O. Should the tool, when taking its cut, thrust backwards with a smaller force than that corresponding to the initial pressure put upon diaphragm X, that pressure must of course be suitably diminished by unscrewing and shortening strut Y.

The general arrangement of the apparatus is shown in three photographs, Plate 125. For these the author is indebted to the kindness of his colleague, Mr. Fishenden, of the School of Technology.

#### EXPERIMENTS MADE WITH FIRST DYNAMOMETER.

The size of steel ordinarily used in the experiments was  $1\frac{1}{4}$  inch square, although  $1\frac{1}{2}$  and 2 inches square steel was sometimes employed. In projecting a series of trials upon the effect of tool angle upon cutting force, the shape of the tool point in plan required first of all to be carefully considered. Almost every variety of shape had been sent in by the steel-makers in the committee's experiments, and there was no indication that any one of these was distinctly better than all the others. The round-nosed tool was the most common form, and is the easiest to forge and keep; but it has the great disadvantage from the point of view of these experiments that the actual cutting angle varies on a given tool with the depth of the cut.

It was therefore decided to make the cutting edge horizontal and at an angle in plan of  $45^\circ$  with the axis of the work. The top surface of the tool was a plane containing the cutting edge, and inclined at the angle called "the cutting angle" to the vertical plane which also contained the cutting edge. The cutting edge terminated at a point  $\frac{3}{8}$  inch from the right-hand corner of the tool (in  $1\frac{1}{4}$  inch square tools), so that the average cut taken would give a downward thrust, acting as nearly as could be arranged in the centre line of the tool, so as to prevent any twisting action and undue load upon the steel centre points. The nose of the tool had a clearance angle in plan of not less than  $1^\circ$ , and a small radius was ground on the corner between the two edges. The front clearance was  $6^\circ$ , the tools being used with the cutting edge on the level of the centre of the work. The form of the tool end is shown in plan and elevation in Figs. 24 and 25 (page 908).

(In the series of experiments made with the second dynamometer for elucidating the effect of different values of the angle (in plan) made by the cutting edge with the lathe centre line, the cutting edge was still kept horizontal, whether the plan angle was  $22\frac{1}{2}^\circ$ ,  $45^\circ$ ,  $67\frac{1}{2}^\circ$  or  $90^\circ$ .)

The results of the series of trials made with the first dynamometer, in which the vertical component only of the cutting force was measured, are given in Tables 1, 2, 3 and 4, and have been plotted in Figs. 11 to 20, Plates 126 to 128 inclusive.

Tables 1 and 2 (pages 892 to 894) refer to medium cast-iron; Tables 3 and 4 (pages 896 to 898) to soft (fluid-pressed) steel; these being the only materials so far used in these trials. The former material is somewhat harder than ordinary shop cast-iron (*vide* Manchester report), whilst the latter is a tough but not very hard steel.

Referring to Tables 1 and 3, the first two columns give the date and number of the trial, the third and fourth the intended cut and traverse, whilst the fifth and sixth give the tool angles, the seventh and eighth the actual cut and traverse, and the ninth gives the product of these, called the area of the cut. Column 10 records the vertical force actually observed upon the tool point, whilst column 11 gives the cutting stress, being the quotient of the cutting

force (col. 10) by the area of the cut (col. 9). Column 12 gives the actual cutting speed, and column 13 the horse-power required for cutting, being the products of the numbers in columns 10 and 12 divided by 33,000. The last column contains remarks as to the state of the tool at the commencement of each trial and other points of special interest.

For both cast-iron and steel it was the intention to make trials with each of four different traverses:  $\frac{1}{16}$  inch,  $\frac{1}{8}$  inch,  $\frac{1}{4}$  inch, and  $\frac{3}{8}$  inch, and with four depths of cut for each traverse:  $\frac{1}{8}$  inch,  $\frac{1}{4}$  inch,  $\frac{3}{8}$  inch, and  $\frac{1}{2}$  inch. This scheme was carried out in the case of the cast-iron, so far as was possible with the means available, for each of the four cutting angles of  $45^\circ$ ,  $60^\circ$ ,  $75^\circ$ , and  $90^\circ$ .

Table 2 indicates the scope of the cast-iron series, and records the cutting stresses observed, in tons per square inch, for each series of cuts and each of the four cutting angles employed.

The cutting stresses tabulated in Table 2 (page 894), which are obtained by dividing the observed (vertical) cutting forces by 2240 and by the area of the cut, as given in Table 1 (columns 10 and 9), have been averaged for each traverse and tool angle in Plate 126, and the results obtained have been plotted in Fig. 19, Plate 128, as ordinates on a base of cutting angles.

This Plate indicates a somewhat lower stress for wide than for fine traverses, although this conclusion does not appear to hold in its entirety, especially for the keenest cutting angle used ( $45^\circ$ ). It may be pointed out that the spots plotted in Figs. 19 and 20, Plate 128, are not single experiments, but are the average stresses for all depths of cut deduced from the sloping straight lines of Figs. 11 to 14, Plate 126 (or Figs. 15 to 18, Plate 127, for steel). These sloping lines are drawn so as to allow for the differing degree of sharpness of the tool used in each experiment depending on the number of previous runs it had had. [The small figures beside each spot on the last-mentioned Plates indicate the number of trials on which the tool had already been used without regrinding.]

The lines are drawn straight in Figs. 11 to 13, Plate 126, as expressing the conclusion, which is the simplest that can be obtained as a first approximation to the observations, that, for a given traverse,

TABLE 1.  
Results of First Dynamometer Trials on Medium Cast-Iron.  
(Speed 25 feet per minute.)

Date.	No. of Experiment.	Intended.		Tool Angles.		Actual.		Area.	Observed Vertical.		Cutting Speed.	Horse-Power required.	Remarks.
		Cut.	Trav.	Plan.	Cutting.	Cut.	Trav.		Force lbs.	Stress tons.			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1903.		inch.	inch.			inch.	inch.	square inch.		square inch.	feet per min.		
21st Nov.	501	1	1	45°	45°	0·101	0·125	0·0126	2128	75·4	24·8	1·6	Fresh tool (failed)
" "	502	1	1	45°	60°	0·1385	0·125	0·0173	2186	56·6	24·7	1·680	Same tool reground
" "	503	1	1	45°	60°	0·2305	0·125	0·0288	3740	58	24·55	2·78	Same tool unground
" "	504	1	1	45°	75°	0·1130	0·125	0·0141	2705	85·8	24·78	2·03	Fresh tool
" "	505	1	1	45°	75°	0·2210	0·125	0·0276	4775	77·3	24·58	3·55	Same tool unground
" "	506	1	1	45°	75°	0·3280	0·125	0·0410	6980	76·2	24·36	5·15	" " "
" "	507	1	1	45°	75°	0·4470	0·125	0·0559	10230	82·5	24·13	7·47	" " "
21th Nov.	508	1	1	45°	60°	0·3620	0·125	0·0453	5400	53·2	24·3	3·98	Fresh tool
" "	509	1	1	45°	60°	0·4700	0·125	0·0587	7700	58·5	24·1	5·62	Same tool unground
" "	510	1	1	45°	90°	0·1000	0·125	0·0125	2760	98·5	24·8	2·075	Fresh tool
" "	511	1	1	45°	90°	0·2010	0·125	0·0250	5175	92·5	24·58	3·85	Same tool unground
" "	512	1	1	45°	90°	0·3070	0·125	0·0384	8310	97·2	24·35	6·16	" " (broke)
" "	513	1	1	45°	45°	0·2260	0·125	0·0283	4450	70	24·53	3·305	Fresh ground
" "	514	1	1	45°	45°	0·3120	0·125	0·0390	6780	77·5	24·36	5·0	Same tool unground (speeded up & failed)

25th Nov.	515	$\frac{1}{8}$	$\frac{1}{8}$	45°	481°	0·1340	0·0625	0·0084	1325	93·5	24·7	0·995	Fresh tool
" "	516	$\frac{1}{8}$	$\frac{1}{8}$	45°	483°	0·2500	0·0625	0·0156	2188	62·5	24·5	1·62	Same tool unground
" "	517	$\frac{1}{8}$	$\frac{1}{8}$	45°	484°	0·3840	0·0625	0·0240	3190	59·3	24·18	2·33	" " "
" "	518	$\frac{1}{8}$	$\frac{1}{8}$	45°	484°	0·4880	0·0625	0·0305	4240	62·1	24	3·2	" " "
" "	519	$\frac{1}{8}$	$\frac{1}{8}$	45°	60°	0·1160	0·0625	0·00726	1173	72·1	24·7	0·88	Fresh tool
" "	520	$\frac{1}{8}$	$\frac{1}{8}$	45°	60°	0·2440	0·0625	0·01523	2186	64·2	24·5	1·622	Same tool unground
" "	521	$\frac{1}{8}$	$\frac{1}{8}$	45°	60°	0·3620	0·0625	0·0226	3106	61·4	24·25	2·29	" " "
" "	522	$\frac{1}{8}$	$\frac{1}{8}$	45°	60°	0·5000	0·0625	0·03125	4486	64·2	23·9	3·24	" " "
1st Dec.	523	$\frac{1}{8}$	$\frac{1}{8}$	45°	75°	0·1260	0·0625	0·00781	1437	82·5	24·75	1·08	Fresh tool
" "	524	$\frac{1}{8}$	$\frac{1}{8}$	45°	75°	0·2375	0·0625	0·01484	2474	74·4	24·4	1·865	Same tool unground
" "	525	$\frac{1}{8}$	$\frac{1}{8}$	45°	75°	0·3635	0·0625	0·02271	3738	73·6	24·22	2·75	" " "
" "	526	$\frac{1}{8}$	$\frac{1}{8}$	45°	75°	0·4975	0·0625	0·03110	5350	77·0	23·9	3·86	Tool reground
" "	527	$\frac{1}{8}$	$\frac{1}{8}$	45°	90°	0·1200	0·0625	0·00750	1840	109·5	24·8	1·38	Fresh tool
" "	528	$\frac{1}{8}$	$\frac{1}{8}$	45°	90°	0·2245	0·0625	0·01403	3278	104·1	24·4	2·42	Same tool reground
" "	529	$\frac{1}{8}$	$\frac{1}{8}$	45°	90°	0·3430	0·0625	0·02143	4658	97·6	24·2	3·42	" " "
" "	530	$\frac{1}{8}$	$\frac{1}{8}$	45°	90°	0·4660	0·0625	0·02912	6152	94·5	23·9	4·46	" " "
8th Dec.	531	$\frac{1}{8}$	$\frac{1}{4}$	45°	75°	0·0885	0·25	0·02212	3680	74·3	24·82	2·77	Fresh tool
" "	532	$\frac{1}{8}$	$\frac{1}{4}$	45°	60°	0·1055	0·25	0·02638	3473	56·6	24·8	2·58	" "
" "	533	$\frac{1}{8}$	$\frac{1}{4}$	45°	60°	0·2300	0·25	0·05750	6525	50·7	24·55	4·84	Same tool reground
" "	534	$\frac{1}{8}$	$\frac{1}{4}$	45°	60°	0·2940	0·25	0·07350	8740	53	24·4	6·47	" " "
" "	535	$\frac{1}{8}$	$\frac{1}{4}$	45°	75°	0·1750	0·25	0·04375	6875	70·3	24·65	5·13	Fresh tool
" "	536	$\frac{1}{8}$	$\frac{1}{4}$	45°	90°	0·1060	0·25	0·0265	4740	80	24·8	3·57	" "
" "	537	$\frac{1}{8}$	$\frac{1}{4}$	45°	90°	0·1835	0·25	0·0459	8110	79	24·6	6·04	Same tool unground
10th Dec.	538	$\frac{1}{8}$	$\frac{1}{4}$	45°	47·5°	0·1010	0·25	0·0252	3230	57·2	24·8	2·425	Fresh tool
" "	539	$\frac{1}{8}$	$\frac{1}{4}$	45°	46°	0·2180	0·25	0·0545	6570	53·6	24·5	4·88	Same tool unground
" "	540	$\frac{1}{8}$	$\frac{1}{4}$	45°	75·5°	0·3300	0·25	0·0825	10350	54	24·3	7·62	Fresh tool
11th Dec.	541	$\frac{1}{8}$	$\frac{3}{8}$	45°	75·5°	0·1200	0·375	0·045	6060	60·3	24·75	4·55	Same tool unground
" "	542	$\frac{1}{8}$	$\frac{3}{8}$	45°	61°	0·0805	0·375	0·0302	5180	77	24·8	3·893	Fresh tool
" "	543	$\frac{1}{8}$	$\frac{3}{8}$	45°	47°	0·0780	0·375	0·0292	5330	81·6	24·8	4·02	" "
" "	544	$\frac{1}{8}$	$\frac{3}{8}$	45°	90°	0·0782	0·375	0·0283	7600	116	24·82	5·72	" "

TABLE 2.

*Medium Cast-Iron Trials, Speed 25 feet per minute.*

Numbers of Trials for reference as given in Table 1, and Cutting Stresses deduced.

Traverses . . .		$\frac{1}{16}$ inch.				$\frac{1}{8}$ inch.				$\frac{1}{4}$ inch.				$\frac{3}{8}$ inch.		
Cuts . . .		$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$
Tool Angles (cutting) }	45° {	515	516	517	518	501	513	514	No.	538	539	No.	No.	543	No.	No.
		93·5	62·5	59·3	62·1	25·4	70	77·5		57·2	53·6			31·6		
	60° {	519	520	521	522	502	503	508	509	532	533	534	No.	542	No.	No.
		72·6	64·2	61·4	64·2	56·6	58	53·2	58·5	56·6	50·7	53		77		
Plan Angle 45° }	75° {	523	524	525	526	504	505	506	507	531	535	540	No.	541	No.	No.
		82·5	74·4	73·6	77·0	85·8	77·3	76·2	82·5	74·3	70·3	54		60·3		
throughout. }	90° {	527	528	529	530	510	511	512	No.	536	537	No.	No.	544	No.	No.
		109·5	104·1	97·6	94·5	98·5	92·5	97·2		80	79			116		

the cutting force is simply proportional to the depth of cut, or that the cutting stress is constant for a given width of traverse and given tool-angle. The positions of the spots in Fig. 19, Plate 128, may therefore be viewed with some degree of confidence in regard to their accuracy.

The variation of the cutting stress with the cutting angle is very marked. It varies by nearly one hundred per cent. of its smallest value, which takes place, in every case, for a cutting angle of about  $60^\circ$ . As subsequently shown, however, this angle of minimum cutting force is by no means that of greatest durability. A cutting angle of  $80^\circ$  is that indicated as being best for shop use, and the cutting stress for this angle is about 75 tons per square inch.

In Table 3 (pages 896 and 897) the results obtained in the experiments on soft (fluid-pressed) steel are recorded in the same manner as already described for cast iron.

In the series of trials with soft (fluid-pressed) steel, the scheme of trials mentioned above was commenced and half completed as shown in Table 4 (page 898), but as by that time the second dynamometer was ready for work a new schedule of trials was made out and executed, and will be described later on.

Table 4 gives for soft steel the same results as were tabulated in Table 2 for cast-iron. The cutting stresses in this Table have again been averaged for each traverse and tool-angle by the method shown on Figs. 15 to 18, Plate 127, and the results obtained for them in this way have been plotted as ordinates on a base of tool-angles in Fig. 20, Plate 128.

The variation of the cutting-stress with the traverse in the case of soft steel is somewhat complicated. For keen cutting angles (below  $75^\circ$ ) fine traverses require less cutting force than wide ones, whilst for blunt-nosed tools (i.e. cutting angles greater than  $75^\circ$ ) the reverse is the case, and the fine traverse cut requires the greater effort to remove. At a cutting angle of  $75^\circ$  the stress is the same whether the traverse be  $\frac{1}{16}$  inch or  $\frac{1}{8}$  inch, and has the value of about 100 tons per square inch. It is curious to remark that this angle of  $75^\circ$  is also about the best angle for shop use, as shown by the durability trials subsequently to be cited.

TABLE 3.

*Results of First Dynamometer Trials on Soft (Fluid-Pressed) Steel.*  
*(Speed 50 feet per minute.)*

Date.	No. of Experiment.	Intended.		Tool Angles.		Actual.		Actual Area of Cut.	Observed Vertical.		Cutting Speed.	Horse-Power required.	Remarks.
		Cut.	Trav.	Plan.	Cutting.	Cut.	Trav.		Force lbs.	Stress tons.			
1	2	3	4	5	6	7	8	9	10	11	12	13	14
1904.		inch.	inch.			inch.	inch.	square inch.		square inch.	feet per min.		
11th Jan.	603	$\frac{1}{8}$	$\frac{1}{8}$	45°	60°	0.1270	0.0625	0.0079	1143	64.6	49.5	1.714	Fresh tool
" "	604	$\frac{1}{4}$	$\frac{1}{8}$	45°	60°	0.2575	0.0625	0.0161	2400	66.4	48.9	3.558	Same tool unground
" "	605	$\frac{3}{8}$	$\frac{1}{8}$	45°	60°	0.3650	0.0625	0.0228	4050	79.5	48.35	5.94	{ " " " (Bad shape of tool shavings curled)
12th Jan.	606	$\frac{3}{8}$	$\frac{1}{8}$	45°	60°	0.3750	0.0625	0.0234	3630	69.3	48.0	5.28	{ Same tool ground to clear cutting
" "	607	$\frac{1}{2}$	$\frac{1}{8}$	45°	60°	0.5020	0.0625	0.0314	6280	89.1	47.8	9.1	Same tool unground
" "	608	$\frac{1}{2}$	$\frac{1}{8}$	45°	75°	0.1245	0.0625	0.0078	1390	79.5	49.5	2.85	Reforged and ground
" "	609	$\frac{1}{2}$	$\frac{1}{8}$	45°	75°	0.2405	0.0625	0.0150	3360	100	48.8	4.97	Same tool unground
" "	610	$\frac{3}{8}$	$\frac{1}{8}$	45°	75°	0.3425	0.0625	0.0214	5470	112	48.5	8.04	" " "

"	"	611	$\frac{1}{16}$	$\frac{1}{16}$	45°	75°	0.4009	0.0625	0.0287	76.30	119	48.0	11.12	"	"	"
"	"	612	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.1145	0.0625	0.0072	2790	173	49.6	4.19	Fresh tool		
"	"	613	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.2200	0.0625	0.0137	5070	165	48.9	7.52	Same tool	unground	
"	"	614	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.3195	0.0625	0.0199	7150	160	48.6	10.52	"	"	"
"	"	615	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.4175	0.0625	0.0261	9130	156.2	48.1	13.35	"	"	"
13th Jan.		616	$\frac{1}{16}$	$\frac{1}{16}$	45°	60°	0.1255	0.125	0.0157	2470	70	49.5	3.705	Fresh tool		
"	"	617	$\frac{1}{16}$	$\frac{1}{16}$	45°	60°	0.2565	0.125	0.0321	5810	80.8	48.8	8.6	Same tool	unground	
"	"	618	$\frac{1}{16}$	$\frac{1}{16}$	45°	60°	0.3570	0.125	0.0446	8880	89	48.4	13.0	"	"	"
"	"	619	$\frac{1}{16}$	$\frac{1}{16}$	45°	60°	0.4875	0.125	0.0609	11900	87.2	47.9	17.3	"	"	"
"	"	620	$\frac{1}{16}$	$\frac{1}{16}$	45°	75°	0.1220	0.125	0.0152	3390	99.6	49.0	5.04	Tool reground		
"	"	621	$\frac{1}{16}$	$\frac{1}{16}$	45°	75°	0.2240	0.125	0.0280	6930	110.6	49.0	10.3	Same tool	unground	
"	"	622	$\frac{1}{16}$	$\frac{1}{16}$	45°	75°	0.3235	0.125	0.0404	9960	110.6	48.5	14.65	"	"	"
"	"	623	$\frac{1}{16}$	$\frac{1}{16}$	45°	75°	0.4575	0.125	0.0572	12700	99	48	18.5	"	"	"
14th Jan.		624	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.1300	0.0625	0.0081	1740	95.3	49.4	2.6	Fresh tool		
"	"	625	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.2580	0.0625	0.0161	3540	98	48.8	5.24	Same tool	unground	
"	"	626	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.3880	0.0625	0.0242	5460	102	48.4	8.0	"	"	"
"	"	627	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.5135	0.0625	0.0321	6440	89.4	47.4	9.25	Same tool	reground	
"	"	628	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.1200	0.125	0.0150	3280	97.4	49.4	4.92	"	"	unground
"	"	629	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.2480	0.125	0.0310	6560	94.5	48.7	9.7	"	"	"
"	"	630	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.4670	0.125	0.0584	12880	98.3	47.7	18.65	"	"	reground
"	"	631	$\frac{1}{16}$	$\frac{1}{16}$	45°	45°	0.3340	0.125	0.0418	9780	109.2	48.4	14.3	"	"	unground
"	"	632	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.0975	0.125	0.0122	3200	117.3	49.5	4.8	Fresh tool		
"	"	633	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.1905	0.125	0.0238	7670	144.2	49	11.38	Same tool	unground	
"	"	634	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.2730	0.125	0.0343	10130	131.7	48.5	14.9	"	"	"
"	"	635	$\frac{1}{16}$	$\frac{1}{16}$	45°	90°	0.4130	0.125	0.0517	14770	127.3	47.9	21.42	"	"	"

TABLE 4.

*Soft (Fluid-Pressed) Steel Trials. Speed 50 feet per minute.*

Numbers of Trials for Reference as in Table 3, and Cutting Stresses deduced.

Traverses . . .		$\frac{1}{16}$ inch.				$\frac{1}{8}$ inch.				$\frac{1}{4}$ inch.				$\frac{3}{8}$ inch.		
Cuts . . .		$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$	$\frac{1}{2}$	$\frac{1}{8}$	$\frac{1}{4}$	$\frac{3}{8}$
Tool Angles (cutting)	45°	624	625	626	627	628	629	631	630							
		95.3	98	102	89.4	97.4	94.5	109.2	98.3							
	60°	603	604	605	607	616	617	618	619							
		61.6	66.4	79.5	89.1	70	80.8	89	87.2							
Plan Angle 45° throughout	75°	608	609	610	611	620	621	622	623							
		79.5	100	112	119	99.6	110.6	110.6	99							
	90°	612	613	614	615	632	633	634	635							
		173	165	160	156.2	117.3	144.2	131.7	127.3							

We may therefore say, with some confidence, that the ordinary shop-tool, when cutting soft steel of this quality, exerts a vertical force of 100 tons per square inch of area of cut removed irrespective of the proportion of width of traverse to depth of cut. [It may be pointed out that 98.5 tons per square inch was obtained in the Manchester experiments as the average cutting stress for the endurance trials on soft steel (Table 20 of Report) in which one shape of tool was used throughout, the cutting angle being about 70°. The tool is figured on page 256 of the Report. According to the results of Fig. 20, Plate 128, the stress on these endurance trials ought to have been about 88 tons or even less, as the speed was 90 feet instead of 50 feet per minute, but it must be remembered that the electrical method of measuring the cutting force from which the figure 98.5 was deduced includes not only the vertical work, but also that done in pushing away the shaving over the face of the tool, and ought in most cases to give a greater value for the cutting stress than that attained with the dynamometer. The agreement is therefore very close, and the two results are mutually confirmatory.]

#### EXPERIMENTS ON DURABILITY OF DIFFERENT CUTTING ANGLES.

All the above trials were made in the endeavour to determine the laws of the variation of *cutting force* with tool-angle and with shape of cut. It was, however, not *à priori* to be expected that the tool-angle which gave the smallest cutting force would also prove the most durable or remove the greatest weight of material before failure. As this is a point of even greater practical importance than the other, two further series of trials were projected, one on the soft steel, the other with the medium cast-iron, for the purpose of finding the cutting angle to be commended for shop use.

In the cast-iron series a cutting speed of 44 feet per minute, with a cut  $\frac{3}{16}$  inch deep by  $\frac{1}{16}$  inch traverse, was decided upon, after about fifteen preliminary trials had been made. It was found in these preliminary experiments that a foot per minute, more or less, in the cutting speed made a great difference in the duration of the experiment ;

and, as time and material had to be economised, the careful adjustment of the speed was necessary to ensure uniform and consistent results. Cutting angles of less than  $60^\circ$  were excluded, but it was decided to use tools of  $60^\circ$ ,  $65^\circ$ ,  $70^\circ$ ,  $75^\circ$ ,  $80^\circ$ ,  $85^\circ$  and  $90^\circ$  cutting angles, and to run them at the above speed *exactly* until they failed.

The results are given in Table 5 (page 901). This Table contains the trial numbers and dates, the intended and actual cuts and traverses, the angles of the tools, and the time required to fail them; or the duration of the run. (The plan angle was  $45^\circ$  throughout.)

The times of failure or durations of these runs are plotted as ordinates on a base of tool-angles in Fig. 21, Plate 128. From Table 5 and Fig. 21, Plate 128, it is clearly seen that a cutting angle of from  $75^\circ$  to  $80^\circ$  with tools of  $45^\circ$  plan angle were the most durable for medium cast-iron. As the cut ( $\frac{3}{16}$  inch) was somewhat shallow, and the tool point had a small radius (about  $\frac{3}{32}$  inch) in plan, the shaving moved off in a direction nearly perpendicular to the axis of the work, instead of at right angles to the cutting edge of the tool ( $45^\circ$  in plan). This means that the actual cutting angle measured in the direction of motion of the shaving (in plan) [or the true cutting angle as per Manchester Report, page 246] was about  $81^\circ$ .

Tools should therefore be ground for maximum endurance in the cutting of cast-iron in ordinary shop practice, so that their true cutting angles are about  $81^\circ$ , or if they are allowed  $6^\circ$  clearance for working on the level of lathe centres, they should have an included angle of about  $75^\circ$ .

The series of trials made to determine the most durable angle of tool for the rapid cutting of steel had to be run at a speed of 75 feet per minute, in order to secure failure in a reasonable time on the cut of  $\frac{1}{4}$  inch by  $\frac{1}{8}$  inch, which had been decided upon. Unfortunately the soft-steel shaft supplied by Messrs. Whitworth (originally 22 inches diameter and 9 feet long) was, by the time the trials now referred to were commenced, reduced to a diameter of less than 6 inches in parts, and the vibration which sometimes ensued, together with the difficulty of getting sufficient length of parallel bar for a failure trial, prevented the series from giving a quite conclusive result with regard to soft steel.

TABLE 5.

*Failure Trials with different Cutting Angles on Medium Cast-Iron.*Intended cut  $\frac{3}{16}$  inch, traverse  $\frac{1}{16}$  inch. Cutting speed 44 feet per minute.

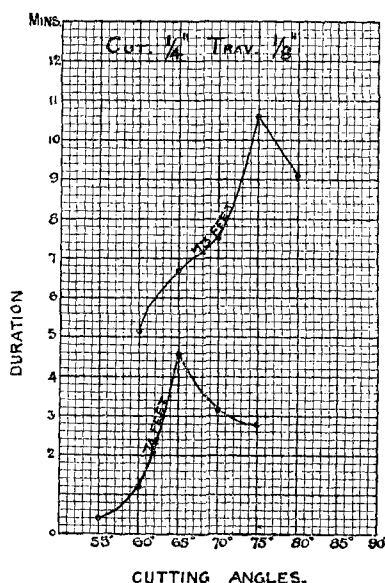
Date.	Number.	Actual		Actual Area.	Angle of Tool.	Size of Tool.	Duration of Trial.		Remarks.
		Cut.	Traverse.						
1903.		inch.	inch.	sq. inch.		sq. inch.	mins.	secs.	
17th December	561	0·1815	0·0625	0·01134	60°	1½	2	47	Too soft.
"	562	0·1815	"	0·01134	60°	1½	0	21	
23rd December	563	0·1830	"	0·01144	65°	1½	4	10	Too soft.
"	564	0·1745	"	0·01090	65°	1½	1	51	
"	566	0·1875	"	0·01172	70°	1½	8	45	Too soft.
"	567	0·1715	"	0·01071	70°	1½	2	0	
"	568	0·1815	"	0·01134	75°	1½	12	15	Too soft.
"	569	0·1800	"	0·01125	75°	1½	4	0	
"	570	0 1770	"	0·01106	80°	1½	8	14	
1904.									
6th January	573	0·1830	"	0·01144	80°	1½	5	30	Too soft
"	574	0·1825	"	0·01141	85°	1½	7	55	Too soft.
"	576	0·1710	"	0·01068	85°	1½	2	40	
"	575	0·1670	"	0·01043	90°	1½	4	50	Too soft.
"	577	0·1710	"	0 01068	90°	1½	1	10	

Table 6 (page 903) and Fig. 22, Plate 128, give the figures and show the nature of the results obtained.

A further series of trials to determine the most durable cutting angle of tool for steel was carried out with the remainder of the bar of *medium* fluid-pressed steel used in the Manchester Committee's experiments.

The trials above reported with the *soft-steel* bar proved inconclusive in their results, as the bar had become so reduced in diameter that a run of duration sufficient to fail a tool was with

FIG. 23.  
FAILURE TRIALS WITH VARIOUS CUTTING ANGLES  
(PLAN ANGLE  $45^\circ$  THROUGHOUT) ON  
MEDIUM STEEL (fluid pressed)



difficulty attainable, and excessive springing of the work and chattering of the tool took place. The medium steel bar had, however, still a diameter of twelve or thirteen inches, and its length allowed of long runs being taken. Two series were made, one at 74 feet per minute, the other at 73 feet per minute, cutting speeds; the cut in both cases being  $\frac{1}{4}$  inch deep and  $\frac{1}{8}$  inch wide. Table 7 (page 904) records the results obtained.

TABLE 6.

*Failure Trials with Different Cutting Angles, on Soft (fluid-pressed) Steel.*Intended cut,  $\frac{1}{4}$  inch; traverse,  $\frac{1}{8}$  inch; cutting speed, 75 feet per minute.

Date.	Number.	Actual		Actual Area.	Angle of Tool.	Size of Tool.	Duration of Trial.		Remarks.
		Cut.	Traverse.						
10th March	805	inch. 0·246	inch. 0·125	sq. inch. 0·03075	55°	square inch. $1\frac{1}{4}$	mins. 5	secs. 10	
" "	806	0·2287	0·125	0·0286	60°	$1\frac{1}{4}$	3	0	
" "	807	0·229	0·125	0·02864	65°	$1\frac{1}{4}$	6	15	
" "	809	0·256	0·125	0·032	55°	$1\frac{1}{4}$	3	0	
" "	810	0·267	0·125	0·0334	60°	$1\frac{1}{4}$	6	35	
" "	811	0·2495	0·125	0·0314	65°	$1\frac{1}{4}$	12	20	
" "	812	0·2415	0·125	0·03015	70°	$1\frac{1}{4}$	19	0	
" "	813	0·2067	0·125	0·02585	75°	$1\frac{1}{4}$	19	35	Not failed.
18th March	814	0·265	0·125	0·03315	55°	$1\frac{1}{2}$	3	25	
" "	815	0·2435	0·125	0·03045	75°	$1\frac{1}{2}$	24	30	Not failed.

The series is to be repeated with medium steel.

TABLE 7.

*Failure Trials with different Cutting Angles on Medium (Fluid-pressed) Steel.*Intended cut  $\frac{1}{8}$  inch, traverse  $\frac{1}{8}$  inch. Series a. Cutting speed 74 feet per minute.

Date.	Number.	Actual.		Actual Area.	Angle of Tool.	Duration of Trial.	Remarks.
		Cut.	Traverse.				
1904. 25th March	818	inch. 0·245	inch. 0·125	sq. inch. 0·03063	55°	min. secs. 0 25	
"	819	0·2415	0·125	0·03018	60°	1 12	
"	820	0·240	0·125	0·03000	65°	4 37	
"	821	0·243	0·125	0·03038	70°	3 10	
"	822	0·233	0·125	0·02913	75°	2 47	
Series b. Cutting speed 73 feet per minute..							
26th March	823	0·244	0·125	0·03050	60°	min. secs. 5 10	
"	824	0·240	0·125	0·03000	65°	6 43	
"	825	0·230	0·125	0·02875	70°	7 30	
"	826	0·231	0·125	0·02890	75°	10 37	
"	827	0·235	0·125	0·02940	80°	9 8	

They are plotted also in Fig. 23 (page 902), the durations of the various trials being set up on a base of cutting angles of the tools employed.

Taken altogether these trials seem to show that a cutting angle of about  $70^\circ$  (included angle  $65^\circ$ ) is that which will last the longest in rapid cutting. The plan angle of the cutting edge was  $45^\circ$  throughout.

#### EXPERIMENTS WITH UNIVERSAL DYNAMOMETER.

The scope of the series of trials with the second or universal form of dynamometer, in which the thrusts in both horizontal directions, as well as in the vertical direction, were measured, is indicated, so far as carried out up to date, in the annexed schedule.

One series was projected in which all the tools were to have the same cutting angle, viz.,  $55^\circ$ , but four different plan angles of the cutting edge, viz.,  $22\frac{1}{2}^\circ$ ,  $45^\circ$ ,  $67\frac{1}{2}^\circ$  and  $90^\circ$ . In the other series a common plan angle of  $45^\circ$  was to be preserved, with cutting angles of either  $45^\circ$ ,  $60^\circ$ ,  $75^\circ$  or  $90^\circ$ .

The observations obtained in these two series of experiments (Schedules A, B and C) with the second or universal type of dynamometer give the three components of the total thrust of the work on the tool point, viz., the force acting vertically downwards ( $V$ ), the force acting horizontally, parallel to the axis of the work and tending to thrust the tool to the right, or draw it in to the left ( $T$  or  $-T$ ), and the horizontal force acting perpendicularly to the centre line of the work which tends to thrust the tool backwards ( $S$ ).

The knowledge of these three components enables the magnitude and direction of the resultant force ( $R$ ) to be determined. Fig. 25 (page 908) represents the tool and cut in plan,  $ab$  being the cutting edge,  $cdbf$  the edge of the work in section,  $dbee^1d$  the section of the cutting which is in course of removal. The actual point of application of  $R$  is of course unknown, but will be taken for convenience at a point  $o$  on the cutting edge midway between  $d$  and  $b$ . The lines  $dh$  and  $b^1g$  represent the direction of motion of the removed shaving, which, for deep cuts, was found to be perpendicular to  $ab$ .

*List of Experiments made with Universal Dynamometer.*

SCHEDULE A.

*First Series ; Variable Plan Angle ; Cutting Angle, 55°. Speed, 50 feet per minute.*

Number of Experiments for Reference to Tables 7 and 8. Dimensions of Cut and Traverse.

Plan Angles 22½°	746 ⅜ × ⅛	721 ⅝ × ⅛	722 ¼ × ⅛	747a & b ⅝ × ⅛		734 ⅝ × ⅝	735 ¼ × ⅝						
45°	717 ⅜ × ⅛	716 & 718 ⅝ × ⅛	719 ¼ × ⅛	720 ⅝ × ⅛	711a ⅝ × ⅝	711b & c ⅝ × ⅝	712a & b ¼ × ⅝	713a ⅜ × ⅝	713b ⅛ × ⅝	713c ⅝ × ⅝	713d ¼ × ⅝	713e ⅝ × ⅝	713f ½ × ⅝
67½°	705 ⅝ × ⅛	706 ⅝ × ⅛	707a & b ⅝ × ⅛		708 ¼ × ⅛	709 ⅝ × ⅝	710 ¼ × ⅝	*	730 ⅝ × ⅝				
90°	714a & b ⅛ × ⅝		741 ⅝ × ⅝		715 ¼ × ⅝		742 & 743 ⅝ × ⅝						

\* A series of experiments was also made at various speeds from 1 foot in 4½ hours up to 84 feet per minute with a tool having 67½° plan, and 55° cutting angle. These tests were numbered as follows:—

SCHEDULE B.

725	726	727	728	729	730	731	732	
$\frac{3}{8} \times \frac{1}{16}$	$\frac{3}{8} \times \frac{1}{8}$	Cut $\frac{3}{8}$ inch deep, traverse $\frac{1}{8}$ inch wide.						
Dead slow.		10	20	30	45	60	84	feet per minute.

## SCHEDULE C.

*Second Series; Variable Cutting Angle; Plan Angle 45°;  
Speed 50 feet per minute.*

Number of Experiments for reference to Table 9. Dimensions of Cut and Traverse.

Cutting Angles. 45°	744 $\frac{1}{8} \times \frac{1}{8}$	745 $\frac{3}{8} \times \frac{1}{8}$	
or 55° 60°	717, 716, 718, 719, 720 as before. Schedule A.		711, 712, 713 as before. Schedule A.
75°	722 bis $\frac{1}{8} \times \frac{1}{8}$	739 $\frac{1}{8} \times \frac{1}{8}$	740 $\frac{3}{8} \times \frac{1}{8}$
90°	737 $\frac{1}{8} \times \frac{1}{8}$	738 $\frac{3}{16} \times \frac{1}{8}$	

From  $o$  draw  $T$  and  $S$  equal to the traversing and surfacing forces (as above described); then the resultant of these two forces ( $H$ ) (acting at the angle  $\gamma$  to  $S$ ) is the total horizontal component of resultant  $R$ .

Obviously:

$$\frac{T}{S} = \tan \gamma, \text{ and } H = S\sqrt{1 + \tan^2 \gamma}; \text{ thus } H \text{ and } \gamma \text{ are known.}$$

If we denote the plan angle of the cutting edge by  $\beta$ , and the angle made by  $H$  with the direction of motion of the cutting (*i.e.* the perpendicular to  $ab$ ) by  $\delta$ , we have also  $\delta = \beta - \gamma$ .

Referring now to Fig. 24 (page 908), which shows a vertical section of tool and work in the plane containing  $H$  (and  $R$ ), the real cutting angle of the tool, called  $\alpha$ , is shown dotted by  $zow$ , while the angle  $zox$ , called  $\alpha_H$ , is the cutting angle measured in the direction of the force  $H$ . Let  $\psi$  be the angle between the force  $R$  and  $ov$  perpendicular to  $ox$ . Then, drawing  $V$  and  $H$  as shown, we have:

$$\frac{V}{H} = \tan(180 - \alpha_H + \psi) = \tan i, \text{ say, where } i = 180 - (\alpha_H + \psi), \text{ is the}$$

### TOOL AND WORK.

(Schedules A, B, and C.)

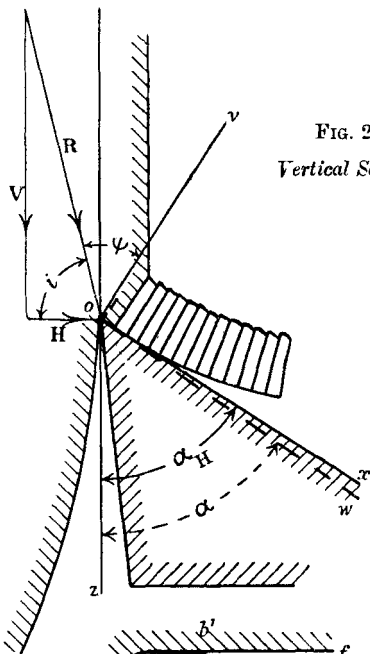


FIG. 24.  
*Vertical Section.*

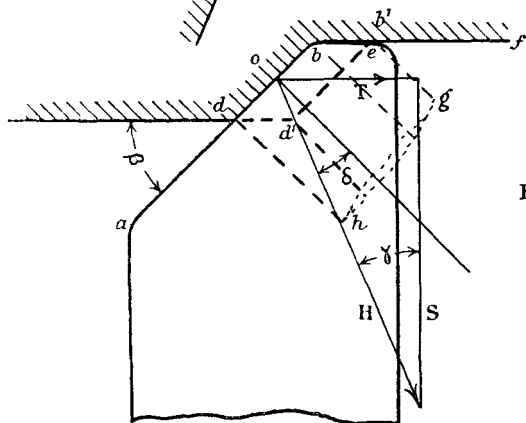


FIG. 25.  
*Plan.*

inclination of  $R$  to the horizontal; and  $R = H\sqrt{1+\tan^2 i}$ . Also  $\tan \alpha_H = \frac{\tan \alpha}{\cos \delta}$ ; so that  $\alpha_H$  and  $\psi$  are known.

The values of these and other quantities, which have been worked out for all the trials made on the Whitworth soft fluid-pressed steel with the universal dynamometer, are given in Tables 8, 9 and 10 (pages 910 to 917).

In these Tables, columns 1 and 2 give the number and date of the trial, columns 3 and 4 the plan and cutting angles of tool employed, columns 5 and 6 the actual depth of cut and width of traverse, column 7 the product of these, called the area of the cut, and column 8 the actual cutting speed at the mean diameter of the work. Columns 9, 10 and 11 record the results of the dynamometer observations; the traversing force ( $T$ ) is the force exerted by the tool when cutting—to push the saddle and rests to the right; the surfacing force ( $S$ ) is that exerted by the tool to spring the rest backwards, and the vertical force ( $V$ ) is that pushing the point of the tool directly downwards. Column 12 gives the ratio of  $T$  to  $S$ , from which  $\gamma$ , the angle of inclination to  $S$  of the resultant horizontal force ( $H$ ), can be found from the formula given above. This force ( $H$ ) is tabulated in column 13. From the ratio of  $V/H$ , given in column 14, the angle ( $i$ ) of inclination to the horizontal of the resultant force ( $R$ ), which acts upon the tool point, can be found as given above; this angle is also tabulated in column 14 and the force ( $R$ ) itself in 15. Columns 16 and 17 give the cutting angle  $\alpha_H$  of the tool measured in the direction of the force  $H$ , and the angle of inclination ( $\psi$ ) of  $R$  to the normal to the top surface of the tool.

Columns 18 and 19 give items of some practical importance, viz., the ratio which  $T$  and  $S$  bear to  $V$ . As a full knowledge of  $V$  for many cuts and traverses has been given from the results of the experiments with the first dynamometer, the percentage ratios now given will enable the surfacing and traversing forces themselves for those shapes and areas of cut to be found.

It is not, however, to be assumed that  $T/V$  and  $S/V$  have the same values for the cutting of cast-iron as those now given, which are

*(Continued on page 918.)*

TABLE 8 (continued on opposite page).

SOFT STEEL.

*Experiments with Universal Dynamometer. Variable Plan-angles.*

Trial Number.	Date.	Tool Angle.		Actual		Actual Area of Cut.	Cutting Speed.	Force Measurements.			T/S or tan $\gamma$ and $\gamma$ .
		Plan.	Cutting.	Depth of Cut.	Width of Traverse.			Traversing T.	Surfacing S.	Vertical V.	
1	2	3	4	5	6	7	8	9	10	11	12
	1904.	$\beta$	$\alpha$	in.	in.	sq. in.	feet per min.	lbs.	lbs.	lbs.	
746	17 Mar.	22 $\frac{1}{2}$ °	55°	0.033	$\frac{1}{16}$	0.0021	49.8	15	383	448	0° —
721	8 „	22 $\frac{1}{2}$ °	55°	0.126	$\frac{1}{16}$	0.0079	49.3	120	657	1680	0.183 10° <sub>30</sub>
722	12 „	22 $\frac{1}{2}$ °	55°	0.276	$\frac{1}{16}$	0.0173	48.4	270	1020	3040	0.265 14° <sub>50</sub>
747	17 „	22 $\frac{1}{2}$ °	55°	0.2385	$\frac{1}{16}$	0.0149	47.5	290	1422	3750	0.211 12°
734	„ „	22 $\frac{1}{2}$ °	55°	0.118	$\frac{1}{8}$	0.0148	49.25	190	1008	3140	0.188 10° <sub>38</sub>
735	„ „	22 $\frac{1}{2}$ °	55°	0.234	$\frac{1}{8}$	0.0293	48.2	425	1934	6530	0.2186 12° <sub>20</sub>
716	8 „	45°	55°	0.115	$\frac{1}{16}$	0.0072	49.5	78	665	1123	
718	„ „	45°	55°	0.131	$\frac{1}{16}$	0.0082	49.5	112	711	1344	
719	„ „	45°	55°	0.263	$\frac{1}{16}$	0.01645	48.5	320	1026	3250	
720	„ „	45°	55°	0.370	$\frac{1}{16}$	0.0231	48.2	510	1215	5150	
711a	24 Feb.	45°	55°	0.0475	$\frac{1}{8}$	0.0059	49.6	-70	596	1510	-0.117 -6° <sub>38</sub>
711b	„ „	45°	55°	0.0655	$\frac{1}{8}$	0.0082	49.0	-51	662	1847	-0.077 -4° <sub>24</sub>
711c	„ „	45°	55°	0.119	$\frac{1}{8}$	0.0149	49.0	+18	836	3050	+0.022 +1° <sub>15</sub>
712a	„ „	45°	55°	0.218	$\frac{1}{8}$	0.0273	48.5	240	1560	5710	0.154 8° <sub>45</sub>
712b	„ „	45°	55°	0.2435	$\frac{1}{8}$	0.0304	47.5	336	1593	6210	0.211 11° <sub>55</sub>
713a	† 3 Mar.	45°	55°	0.0325	$\frac{1}{8}$	0.0041	50	-90	423	1008	-0.213 -12°

† Mr. J. Hartley Wicksteed present.

SOFT STEEL.

(continued from opposite page) TABLE 8.

*Experiments with Universal Dynamometer. Variable Plan-angles.*

Horizontal Force $H$ .	$V/H = \tan [180 - (a_H + \psi)]$ and $180 - (a_H + \psi)$ .	Resultant Force $R$ .	$a_H + \psi$ and $a_H$ .	$\psi$ .	$T/V \times 100$ .	$S/V \times 100$ .	Horse Power by Dynamometer.		Cutting Stress Tons.	Remarks.
13	14	15	16	17	18	19	20	21	22	23
lbs.		lbs.							per sq. in.	
383	1.172 49°30	591	130°30 55°	75°30	3.1	85.5	0.678		97	Machine $\frac{1}{8}$ -traverse to clean up bar and for finishing cut. 0*
670	2.51 68°18	1810	111°42 55°30	56°12	7.16	39.1	2.51		95	
1060	2.87 70°45	3220	109°15 55°15	54°	8.9	34.6	4.46		78.5	2
1455	2.58 68°48	4030	111°12 55°30	55°32	7.75	38.0	5.4	96	112	2 {Same as used in 746.
1025	3.26 73°	3490	109° 55°36	53°30	6.05	32.1	4.68		95	0 Fresh tool.
1990	3.285 73°	6830	109° 55°24	53°36	6.5	29.6	9.5		100	1 {Same as used in 734.
					7.0 8.35 9.9 9.93 -4.63	58.2 33.0 31.7 23.7 39.5				0 2 3 4 0
600	2.52 69°48	1626	110°12 61°12	49°						
662	2.79 70°18	1965			-2.7	36			100	1
836	3.64 74°38	3168	105°22 63°24	42°	+0.525	27.5			91.5	2
1580	3.62 74°33	5940	105°27 60°36	45°	4.2	27.4		94	93.5	3
1630	3.82 75°20	6460	104°40 59°36	45°	5.4	25.7			91.5	4
483	2.81 66°36	1095	113°24 69°8	44°16	-8.9	41.8	1.53		110	0

\* Reference Numbers in remarks column indicate the number of trials previously made by tool without regrinding.

TABLE 8 (continued on opposite page).

SOFT STEEL.

*Experiments with Universal Dynamometer. Variable Plan-angles.*

Trial Number.	Date.	Tool Angle.		Actual		Actual Area of Cut.	Cutting Speed.	Force Measurements.			T/S or tan $\gamma$ and $\gamma$ .
		Plan.	Cutting.	Depth of Cut.	Width of Traverse.			Traversing T.	Surfacing S.	Vertical V.	
1	2	3	4	5	6	7	8	9	10	11	12
	1904.	$\beta$	$\alpha$	in.	in.	sq. in.	feet per min.	lbs.	lbs.	lbs.	
713b	† 3 Mar.	45°	55°	0.0645	$\frac{1}{8}$	0.0081	49.5	-84	534	1750	-0.157 -9°
713c	† „ „	45°	55°	0.1225	$\frac{1}{8}$	0.0153	49.0	+ 6	716	3360	0.0084 +0°30
713d	† „ „	45°	55°	0.250	$\frac{1}{8}$	0.03125	48.5	366	1185	6500	0.319 17°42
713e	† „ „	45°	55°	0.3605	$\frac{1}{8}$	0.0451	48.0	666	1595	8750	0.418 22°42
713f	† „ „	45°	55°	0.4755	$\frac{1}{8}$	0.0594	47.5	858	2100	11200	0.408 22°12
707	24 Feb.	67½°	55°	0.127	$\frac{1}{16}$	0.00795	49.5	36.2	644	1768	0.056 3°32
708	„ „	67½°	55°	0.2555	$\frac{1}{16}$	0.0160	49	211	1118	3670	0.169 9°36
709	„ „	67½°	55°	0.118	$\frac{1}{8}$	0.0148	49.5	114	945	3140	0.079 4°30
710	24 Feb.	67½°	55°	0.239	$\frac{1}{8}$	0.0299	49	264	1800	6440	0.1372 7°48
714	„ „	90°	55°	—	$\frac{1}{8}$	—	50	-160	945	1680	—
741	17 Mar.	90°	55°	0.110	$\frac{1}{8}$	0.01375	49.5	178	1602	4340	0.111 6°18
715	24 Feb.	90°	55°	0.218	$\frac{1}{8}$	0.0273	49	792	2080	6400	0.381 20°54
742	17 Mar.	90°	55°	Tool broke			—	—	—	—	—
743	„ „	90°	55°	0.2885	$\frac{1}{8}$	0.0360	49	839	2682	9530	0.3128 17°22

† Mr. J. Hartley Wicksteed present.

SOFT STEEL.

(concluded from page 910) TABLE 8.

*Experiments with Universal Dynamometer. Variable Plan-angles.*

Horizontal Force $H$ .	$V/H = \tan \left[ \frac{180 - (a_H + \psi)}{180 - (a_H + \psi)} \right]$ and $180 - (a_H + \psi)$ .	Resulting Force $R$ .	$a_H + \psi$ and $a_H$ .	$\psi$ .	$T/V \times 100$ .	$S/V \times 100$ .	Horse Power by Dynamometer.		Cutting Stress Tons.	Remarks.
13	14	15	16	17	18	19	20	21	22	23
lbs.		lbs.							per sq. in.	
540	3.24 72°50	1835	107°10 67°36	39°30	-4.8	30.4	2.63	94	96.5	1*
716	4.69 78°	3430	102° 63°40	38°20	+0.18	21.3	5.0		98	2
1245	5.23 79°11	6620	100° 58°10	41°50	5.64	18.3	9.55		93	3
1730	5.06 78°49	8920	101°11 57°	44°11	7.62	18.3	12.70		87	4
2270	4.94 78°35	11450	101°25 57°12	44°13	7.65	18.8	16.20		84.4	5
644	2.74 70°	1890	110° 73°	37°30	2.05	36.5	2.65	98	99.2	0
1140	3.22 72°45	3850	107°15 69°45	37°30	5.75	30.5	5.45		102.5	1
1450	2.16 65°12	3450	114°48 72°12	42°30	3.64	30.0	4.72		94.8	2
1940	3.32 73°14	6720	106°46 70°42	36°	+4.1	28.0	9.57		96.0	3
—	—	—	—	—	—	—	2.55	121	—	6 { same tool as used for 713f. 0 fresh tool.
1602	2.64 69°18	4540	110°42 55°0	55°42	4.1	37.0	—		141	
2225	2.88 70°54	6740	109°6 76°	33°0	3.8	32.7	—		105	7 same as for 714.
—	—	—	—	—	—	—	—		—	1
2810	3.3914 73°34	9933	106°26 55°	50°42 28°14	8.7	28.0	—		118	0

\* Reference Numbers in Remarks Column indicate the number of trials previously made by tool without regrinding.

TABLE 9 (continued on opposite page).

SOFT STEEL.

*Experiments with Universal Dynamometer. Variable Speed.*

Trial Number.	Date.	Tool Angles.		Actual		Actual Area of Cut.	Cutting Speed.	Force Measurements.			T/S or tan $\gamma$ and $\gamma$ .
		Plan.	Cutting.	Depth of Cut.	Width of Traverse.			Traversing T.	Surfacing S.	Vertical V.	
1	2	3	4	5	6	7	8	9	10	11	12
	1904.	$\beta$	$\alpha$	in.	in.	sq. in.	feet per min.	lbs.	lbs.	lbs.	
724	14 Mar.	45°	45°	0.375	$\frac{1}{16}$			Dead Slow Experiment.			
725	" "	67½°	55°	0.3545	$\frac{1}{16}$	0.0222	{ Dead slow.	110	990	5140	
726	" "	67½°	55°	0.3545	$\frac{1}{8}$	0.0443	{ Dead slow.	500 to 150	1540 to 1360	9060 to 8840	
727	" "	67½°	55°	0.3545	$\frac{1}{8}$	0.0443	10	400	1413	8540	
728	" "	67½°	55°	0.3545	$\frac{1}{8}$	0.0443	20	405	1539	8540	
729	" "	67½°	55°	0.3545	$\frac{1}{8}$	0.0443	30	470	1500	8400	
730	" "	67½°	55°	0.3625	$\frac{1}{8}$	0.0453	45	600	1610	8415	0.373 20°33
731a	" "	67½°	55°	0.3405	$\frac{1}{8}$	0.0426	60	330	1480	8100	
731b	" "		55°	0.3465	$\frac{1}{8}$	0.0433	60	330	1250	8780	
732	" "	67½°		0.3410	$\frac{1}{8}$	0.04262	84	*	1390	7480	

\* No reading, as vibration closed the gauge cock.

SOFT STEEL.

(concluded from opposite page) TABLE 9.

*Experiments with Universal Dynamometer. Variable Speed.*

Horizontal Force $H$ .	$V/H = \tan [180 - (a_H + \psi)]$ and $180 - (a_H + \psi)$ .	Resultant Force $R$ .	$a_H + \psi$ and $a_H$ .	$\psi$ .	$T/V \times 100$ .	$S/V \times 100$ .	Horse Power by Dynamometer.		Cutting Stress Tons.	Remarks.
13	14	15	16	17	18	19	20	21	22	23
lbs.		lbs.							per sq. in.	
Tool Broke.										0*
										{ Same tool used throughout
									113	0
							2.58		86.5	1
							5.16		86.5	2
							7.64		85.0	3
1720	4.88 78°30	8630	101°30 64°30	37°	7.13	19.2	11.45		83.0	4
							14.71		84.9	5 Jarring badly
							16.00		90	6 Jarring ceased
							19.0		78.5	7 { Jarring terribly
(Tool failed in 1 min. 12 secs.)										

\* Reference Numbers in Remarks Column indicate the number of trials previously made by tool without regrinding.

TABLE 10 (continued on opposite page).

SOFT STEEL.

*Experiments with Universal Dynamometer. Variable Cutting Angles.*

Trial Number.	Date.	Tool Angles.		Actual		Actual Area of Cut.	Cutting Speed.	Force Measurements.			T/S or tan $\gamma$ and $\gamma$ .
		Plan.	Cutting.	Depth of Cut.	Width of Traverse.			Traversing T.	Surfacing S.	Vertical V.	
1	2	3	4	5	6	7	8	9	10	11	12
	1904.	$\beta$	$\alpha$	in.	in.	sq. in.	feet per min.	lbs.	lbs.	lbs.	
744	17 Mar.	45°	45°	0·1255	$\frac{1}{8}$	0·0157	49	105	1156	3470	0·091 5°12
745	" "	45°	45°	0·342	$\frac{1}{8}$	0·0428	48	825	2182	9300	0·378 20°42
717	8 "	45°	55°	0·030	$\frac{1}{16}$	—	—	—	—	—	—
716	" "	45°	55°	0·115	$\frac{1}{16}$	0·0072	49·5	78	665	1123	} See Table 8.
718	" "	45°	55°	0·131	$\frac{1}{16}$	0·0082	49·5	112	711	1344	
719	" "	45°	55°	0·263	$\frac{1}{16}$	0·01645	48·5	320	1026	3250	
720	" "	45°	55°	0·370	$\frac{1}{16}$	0·0231	48·2	510	1215	5150	
711c	24 Feb.	45°	55°	0·119	$\frac{1}{8}$	0·0149	49	+18	836	3050	
712b	" "	45°	55°	0·2435	$\frac{1}{8}$	0·0304	48·5	336	1593	6210	} See Table 8.
713e	3 Mar.	45°	55°	0·3605	$\frac{1}{8}$	0·0451	48	666	1595	8750	
722 bis	14 "	45°	75°	0·125	$\frac{1}{8}$	—	49	350	1580	3360	—
739	17 "	45°	75°	0·111	$\frac{1}{8}$	0·0140	49	752	1908	4370	0·394 21°30
740	" "	45°	75°	0·2315	$\frac{1}{8}$	0·029	48·5	1450	2538	7220	0·572 29°48
737	" "	45°	90°	0·071	$\frac{1}{8}$	0·009	50	730	2610	3360	0·28 15°42
738	" "	45°	90°	0·1875	$\frac{1}{8}$	—	—	—	3000	—	—

## SOFT STEEL.

(concluded from opposite page) TABLE 10.

*Experiments with Universal Dynamometer. Variable Cutting Angles.*

Horizontal Force <i>H</i> .	$V/H = \tan [180 - (a_H + \psi)]$ and $180 - (a_H + \psi)$ .	Resultant Force <i>R</i> .	$a_H + \psi$ and $a_H$ .	$\psi$	$T/V \times 100$ .	$S/V \times 100$ .	Horse-Power by Dynamometer.	Cutting Stress tons.	Remarks.
13	14	15	16	17	18	19	20	21	22
lbs.		lbs.							per sq. in.
1160	3.0 71°30	3570	108°30 52°20	56°	3.0	33.4	—	—	0*
2336	3.98 75°54	9580	104°6 47°52	56°14	8.96	23.5	—	—	1
—	—	—	—	—	—	—	—	—	1 as for 716
—	—	—	—	—	7.0	58.2	—	—	0 fresh tool
—	—	—	—	—	8.35	33.0	—	—	2 as for 717
—	—	—	—	—	9.9	31.7	—	—	3 „ 718
—	—	—	—	—	9.93	23.7	—	—	4 „ 719
—	—	—	—	—	0.52	27.5	—	—	2
—	—	—	—	—	5.4	25.7	—	—	4
—	—	—	—	—	7.62	18.3	12.7	—	4
—	—	—	—	—	—	—	—	—	0
2050	2.13 65°	4850	115° 76°12	38°48	12.7	43.7	—	—	139 0
2922	2.47 68°	7790	112° 75°30	36°30	20	35	—	—	111 1
2710	1.24 51°12	4350	128°48 90°	38°48	21.7	78	—	—	0
—	—	—	—	—	—	—	—	—	1

\* Reference Numbers in Remarks Column indicate the number of trials previously made by tool without regrinding.

for soft (fluid-pressed) steel; further experiments are required to determine these values for cast-iron.

Column 20 gives the horse-power required for cutting, being the result of multiplying the actual cutting speed by the vertical force  $V$ , and dividing by 33,000. Column 22 gives the cutting stress in tons per square inch, and is got by dividing the vertical force ( $V$ , col. 11) by the area of the cut (col. 7) and by 2240.

In the Tables the tests are arranged in the same way as in Schedules A, B and C, viz., Table 8 refers to experiments with variable plan angle of tool, the cutting angle being  $55^\circ$  throughout. Table 9 refers to a special series made with one and the same tool ( $67\frac{1}{2}^\circ$  plan,  $55^\circ$  cutting angle) at seven different speeds from dead slow to 84 feet per minute, the cut being  $\frac{3}{8}$  inch by  $\frac{1}{8}$  inch; whilst Table 10 records the results of tests made with tools of various cutting angles, the plan angle being constant throughout, and equal to  $45^\circ$ .

Certain of the results in these Tables have been selected for graphic representation in Plate 129 and Fig. 30 (page 920). Fig. 26, Plate 129, depicts the variation of the surfacing and traversing forces, expressed as percentages of the vertical force, with the different plan-angles of tools employed, viz.,  $22\frac{1}{2}^\circ$ ,  $45^\circ$ ,  $67\frac{1}{2}^\circ$ , and  $90^\circ$ . [This angle is shown and called  $\beta$  in Figs. 25 (page 908) and Fig. 30 (page 920).] It is seen that the traversing force ratio varies but little and irregularly, and is of smaller importance than the surfacing force.

The surfacing force ratio is seen to have its smallest values for tools with a plan angle of  $45^\circ$  (the cutting angle being  $55^\circ$ ). This minimum varies from 33 per cent. of  $V$  for light cuts to 18 per cent. of  $V$  for heavy cuts. On the other hand, the percentage sometimes rises to nearly 40 per cent.

In Fig. 27, Plate 129, curves have been drawn showing the variations of the same percentages with tools of different cutting angles, all the tools being ground with a  $45^\circ$  plan angle.

Both the  $T/V$  and the  $S/V$  ratios are seen to pass through minimum values in the neighbourhood of  $55^\circ$ . The minimum values of the percentage ratio of surfacing to vertical force vary

from 25 per cent. for light to 18 per cent. for heavier cuts. With a right angle for the cutting angle and for light cuts this ratio may attain 80 per cent. of  $V$ .  $T/V$  is again not so important as  $S/V$ , but it may reach 20 per cent. with obtuse cutting angles.

It is curious to observe that whilst  $S/V$  diminishes as the cut gets heavier, the reverse takes place with  $T/V$ . This is clearly shown in Fig. 28, Plate 129, where the results of experiments No. 713 *a, b, c, d, e, and f*, made with a single tool, are plotted for different depths of cut from  $\frac{1}{32}$  inch by  $\frac{1}{8}$  inch to  $\frac{1}{2}$  inch by  $\frac{1}{8}$  inch (tool  $45^\circ$  plan,  $55^\circ$  cutting angle).

Fig. 29, Plate 129, shows how (*i*), the angle of inclination of  $R$  to the horizontal, alters with tools of different cutting angles (plan angle  $45^\circ$ ). It also shows how the angle of inclination ( $\psi$ ) of  $R$  to the normal to the face of the tool is affected by changing the value of the cutting angle.

The inclination of  $R$  to the perpendicular to the tool face ( $\psi$ ) is remarkably constant for all tools except the keenest. It does not vary by more than one degree for tools of  $55^\circ$ ,  $75^\circ$  and  $90^\circ$  cutting angle, the average value for these being about  $39^\circ$ .

The angle  $i = [180 - (\alpha_H + \psi)]$  at first increases and then diminishes as the cutting angle gets more acute. It attains a maximum value of  $78^\circ$  at a cutting angle of  $55^\circ$ , at which  $V$ ,  $T/V$  and  $S/V$  are a minimum. Fig. 30 (page 920) shows some of these variations in a more realistic manner. The lower and upper views are of the same kind as already described in Figs. 24 and 25 (page 908).

The experiments (numbered 725 to 732 inclusive), the results of which are given in Table 9 are of special interest in regard to: first, the variation of the cutting force as the cut progresses at a very slow speed; second, the variation of the cutting stresses with large ranges of speed variation.

These experiments were made with a tool having a  $55^\circ$  cutting, and a  $67\frac{1}{2}^\circ$  plan angle; a cut  $\frac{3}{8}$  inch deep by  $\frac{1}{8}$  inch wide being taken.

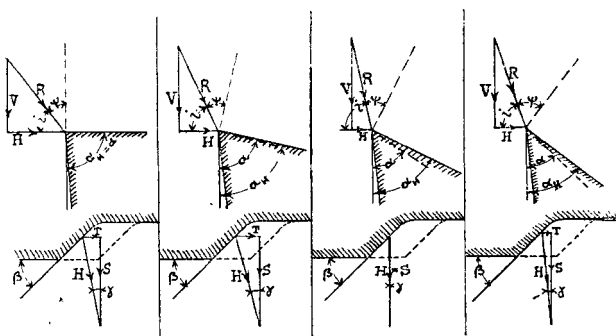
For numbers 725 and 726 the lathe was turned round at a cutting speed of about 1 foot in 5 hours, by means of a wire rope made fast round the large cone pulley, and hauled upon by a man operating a winch.

A pointer about 5 feet long was clamped upon the forging, and the four dynamometer gauges were read at every half-an-inch of motion of the end of this pointer, *i.e.* at about six one-hundredths (0.0625) of an inch of the cut. The vertical force varies from 9080 to 8920 every  $\frac{3}{8}$  of an inch of motion of the tool, the same wave length characterising the variation of the surfacing and

FIG. 30.

Trial.	737	739	713c	744
$\alpha$	90°	75°	55°	45°
$i$	51°12	65°	78°	71°30
$\psi$	38°48	38°48	38°20	56°
Area of Cut	0.009	0.014	0.015	0.0157

All light cuts.



traversing forces. The observations have been plotted in Fig. 31, Plate 130, on a base of actual relative tool motion.

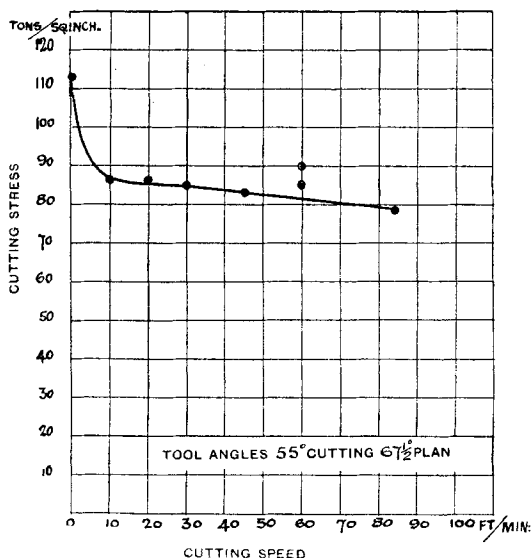
A similar experiment, No. 636, carried out with the first dynamometer, is shown in Fig. 32, Plate 130. Here the cut was heavier,  $\frac{3}{8}$  inch by  $\frac{1}{4}$  inch, and the tool had a 45° plan, and 60° cutting angle. The wave length of the force-curve is about 0.6 inch for this experiment, and it varies between 13,000 and 8,000 lbs. It will be observed that the force attains a maximum soon after

the cutting commences to crack or shear across, and that it drops to a minimum when the small piece of cutting falls off the forging. At such a slow speed as this the cutting has time to shear off right across in separate fragments, whereas it forms a continuous curl of considerable rigidity when the cutting speed is higher than a few feet per minute. These fragments measured, in this experiment, about  $\frac{1}{4}$  inch across the widest part of their surface next the top of the tool in the direction of motion.

FIG. 33,

## EXPERIMENTS 726 TO 732.

ON SOFT STEEL, (fluid pressed).



Experiments 727 to 732 show a constantly diminishing cutting stress as the speed increases up to 84 feet per minute, notwithstanding the fact that the same tool was used upon the whole series of cuts without regrinding. The results of these trials are shown graphically in Fig. 33. In experiment 732, when running 84 feet per minute, the tool was removing material at the rate of 12.3 lbs. per minute; but failure ensued in one minute twelve seconds.

Further comment on the results of these experiments is reserved until the heavier cuts required to complete the series have been made.

In conclusion, the author desires to record his great indebtedness to the following: Mr. Dempster Smith, Demonstrator of Mechanical Engineering in the School of Technology, for assistance in the laborious work of compilation and reproduction of the results. To Mr. J. T. Hodgson, Mechanical Superintendent, by whose care and ingenuity the difficulties connected with the construction and successful use of the dynamometers, which were constructed in the school workshops, were eventually overcome; and to Mr. C. Coups, turner, who carried out all the trials not only of this series, but of those for the Manchester Committee. The consistency of the results obtained is largely due to the high degree of intelligence and skill displayed by him.

The Paper is illustrated by Plates 122 to 130 and 5 Figs. in the letterpress.

---

#### APPENDIX.\*

*Summary of Conclusions.*—In the case of both steel and cast-iron, the simplest close approximation to the law of variation of cutting force with area of section of cut is that for a given traverse it is simply proportional to the depth of the cut; or, in other words, that the cutting stress is constant for a given width of traverse, and a given cutting angle of the tool. (Compare Figs. 11 to 18, Plates 126 and 127.)

The way in which the width of traverse feed affects the cutting stress is shown in Figs. 19 and 20, Plate 128; the former for cast-iron, the latter for steel.

---

\* This Appendix was added on the occasion of the Paper being read.

In the case of cast-iron the cutting stress is, on the whole, less for coarse than for fine traverses; whilst for steel the reverse is the case for keen tools.

The cutting stress varies a good deal with the cutting angle of the tool. It is a minimum both for cast-iron and steel in the neighbourhood of a  $60^\circ$  cutting angle.

From other series of trials it was found that the cutting angles which showed the lowest values of cutting stress were by no means those which withstood the greatest amount of cutting before requiring to be reground. The most durable angles were found to be about  $80^\circ$  for cast-iron and about  $70^\circ$  for steel. Whilst with tools of  $60^\circ$  cutting angle, the cutting stress was only from 50 to 60 tons per square inch for cast-iron (medium hardness); the cutting stress for the most durable angle—that, namely, to be recommended for shop use (about  $80^\circ$ )—is from 76 to 84 tons per square inch.

Similarly, for steel (soft fluid-pressed) the minimum cutting stresses are from 65 to 78 tons per square inch (cutting angle,  $60^\circ$ ); whilst those stresses for the best shop angle of tool—namely  $70^\circ$ —are from 88 to 92 tons per square inch.

The cutting stress varies but little with the speed of cutting, whether in the case of cast-iron or of steel.

The net horse-power required for cutting may be roughly estimated by multiplying the cutting stress in pounds per square inch (*i.e.*, the vertical component of the resultant cutting stress) by the area of the cut in square inches ( $a$ ), by the cutting speed in feet per minute ( $v$ ), and dividing by 33,000. Thus we obtain for

Cast-iron . . . . . Shop angle  $\approx 80^\circ$ .

$$\text{Net cutting horse-power} = \frac{80 \times 2240}{33,000} a v = 5.43 a v.$$

To find the horse-power to be supplied in order to remove 1 lb. of cast-iron per minute,  $a v$  must be such that [ $\mu$  being the density in lbs. per cubic inch]—

$$12 \mu a v = 1 \text{ lb.},$$

or,

$$a v \text{ must} = \frac{1}{12 \mu}.$$

This (medium) cast-iron had a density of 0.259 lb. per cubic inch, therefore  $a v = 0.322$ ; and

$$\text{Horse-power} = 5.43 \times 0.322 = 1.746 \text{ per lb. per minute.}$$

If the horse-power lost in friction is 0.3 per lb. per minute, the gross horse-power required to remove cast-iron at the rate of 1 lb. per minute will be—

$$\text{Gross horse-power} = 1.746 + 0.3 = 2.046 \text{ per lb. per minute.}$$

$$\text{For steel shop angle} = 70^\circ.$$

$$\text{Net cutting horse-power} = \frac{90 \times 2240}{33000} a v = 6.1 a v.$$

To remove 1 lb. of steel per minute we must have

$$a v = \frac{1}{12 \times 0.285} = 0.292 \text{ } [\mu \text{ being } 0.285 \text{ lb. per cubic inch.}]$$

So that the net horse-power required for removing 1 lb. per minute is

$$\text{Horse-power} = 6.1 \times 0.292 = 1.78 \text{ per lb. per minute,}$$

and with the same allowance for friction as for cast-iron. The

$$\text{Gross horse-power} = 1.78 + 0.3 = 2.08 \text{ per lb. per minute.}$$

Thus the horse-power required *per pound of material machined per minute* is about 2, whether the material be steel or cast-iron.

*Per unit of volume* removed the horse-power is about 15 per cent. (of the value for cast-iron) more for steel than for cast-iron.

As seen by reference to Fig. 27, Plate 129, the traversing and surfacing forces (like the vertical force) vary considerably with the cutting angle of the tool, the latter being much greater than the former.

The surfacing force varies from 25 to 75 per cent. of the vertical force as the cutting angle increases from  $55^\circ$  to  $90^\circ$ .

Its value for the best shop angle for cutting steel ( $70^\circ$ ) is about 30 per cent. of the vertical cutting stress, or, say, 30 tons per square inch of area of cut.

The traversing force varies from 8 to 20 per cent. of the vertical as the cutting angle increases from  $55^\circ$  to  $90^\circ$ ; and for the above shop angle of  $70^\circ$  it is about 10 per cent. of the vertical cutting stress, or, say, about 9 tons per square inch of area of cut.

The surfacing force thrusts the saddle against the bed, and a frictional resistance to the traversing motion of the former is thereby produced. If the coefficient of friction be taken at  $\frac{1}{3}$ , then the total force to be overcome at the saddle by the self-acting traversing mechanism due to both of the above forces would be  $\frac{30}{3} + 9 = 19$  tons per square inch of area of cut, the material being soft steel.

The proportions of traversing and surfacing to vertical forces for cast-iron have not yet been determined.

Variations of the angle which the cutting edge of the tool makes with the axis of the work (in plan) do not produce much change, either in the vertical or the two horizontal components of the resultant cutting force. The shape of the tool in plan does not, therefore, materially influence the cutting force. The best shape to give the tool is that which lends itself most easily to forging and grinding; which, *i.e.*, is easiest to keep, and loses least material by successive regrindings. The round-nosed tool appears to meet these requirements best.

---

### *Discussion.*

Mr. HARRINGTON EMERSON said that the author had referred to the revolutionary character of the discovery made by Messrs. White and Taylor in machine-shop practice by developing these new cutting steels. In studying that question and in working with these new cutting steels he himself had found that they had led to something that seemed even more valuable than their power to remove metal rapidly. Mr. Taylor had made a very intimate time-study of operations, and it was because he was making this time-study that he was led to the discovery of this steel. He had found that there were certain steels that cut more rapidly than others. This fact had instantly fascinated Mr. Taylor, who wanted to know the cause. His associate, Mr. White, analyzed different steels, and found there was practically no difference whatever in the analysis.

(Mr. Harrington Emerson.)

The tempering treatment was next studied, until the discovery was made that when steels of certain composition were heated almost to the melting point, and then cooled very rapidly, they acquired the power to cut at a very high speed and at a high temperature.

It was this point that he wished to demonstrate. Recently in an operation performed by one of these high-speed steels they were able to reduce the former time of 40 hours to 20 hours; but for those 20 hours the steel was cutting only  $3\frac{1}{2}$  hours. Now, if they could find a steel that would cut in no time at all it would only save  $3\frac{1}{2}$  hours. In the other  $16\frac{1}{2}$  hours they could undoubtedly save, by careful analysis and study of every single operation, more than the three and a half hours that was now taken in the cutting operation. The particular value that he had found in these steels was that it led the man who was directing operations with them to study every single part of the whole operation, the quality of the castings, the centering of the pieces, the speeds of the lathe, and so on; and if this was done, it would be found that there was more time-gain to be made by cutting out wastes than by the greater capacity of the steel alone. In other words, taking the same operation in two different machine-shops, one machine-shop with a high-speed steel and the other machine-shop with the ordinary carbon-steel, but with every single detail element toned up to its uttermost, he ventured to say that the shop with the carbon-steel, but with everything else toned up, would do faster work than the shop using high-cutting steel, but let them go as they pleased in other respects. If they gave, however, the well-regulated shop good steel in addition to its other economies, the results would be astonishing.

Mr. JOHN McGEORGE said he was not surprised that there was hesitation in discussing this Paper. It required thought. He wished to express his thanks to the author for it. It cleared up points on which he had been looking for information for a long time. There was not only the value of the information on the speed of cutting, but the value of the Paper consisted largely in information that it gave with regard to the requisite strength of the machine.

He had had to go through a little experience, not long ago, with the breaking down of one or two tools just at the time they were required for work, because they were forced a little beyond their usual capacity, and it seemed to him that it was just for the want of such information as this that those tools broke down; they had not the requisite strength in the parts where it was required. Usually manufacturers were too busy getting out orders to go into these matters. His principal reason for joining in the discussion was to ask if Professor Benjamin would try and secure his share of that money that had just gone to their own institute (the Case School) to carry out fully some experiments in this direction, not only with lathes, but with regard to other tools as well, such as the planer, giving the side thrust and the up thrust, and in all directions; the same with the miller, and the same with the drilling machine, to find out where the stress came exactly, because they knew the directions of strains were very complicated, and they did not know which parts were going to fail first. In allowing for speeding up and the new strains that were coming on the tools made of the new steels, they hardly knew just where to put the extra strength, and he would draw Professor Benjamin's attention to the fact that these experiments should be made, and it would be a very useful thing for a school like his, which had contributed so much in the way of information to the profession, to carry out this idea further.

Professor C. H. BENJAMIN said he had not expected to participate in this discussion, because after reading the Paper he felt that he knew so little about the subject as to make it hardly worth while to say anything. He considered this the most valuable series of experiments on the cutting power of steels that had ever been made in the history of engineering. The completeness with which they were carried out, the universal character of the dynamometer and the resolution of the cutting pressure into its elements—longitudinal, radial, and tangential—were all worthy of mention.

What Mr. George had just said in reference to making experiments of this kind in this country at some place where there was time to devote to it, had led the speaker to say a few words on

(Professor C. H. Benjamin.)

that subject. It had been his intention to carry out some experiments during the coming year on the high-speed steels in the laboratory of the school, and, for that purpose, to buy some special machinery. He felt, however, that those experiments would be entirely incomplete without some such apparatus as had been described in the Paper, and that to make such experiments with the ordinary forms of dynamometer that had been used in the past would be puerile. He did not know what the possibilities would be in the way of procuring or of building a dynamometer of this character which could be used on lathes, on planers, on boring mills, and on other types of machines. He hoped, however, that means would be provided in some way to accomplish this, because there was no question but that the use of high-speed steels was one of the recent factors in our industrial development which had done more to increase the output of the machine shop than any other one element. If there were any manufacturers here who were interested in this question and in the further solution of the problem he would be glad to get in touch with them, because it was only by collaboration and co-operation that they could hope to accomplish anything. He wished some public-spirited citizen would import one of these dynamometers from Great Britain and give them the benefit of it.

Mr. WILLIAM PILTON remarked that a recent editorial comment very truly judged these experiments as "far and away the most complete that have been undertaken in any country." These experiments were of special value in that Professor Nicolson had taken practical cuts both as to depth and the feed with effective cutting speeds of about fifty feet per minute, it being clearly shown in his endurance or "failure trials" that the tool failed very quickly at 75 feet per minute with heavy roughing cuts.

Quoting from the experience of one who had tried about every make of high-speed steel, "We have cut a  $\frac{1}{16}$ -inch chip at  $\frac{1}{32}$ -inch feed at a rate of 260 feet per minute from a rod of steel. Such speeds are possible for short periods, but whoever buys a rapid cutting steel with the expectation of maintaining such speed will be sadly disappointed." He further stated, "We find that on steel where there is no considerable

thickness of metal to remove, a speed of 100 feet is very satisfactory."

He himself knew, from the actual tests and the lathe-room practice as obtained by the Niles Tool Works Co., of Hamilton, Ohio, that they got such heavy cuts and feeds at from 35 to 50 feet per minute using the modern tool steels, turning high-carbon steel, forged shafts, pinions, &c. The tool point was almost a red heat and the chips beautifully coloured. The lathes they were doing this work on were the same machines as were formerly used with the tools of carbon steels and slower cutting speeds. There had not been one special lathe installed in this turning department, but the speed of the line shafts had been increased, and also the countershafts, so as to get correct turning speed on suitable diameters of work and always retain the power of the back gearing. For instance, an ordinary 24-inch lathe, with its countershaft increased in speed to suit, would take very heavy cuts and feeds on work of from 3 inches to 9 inches diameter with the back gears in, and by using a second countershaft speed the minimum diameter could be further reduced.

At a meeting of the St. Louis Engineers' Club, 7 January 1903, discussing a Paper by Mr. W. A. Layman on Speed Control, Mr. W. Cooper said, in considering the fact that many tools were not designed to stand the high speeds that modern tool steel would permit, "There is no reason why a machine tool that is adapted to do a certain work should not do this work at two or three times the speed. The reason for this seems obvious, in the fact that the strains on a machine are due entirely to the torque required to make a given cut. With this given cut the speed may be increased three or four times without producing any greater strains on the machine itself, because the torque remains constant."

Of course, they were building very heavy and powerfully-gearred boring mills, wheel lathes, &c., especially intended for use with high-speed steel and to carry heavy cuts. In these machines the cast-iron gears were replaced with those of steel casting and steel forged gears. The belt width and the gearing ratio were also increased. Power was required where heavy cuts and feeds on steel

(Mr. William Pilton.)

castings were specified on orders for certain machine tools. A nominal power at the tool of 5,000 or 6,000 lbs. for each  $\frac{1}{32}$  inch of chip area was required for turning soft steel castings. This increased with the harder grades. As to cast-iron, it was more difficult to arrive at a nominal power, because of the varying degrees of hardness in some instances the horse-power per cubic inch of metal removed being almost equal to that of some steel castings.

The PRESIDENT (Mr. Wicksteed) said he thought it stated in the beginning of the Paper that the whole of this new movement for rapid cutting was started by Messrs. Taylor and White, of the Bethlehem Steel Co., in the United States. They made a most remarkable exhibition in Paris, at the Exposition, in which the engineering world was astonished to see, instead of the deliberate manner in which steel was formerly removed by tooling in a lathe, the cuttings coming off in long continuous pieces coloured purple with heat and to be able to see that, underneath the cutting, the tool was glowing with a dull red. It was about as surprising as when it was discovered that a carbon filament could be used for electric current without consuming itself. The whole idea of a tool preserving its edge when in a state of dull red heat was, he thought, to all of them a revelation, and it had a most stimulating effect upon these gentlemen and others, because as soon as people knew that it was possible to do it a number of persons found they were able to do what before that time had been thought impossible. Now, he himself was particularly engaged in tool making, and he considered that it was by far the greatest revolution that had taken place in his life. When the discovery came out, it was not understood as to how steel could be made to do such work, nor was it understood what conditions would have to be used to take advantage of it. It was not known, for instance, whether according to the law of the flow of solids one could remove the material with a smaller pressure at a slow speed than one could at a quick speed. That was settled crucially by Dr. Nicolson, who made one experiment in which he only moved the work round at the rate of 1 foot in four and one-half hours. It did not come off with any less pressure on the point of the the tool than it did when he was moving it at the rate of 50 feet

per minute. Incidentally in that experiment he found out, what was very important to know, the cause of the vibrations that were set up in removing the shaving; he was able to take a diagram of the pressure of the tools at the different stages, and he found that first of all the tool compressed a flake of metal, that is, set up a plane of cleavage, and then shot it off like the scale of a fish, and that the diagram was a diagram of very tall peaks, thirteen above zero of pressure, and valley only eight above zero, the pressure on the tool rising to a certain point, and then going down, all of which would be found in the Paper. That showed that one had to provide for vibrations, and that was the explanation why it was that one could not make good use of the new steel by simply speeding up existing lathes, at least, not in all cases, for this steel not only gave the power of going at a greater speed, but it was a steel which would preserve its edge better and would enable one to take deeper cuts and greater travel.

A Paper was read at the Institution of Mechanical Engineers, in London, upon the Cutting Angles of Tools,\* in which a tool dynamometer had been used, and this tool dynamometer showed certain results which did not conform to the results shown by other experimenters, who had arrived at their results by measuring the power that went into the lathe head-stock. Dr. Nicolson, however, had devised a very improved tool dynamometer, which gave its results almost as accurately as a testing machine with which one tested the strength of materials. It measured the force downwards and the backward thrust of the tool. Then, together with this tool dynamometer, he had a belt dynamometer that measured the power that was going through the belt, and also the ammeter, and he was able to put the whole of these results together and there were no discrepancies; there were differences, but they were accounted for, but the net value on the tool was all confirmed by the records of the ammeter and by the belt dynamometer. Dr. Nicolson designed his dynamometer to give him a load up to 15 tons pressure on the tool, with which one could take presumably a pretty fair cut. He

---

\* Proceedings, 1903, Part 1, page 5.

(The President.)

carried out his experiments, he thought, to about half that; but he had not finished yet. He would proceed to carry the experiments further, and with still deeper cuts. He thought that what he had arrived at so far was that he had removed successfully  $9\frac{1}{2}$  lbs. weight per minute, and had found a cutting stress of 90 tons per square inch section of the cut upon soft fluid compressed steel. He thought he had used about  $19\frac{1}{2}$  gross horse-power in doing that, and he had found a very large difference in the horse-power that was absorbed resulting from the different angles to which the tools were ground. So that incidentally this Paper was extremely valuable in giving the best angles for tools, both in regard to endurance and also in regard to the power that was absorbed.

There was one other striking remark in the Paper, and which seemed to point to a critical speed (page 899): "It was found in these preliminary experiments that a foot per minute, more or less, in the cutting speed made a great difference in the duration of the experiment." Was this to be understood to mean that if the tool did not last as long as one would wish it to, it did not follow that it was because one was cutting too fast, but might be because one was cutting too slow? He was not sure what the material was as to which that remark was made, but it did seem to him a point for very interesting investigation to find out more about it.

Mr. CHAMBERS said that it was cast-iron material.

Mr. WICKSTEED said that perhaps that accounted for a great deal of variation in people's opinion as to the speed at which cast-iron could be cut. He would now ask Mr. Adamson to reply on behalf of Dr. Nicolson.

Mr. DANIEL ADAMSON said that he thanked them very much for the discussion, and that Dr. Nicolson and the Committee who were associated with him in the earlier experiments—referred to in the article in the "American Machinist" mentioned by Mr. William Pilton, and to which this Paper was a sort of supplement—all felt that they were only at the beginning of this interesting

investigation, and they would be very glad to hear of any further experiments being carried out, either here or elsewhere. There was ample room for a very instructive series of experiments.

Professor WILLIAM T. MAGRUDER said that a somewhat similar set of experiments to those here recorded were made in 1900 under his direction by Mr. W. A. Knight, at that time instructor and at present Assistant Professor of Machine Shop Practice, at the Ohio State University, as a thesis for the degree of Mechanical Engineer. The object sought was not solely to measure the work performed in cutting metal, but rather to measure the "workability of cast-iron" and other metals. For this purpose, a Pratt and Whitney planer was used. A specially constructed diaphragm pressure-gauge was inserted in the tool-box, so as to receive the pressure exerted upon the tool by the piece of metal being cut. A cutting-tool of constant shape was mounted in a tool-holder of such shape that the point of the cutting-tool was vertically in line below its point of suspension. The pressure received by the diaphragm of the pressure-gauge was transmitted by oil to a double-tube Bourdon pressure-gauge, and from it by a parallel motion to an inking pen which recorded the pressure required to make the cut. The record was made on a strip of paper positively moved by the planer-table.

The usual difficulties incident to such work were met and overcome, and the results were of much interest, as they showed that the forces required to remove metal by a planer, when run at a known speed, gave very different results with different kinds of cast-iron, which differed both in character and amount from the diagrams obtained by cutting bar-brass, wrought iron, and the different steels. The uniformity of the texture of brass, the hard spots in cast-iron, the seaminess of wrought iron, and even the greater homogeneity of tool steel, as compared with machinery steel, were noted by the apparatus and recorded autographically with much uniformity of result. As the thesis giving the records was at present among the exhibits of the Agricultural and Mechanical Colleges at the Louisiana Purchase Exposition at St. Louis, he was unable to give greater details at this time.

Dr. Nicolson, in reply, said he wished to thank Mr. Wicksteed and the other speakers for the appreciatory remarks they had made regarding the work done and reported in the Paper. He agreed with all that had fallen from Mr. Wicksteed, with the exception of his last sentence or two. He hardly thought the quotation he had made from the Paper would bear the interpretation that, "if the tool did not last as long as one would wish it to, . . . it might be because one was cutting too slow." It had never been found in these experiments that a tool could be made to last longer by a small increase of speed. Perhaps Mr. Wicksteed had in mind a possible synchronization of tool and work vibrations which might be destroyed by a slight change of cutting speed. This might happen; but it had not occurred in the author's experience.

With regard to Mr. John McGeorge and Professor Benjamin's remarks as to further experiments being made, he would be very glad to furnish to Professor Benjamin blue prints and full instructions for the construction of a dynamometer; and would recommend that experiments be undertaken on the principal alloys used in engineering, such as gun-metal, brass, phosphor-bronze and the like. He did not see that the action in planing should be much different from that of tooling in a lathe. Drilling was a subject requiring study; and he had already instituted experiments in this direction.

Mr. Harrington Emerson's remarks regarding the small saving which would be effected by the use of high-speed steel, unless every detail of working was looked into, seemed to be very much to the point. If three-fourths of the working time of a lathe was wasted by bad management, it mattered very little whether the cut be taken at 50 feet or 15 feet.

It was interesting to learn that Professor Magruder had used a "diaphragm pressure-gauge" on the tool box of a planer in 1900. If the question be one of priority, it might be mentioned that the author used the method in 1894 at McGill University, and presented a diaphragm dynamometer to Cambridge University Engineering Laboratory in that year.

Mr. Pilton thought that all that was required in the lathes as now used to make them available for high-speed steel was to speed them

up. That depended on how the gearing was arranged, and what the present speed of the cone belting was. It seemed clear that most cone belts ran too slow and that speeds of 4,000 or to 5,000 feet per minute in them were admissible, provided the cone was off the main spindle. In conclusion the author tendered his best thanks to Mr. Daniel Adamson for looking after the Paper upon its presentation in Chicago.

---

*First Dynamometer, measuring Vertical Force only.*

Fig. 1. *Side Elevation.*

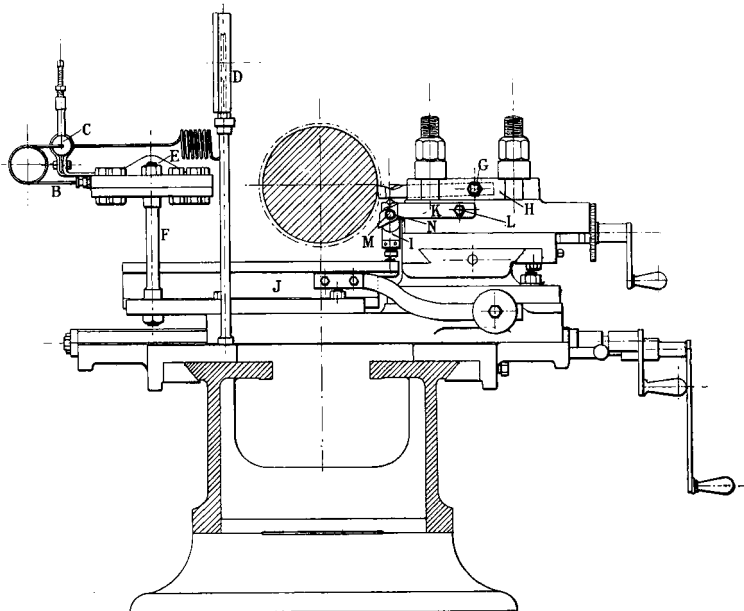


Fig. 2. *Front View.*

Fig. 3. *Back View.*

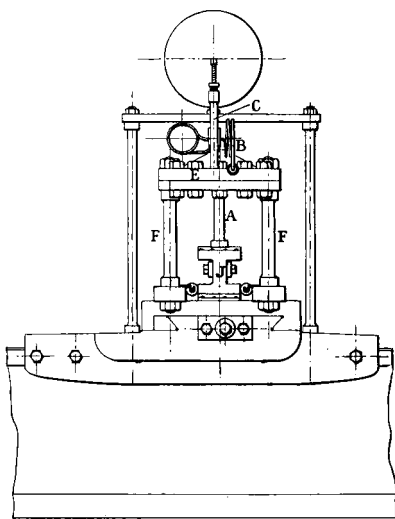
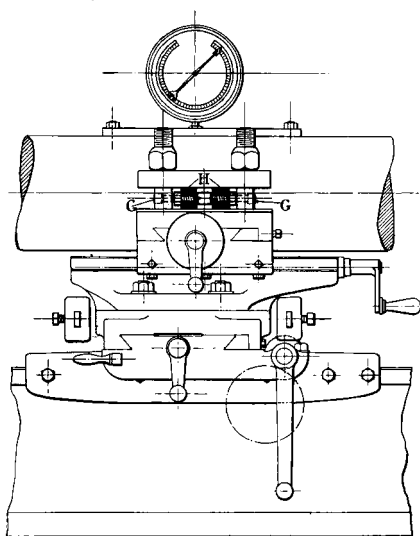


Fig. 4. *Sectional Elevation.*

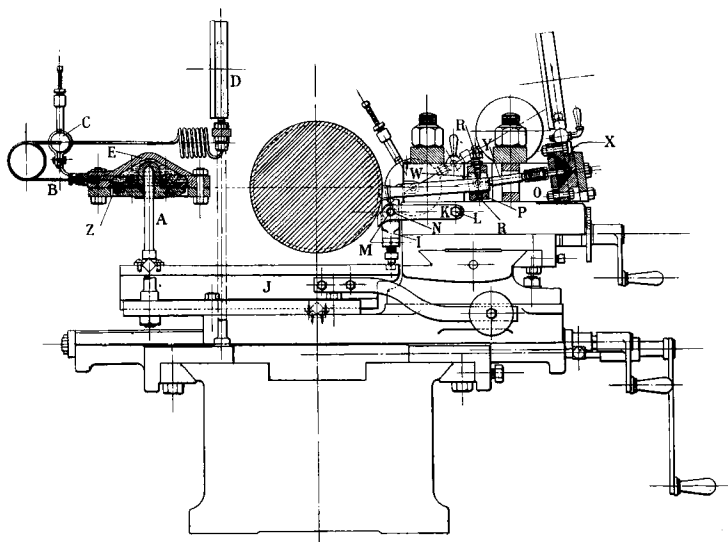
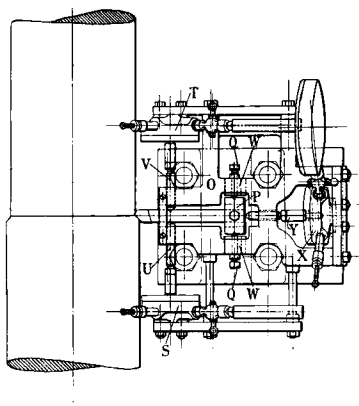


Fig. 5. *Plan.*



*Second or Universal Dynamometer.*

Fig. 6. *Front View.*

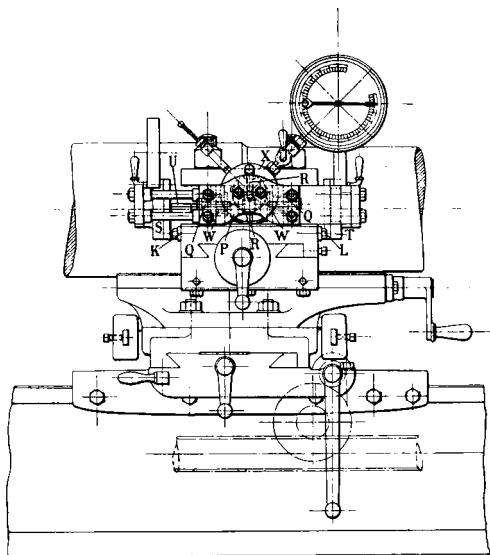
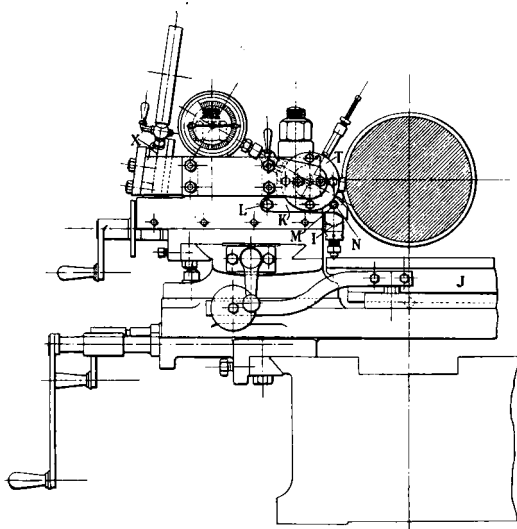


Fig. 7. *Side View.*



LATHE-TOOL DYNAMOMETER EXPERIMENTS. *Pl. 125.*  
*Universal Dynamometer.*

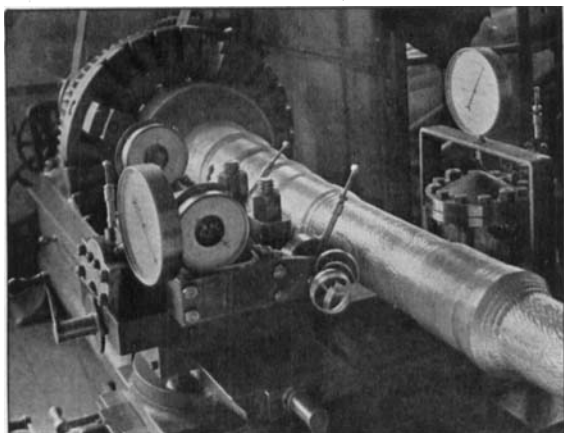


Fig. 8.  
*Side View.*

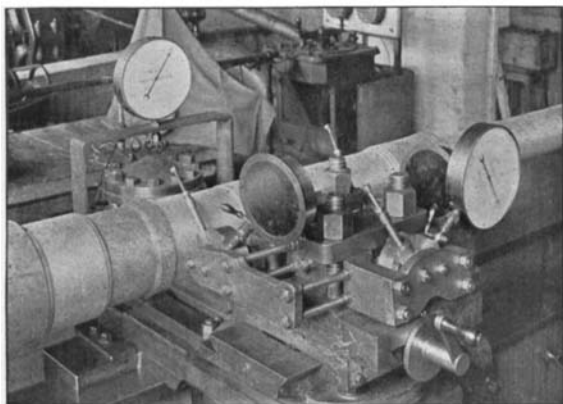


Fig. 9.  
*Front View.*

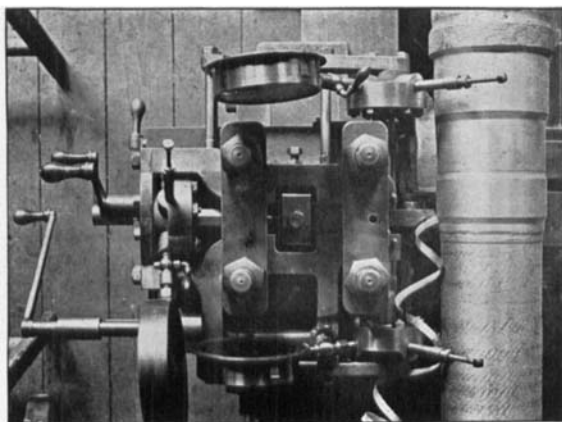
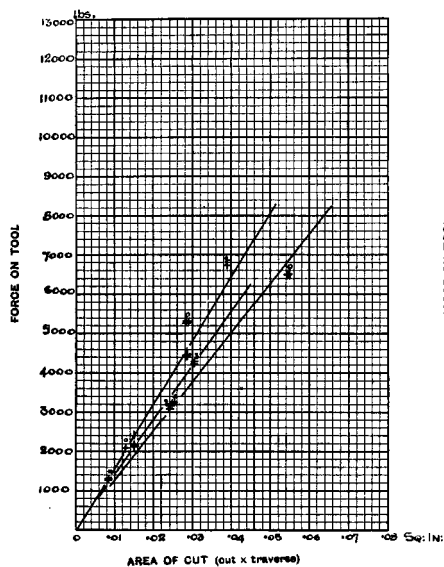


Fig. 10.  
*Plan.*

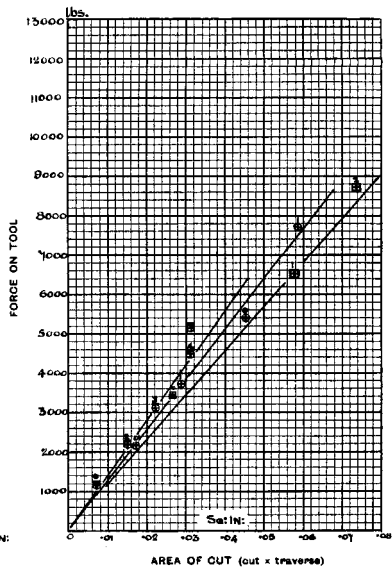
Fig. 11.  
MEDIUM CAST IRON.



TOOL ANGLES 45° CUTTING 45° PLAN

TRAVERSE: 1/16" 1/8" 3/16" 1/4" 5/16" 3/8" 7/16" 1/2"

Fig. 12.  
MEDIUM CAST IRON.

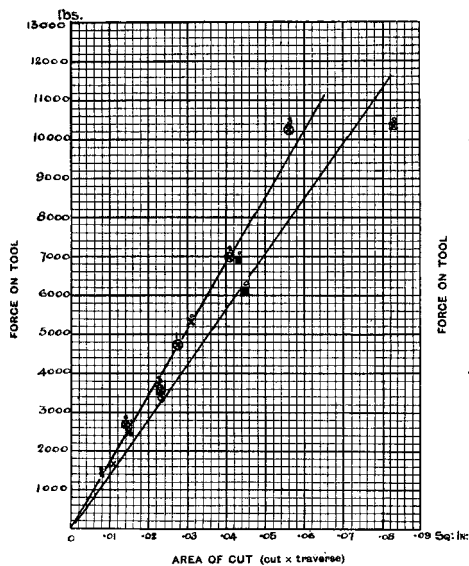


TOOL ANGLES 60° CUTTING 45° PLAN

TRAVERSE: 1/16" 1/8" 3/16" 1/4" 5/16" 3/8" 7/16" 1/2"

Fig. 13.

MEDIUM CAST IRON.

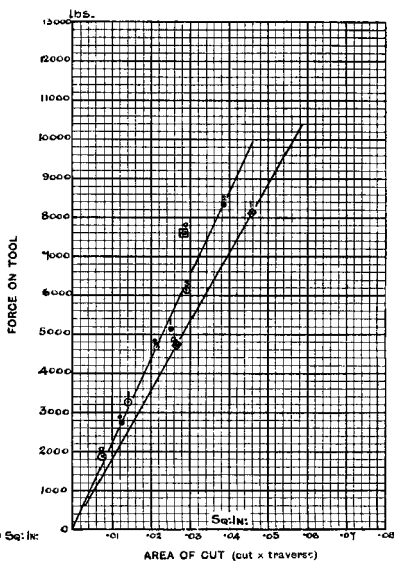


TOOL ANGLES 75° CUTTING 45° PLAN

TRAVERSE: 1/16" 1/8" 3/16" 1/4" 5/16" 3/8" 7/16" 1/2"

Fig. 14.

MEDIUM CAST IRON.



TOOL ANGLES 90° CUTTING 45° PLAN

TRAVERSE: 1/16" 1/8" 3/16" 1/4" 5/16" 3/8" 7/16" 1/2"

Fig. 15.

SOFT STEEL, (fluid pressed).

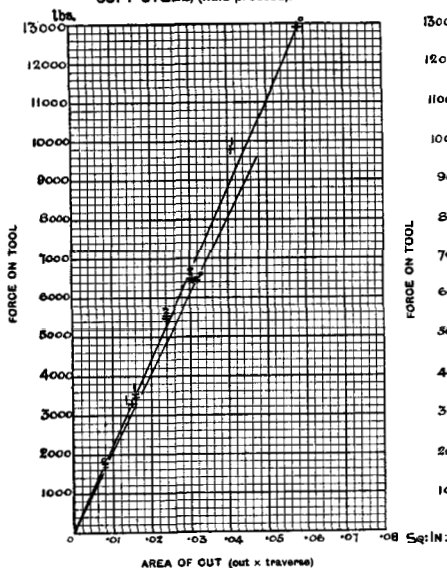


Fig. 16.

SOFT STEEL, (fluid pressed).

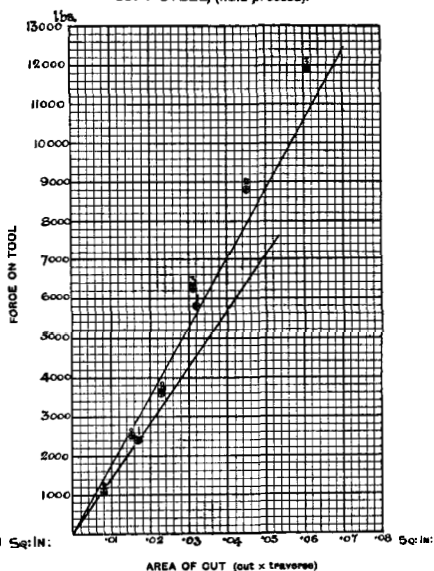


Fig. 18.

SOFT STEEL, (fluid pressed).

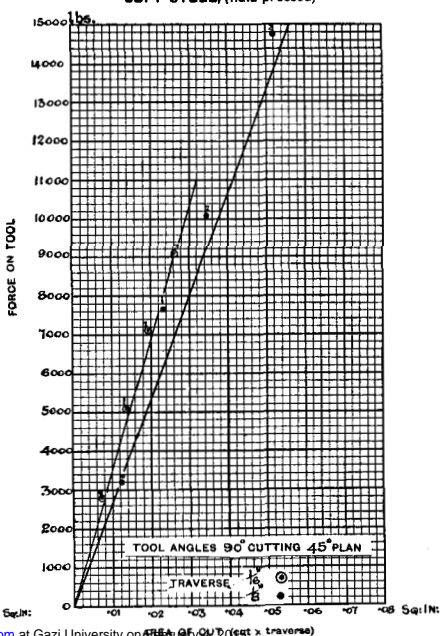


Fig. 17.

SOFT STEEL, (fluid pressed).

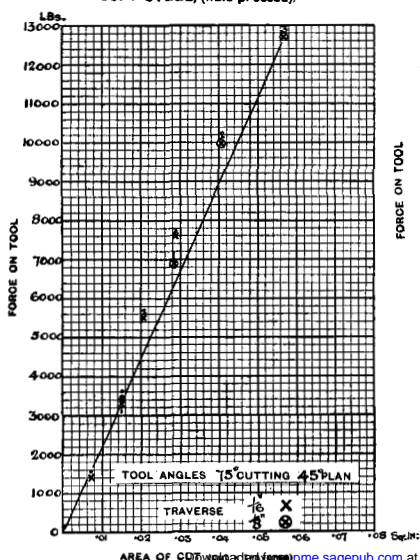


Fig. 19.

MEDIUM CAST IRON

VARIAION OF CUTTING STRESS WITH ANGLE OF TOOL.  
(DIFFERENT TRAVERSES)

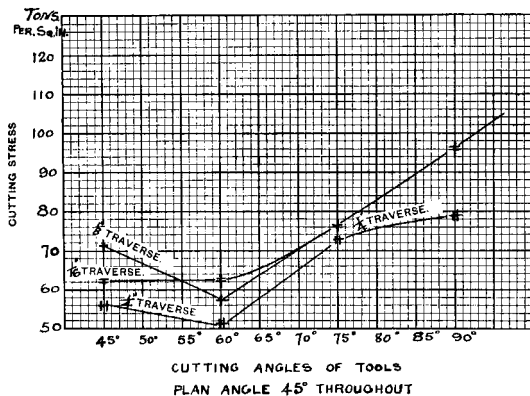
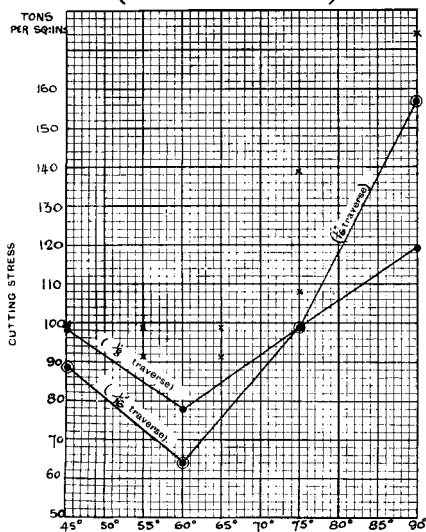


Fig. 20.

SOFT STEEL, (fluid pressed).

VARIAION OF CUTTING STRESS WITH ANGLE OF TOOL CUT  $\frac{1}{8}$ "  
(DIFFERENT TRAVERSES)



CUTTING ANGLES OF TOOLS

PLAN ANGLE 45° THROUGHOUT

Downloaded from pme.sagepub.com at Gazi University on February 4, 2015

Fig. 22.

FAILURE TRIALS OF TOOLS  
WITH VARIOUS CUTTING ANGLES  
CUT  $\frac{1}{4}$ ", TRAVERSE  $\frac{1}{8}$ "  
SPEED 75 FEET PER MIN.

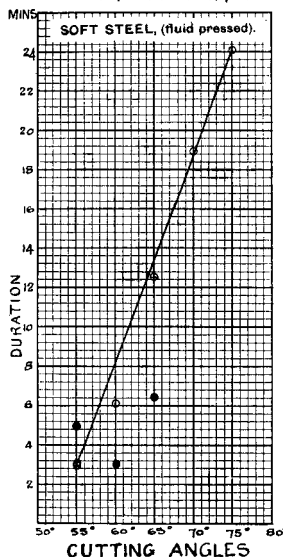
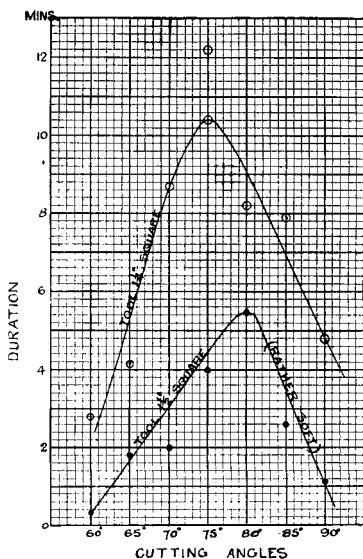


Fig. 21.

FAILURE TRIALS OF TOOLS  
WITH VARIOUS CUTTING ANGLES  
CUT  $\frac{3}{8}$ " TRAVERSE  $\frac{1}{8}$ " SPEED 44 FEET PER MIN.  
MEDIUM CAST IRON.



CUTTING ANGLES

Mechanical Engineers 1904.

Fig. 26.

VARIATION OF SURFACING & TRAVERSING FORCES  
WITH DIFFERENT PLAN ANGLES.  
(CUTTING ANGLE 55° THROUGHOUT)  
SOFT STEEL (fluid pressed)

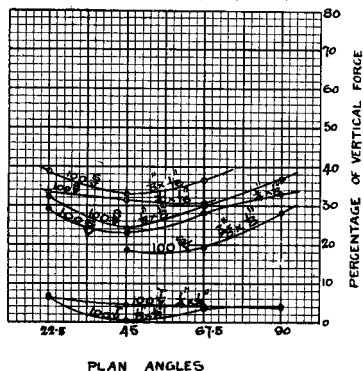


Fig. 27.

VARIATION OF SURFACING & TRAVERSING FORCES  
WITH DIFFERENT CUTTING ANGLES.  
(PLAN ANGLE 45° THROUGHOUT)  
SOFT STEEL (fluid pressed)

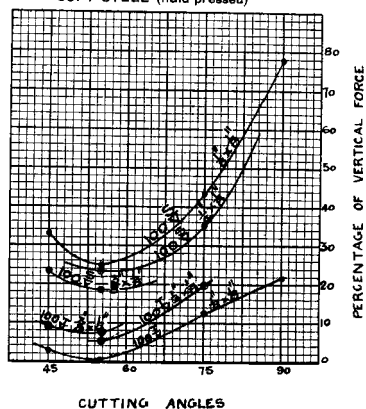


Fig. 28.

VARIATION OF PERCENTAGE OF SURFACING AND  
TRAVERSING FORCES WITH DIFFERENT CUTS.  
EXPERIMENT No 713 a, b, c, d, e and f.  
TOOL ANGLES 55° CUTTING 45° PLAN.

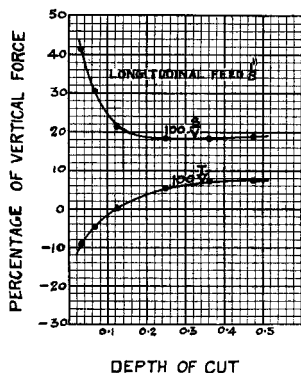
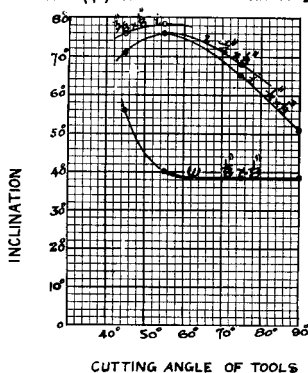


Fig. 29.

VARIATION OF ANGLE OF INCLINATION OF R TO THE  
HORIZONTAL  $[180 - (\alpha_H + \psi)] = \psi$ , AND OF ANGLE  
OF INCLINATION OF R TO THE NORMAL TO THE TOP  
TOOL SURFACE ( $\psi$ ) WITH CUTTING ANGLE.



# LATHE-TOOL DYNAMOMETER EXPERIMENTS. *Pl. 130.*

Fig. 31. Variation of Cutting Forces as Cut progresses.  
Speed, Dead Slow. Soft Steel (fluid pressed).  
 $\frac{3}{8}$  in. cut.  $\frac{1}{8}$  in. traverse. Tool Angles  $55^\circ$  cutting,  $67\frac{1}{2}^\circ$  plan.

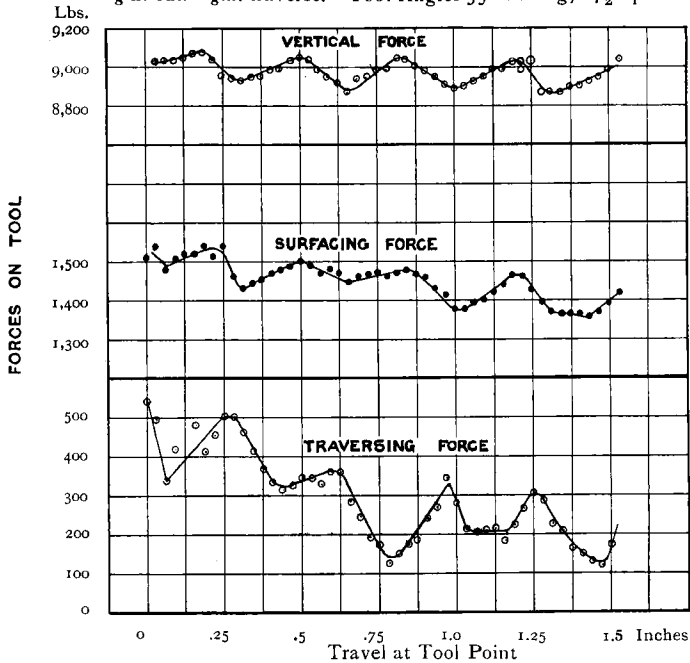


Fig. 32. Diagram of Cutting Force on Soft Steel.  
Expt. No. 636. 1 Feb., 1904. Speed 1 foot in  $4\frac{1}{2}$  hours.  
 $\frac{3}{8}$  in. cut.  $\frac{1}{4}$  in. traverse. Tool angles  $60^\circ$  cutting,  $45^\circ$  plan.

