CUTTING ANGLES OF TOOLS FOR METAL-WORK, AS AFFECTING SPEED AND FEED.

BY MR. H. F. DONALDSON, *Member, OF WOOLWICH.*

The author has approached the preparation of this Paper with considerable hesitation and reluctance, because he feels that he is unable to present the subject for the consideration of the Institution with any real finality of determination by resulting rule, which would be so desirable if it could be evolved. Seeing, however, that he was invited to communicate the results of some experiments made under his direction, he did not feel that he could lightly disregard such a call; and desires to submit the following short Paper, not so much with the idea that, taken alone it will materially add to the interest of the Proceedings, but with the hope that it will fit in with other contributions on kindred subjects, and lead up to discussion and bring out some communication of experiments on similar lines, which may have been undertaken and carried out by other members. The author craves the indulgence of members for the apparent want of finality above referred to, on the ground that the experiments hereafter dealt with were undertaken to obtain sufficient data for use in an inquiry having a still wider scope, and they consequently were only carried just far enough to fulfil the requirements of that investigation, and as a result leave something to be desired when called upon for communication to the Institution. This indulgence he is counting upon.

The importance of the study of the elements which rule speed and feed cannot fail to be recognised by any one interested in matters relating to engineering manufactures, and the author believes that one of the first of these elements, and one which has by no means received the attention which it deserves, is that relating to the individual and combined angles of the tools themselves. Without a fairly clear knowledge of the effect of such combinations, it is a practical impossibility to speak with certainty about absolute speeds which might and ought to be attained under given conditions. What a tool will do, and the angles it requires, will be found to depend upon: (1) the material of which it is made; (2) upon the nature of the material to be cut; (3) upon the speed it is desired to work at; (4) the depth of cut; and (5) the feed.

In the experiments hereafter quoted the tools were all either of ordinary self-hardening steel or ordinary tool-steel, and the materials cut were such as were in daily use in the shops in which the experiments were carried out. These materials of course have varying degrees of hardness, and for purposes of comparison Tables are given (pages 12, 14-15) in which the chemical analysis, or the leading features thereof, and the mechanical tests for each specimen are set out.

It is perhaps well to mention here that, up to the present, no special trial to investigate the best cutting angles for the recently introduced rapid-cutting tool-steels have been undertaken on similar lines. A large number of tools of that nature have been tried, but, as the requirements and the conditions demand as much similarity as possible, it naturally followed that the shapes of tools were kept as uniform as possible. Incidentally, however, these experiments showed that these new steels require more obtuse angles, as well as stouter scantling. This is what would be expected, if data obtained with ordinary tool steel was used as the basis for arriving at the correct angles. Further reference will be made to this point later.

In shops where workmen grind and always have ground their tools for themselves, it will generally be found that from long experience and by trial and error, the best workmen have arrived at a fairly close approximation to the combination of tool angles to suit the work they have to do, but it is by no means common to find one

who can name the angles at which he aims, when grinding, and still more rare is it to find one who is provided with any means of checking the correctness of his grinding, if he knows exactly what he wants. This is one of the great objections to hand-grinding, but with machine-grinding accuracy in this respect can be fully assured; and for this reason, if for no other, machine-grinding should, in the author's opinion, be adopted to the entire exclusion of all hand-grinding in the future. There are, of course, many other reasons which could be advanced in support of the plea for reform in this direction, but the present Paper does not seem the proper place to produce them; it will suffice to point out that, in order to secure efficient results from the use of such investigations as these, machine-grinding must be used.

The variation in the tool angles is always dependent on the nature and hardness of the material to be cut; this is specially the case in the cutting angles, but the influence and effect of the depth of cut and the fineness or coarseness of the feed must not be overlooked. There are indications in the experiments that a light cut and a fine feed should be attacked with a sharper angle than would be permissible with a heavy cut and a coarse feed. Experience, both during the investigation and subsequently, goes to show that if the work will stand it, a heavy cut and slow speed will be more efficient in production than a light cut and quick speed, even though figures would seem to show that the result should be the same.

It will be seen that the experiments covered fourteen different qualities of material, of which seven were steel, one wrought-iron, one cast-iron, and five yellow metal alloys of different degrees of hardness, and chemical constitution. It will also be seen (page 14) that the angles of the cutting edges of tools range from 55° to 75° , while the clearance angles, though showing some variation, do not appear to have the same importance. Subsequent experience indicates that these should under no circumstances be less than 3° , but should be greater as the diameter of the work in the lathe increases. The experiments were all made with pointed roughing tools, though in some cases (notably in specimens VI and VII) the point was somewhat rounded off. The angles mentioned are as follows, Fig. 1 (page 8):—

FIG. 1.
Cutting and Clearance Angles of Tools.

During the course of the experiments, it was thought desirable to secure some data with regard to the actual weight brought to bear upon the point of the tool when cutting, and a device was worked out by one of those to whose care the experiments hereafter detailed were entrusted, of which some short description may be of interest to Members. It is not suggested that it is in all respects perfect, or that there are not several improvements easily open to suggestion. For instance, there are parts where frictional effects are rather large, but for the purposes for which the device was produced, it was sufficiently accurate, and fulfilled its object. The apparatus may be shortly described, with the aid of the drawing, Plate 1.

It consists of an attachment, fixed by the ordinary tool studs to the slide-rest of an ordinary lathe, forming a holder for the body of the tool to be tried. Along its front edge a knife-edge A is provided, which forms the fulcrum on which the forward portion of the tool rests; at the hinder end of the tool a stop B is arranged, also beneath the tool; the tool is primarily rested upon these two points; a set-screw C is devised to be brought to bear on the top hinder end of the tool, and is adjusted when the tool is first inserted, to allow a certain amount of play, while preventing the tool from tilting an undue amount, when the cut is first put on. At a distance from the fulcrum A, about equal to that from the point of the tool to the fulcrum, is a small ram D, having a sliding block E attached to its

lower end, and capable of being moved forward by the rotation of the capstan-headed screw, housed in the ram. The cylinder into which the ram fits is part of the main attachment; and the hydraulic joint is made with a small hat-leather; into the top of the cylinder a spring gauge F is screwed. At the back of the tool a similar arrangement is provided with gauge G, the only material difference being that there is no sliding block, but the pressure is taken up on a point. The omission of a sliding block at this place, as well as at the side gauge H, is responsible for the greater portion of the frictional errors which had to be allowed for. The side gauge is arranged for on identical lines, but it may be well to eliminate this from further remark, because, owing to the friction at the end of the tool, no readings of any value were obtained. The only other moving parts are the set-screws I J disposed at each side of the tool, and in the same plane as the knife-edge fulcrum.

The process was as follows: the tool was laid upon the fulcrum A and the stop B; the set-screws I J were given a light bearing, and set-screw C was also adjusted so that the tool could not tilt much above the horizontal; the end and side ram points were also given a firm bearing each, and the cut was put on. When the desired depth was reached, the sliding block was screwed hard down, until the axis of the tool was horizontal, and thus its contact ceased with stop B and set-screw C. The vehicle for transmitting the pressure to the gauges was oil, and the readings were direct, except that to obtain actual pressures the reading required to be multiplied by the ratio of the distance from the centre of pressure to the fulcrum, and the point of the tool to the fulcrum, seeing that it is practically impossible to fix these with exact equality.

The material operated upon was medium hard steel, the tool was an ordinary pointed one, and its angles were:—

Front cutting	.	.	.	.	.	63°
Front clearance	.	.	.	.	.	5°
Side cutting	.	.	.	.	.	60°
Side clearance	.	.	.	.	.	5°
Horizontal	.	.	.	.	.	40°

The following Table 1 gives results of some tests:—

TABLE 1.

Material.	Revs.		Feed.	Depth of cut.	Pressure on top in lbs. per sq. inch.	Actual pressure in lbs.	Travel.	Pressure at end in lbs.	Remarks.
Medium hard steel.	A	14	in. $\frac{1}{8}$	in. 0.1	75.0	81.25	in. —	25	At starting of cut the pressure was 250 lbs., and dropped to 150 lbs.
	B	14	$\frac{3}{8}$	0.125	80.0	86.66	1	25	
	C	14	$\frac{5}{8}$	0.125	150.0	162.5	1	25	
	Speed of Material.								
A = 14.65 ft. per min.									
B = 14.65 ft. per min.									
C = 14.65 ft. per min.									

It will be seen from the above that a comparatively small increase in the feed is responsible for a much more considerable increase in the pressure at the point of the tool, and that, in one experiment at any rate, there was a decided rise in the pressure at the beginning of the cut. The deductions possible from investigations of this nature will be found of great utility, in dealing not only with the steels of usual quality, but still more so if a close examination is undertaken in regard to the requisite strength of machines capable of standing up to the extra stresses likely to be brought upon them when using the newer qualities of rapid cutting tool steels. They are, moreover, valuable in considering the shape and points of tools. As stated, pointed tools were used in these tests, and it is therefore calculable, with measurements, to compare the power required if a round tool is used. With the latter more power is of course required, but for ordinary work, which will stand the strain, the efficiency, both in length of life of the tool, and in the greater amount of metal removed in a given time, seems to give a balance of advantage in its favour. When cutting the harder natures of steel this is particularly the case, because this shape of tool has necessarily more metal in it, and consequently takes up heat less quickly, and also when hot has a greater area from which to get rid of it; moreover, being stronger it

is less liable to chip. Allied to this matter of strength is the subject of the method of fixing the tool in its rest; this is of much importance, for the more rigidly the tool can be fixed, the better will it cut, and the longer will it last. For this reason the nearer the point of the tool can be fixed to its rest the better; to attain this to the greatest extent possible, it will be necessary to use straight-bodied tools, and to avoid adopting tools forged with a bend or spring towards the point. "Spring" in a tool, with its attendant evils, should be avoided wherever possible. The pointed tool, however, has its distinct advantages under certain conditions, as for example, the experiments, hereafter quoted, seem clearly to indicate that it is better for light cuts and fine feeds. When using tools of rapid cutting steel, there is no doubt that the straight, heavy round-nosed tool is the best.

Turning now to Table 3 (pages 14-15), showing results of experiments with various combinations of tool angles, speeds and feeds, the author has thought it undesirable to burden this Paper with a complete list of all experiments, and therefore only enumerates the "Best Results." He gives two Tables, Table 2 (page 12) containing the chemical analysis and mechanical tests, and Table 3 (pages 14-15) the depths of cut, the speeds of material and tool, the angles of tools, the state of tools after work, the qualities of shavings, and the appearance of the work. Both Tables indicate the assessed degree of hardness.

It would be impossible, within the limits of such a Paper as this, to embark upon anything like an exhaustive analysis of the data these Tables afford, and the author therefore proposes, while remarking upon a few points, to confine himself to inviting attention to the conclusions he has drawn for himself. He has already referred to the more important of these. For instance, the tests indicate that when working with a high speed of material, a light cut, and a fine feed, different angles are required to those found most suitable for a heavier cut, a slower speed of material, and a coarser feed. Having special reference to this point, specimens II and VI are worth noticing. Both of these are similarly classed, as regards hardness, and there is only a difference in the respective cutting angles of 4° .

TABLE 2.—*Chemical Analysis and Mechanical Tests of Material Operated upon.*

Material Index No. and Degree of Hardness. (See Table 3, page 14.)	Chemical Compositions.								Mechanical Tests.	
	Carbon.	Silicon.	Man- ganese.	Nickel.	Phos- phorus.	Sulphur.			Ultimate Stress in tons per sq. inch.	Exten- sion per cent. in a 2-inch length.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.				per cent.
I. Steel HHH.	1.1 to 1.35	—	—	—	—	—			55 to 60	10 to 15
II. " H.	0.6 to 0.75	—	—	—	—	—			45 to 52	12 to 15
III. " HHN.	0.6	0.2	0.5	0.5	—	—			50 to 60	10 to 15
IV. " cast HH.	0.35 to 0.45	0.2 to 0.3	0.7 to 0.9	—	—	—			28 to 38	4 to 9
V. " HH.	0.3 to 0.35	0.1 to 0.2	0.5 to 0.7	—	—	—			35	30
VI. " H.	0.33	0.06	0.54	—	0.04	0.02			31	23
VII. " H.O.	33	0.06	0.54	—	0.04	0.02			39	20.5
VIII. Wrought Iron M.	0.08	trace	trace	—	—	—			23 to 25	40 to 60
IX. Cast Iron.	0.36	0.25	0.7	—	0.1	—			10 to 12	
	Copper.	Tin.	Zinc.	Lead.	Phos: Tin.	Alumin- ium.	Iron.	Man- ganese.		
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.		
X. G.M. hard alloy } HH.	90	8	2	—	2	—	—	—	19.5	30
XI. " medium " } M.	87 ± 2	3.5 ± 1	6 ± 2	3.5 ± 1	—	—	—	—	14.5	28
*XII. " soft " } S.	87 ± 2	3.5 ± 1	6 ± 2	3.5 ± 1	—	—	—	—	14.5	28
XIII. " forged " } HH.	60	—	40	—	—	0.25	0.25	2	27	22
XIV. " " " } H.	60	—	40	2	—	0.25	—	—	32	35

* Chiefly old metal.

The ruling factor, in fixing cutting angles, must in all cases depend to a very large extent upon the hardness of the metal to be cut; the harder the metal, the more obtuse will be the angles of the tool. Thus in specimen II, classed as H, specimen V, classed as HH, and specimen I, classed as HHH, with a tolerably even gradation in speed of material and lightness of feed, the best cutting angles appear to be 59° , 62° and 75° respectively. In each of these examples the depth of cuts and the nature and size of tools are approximately the same. Similar evidence is forthcoming on examination of specimens VI and VII; the material in both these cases is the same, but the latter is oil-hardened. The softer material clearly requires the sharper angle of tool, but for purposes of finish the feed is rather finer, and this supports the suggestion that, other things permitting, the variations in the angles are closely allied to speed and feed.

It will be noted, especially in connection with operations on yellow metal alloys, that the possibilities of speed of working on hard, medium, and soft material rise in accordance with the nature of the material, but that with medium and soft material, specimens XI and XII, no change of angles was necessary; from this it may be deduced that the tendency of the soft metal to hang to the point of the tool is responsible for the obtuseness in the required angle.

The information gathered from these investigations has not been without practical results in several subsequent steps. It has tended to assist in the consideration of more than one subject connected with shop administration, with, as the author believes, very beneficial results. Among other good objects, it affords a reasonably sound basis for determining the cutting speeds with which those in authority may be content; it therefore will naturally be available and useful in the formation of estimates, whether for rate fixing, promises for delivery, or quotations to customers. It can also be used for the assistance of the workmen in the shop. Rule of thumb, and practical experience, of course have their value in dealing with such subjects, but, in the author's opinion, work-shop administration can be, and ought, in these days, to be based upon a more defined foundation. This can be much assisted by a study of anything which

TABLE 3 (continued on next page).

Table showing Best Results in

Material, Index No., and Degree of Hardness.		Diameter.		Speed of Material.		Speed of Tool.			Tools and Angles.					
		Before.	After.	Revolutions per minute.	Feet per minute.	Feed.	Travel.	Time.	Nature of Tool.	Front Cutting.	Side Cutting.	Front Clearance.	Side Clearance.	Horizontal.
I.	Steel HHH.	3.4	3.2	18	15	$\frac{1}{16}$	3	6.75	1½ Mu.	75	69	2	2	33
II.	Steel H.	1.85	1.7	70	32	$\frac{1}{16}$	6	6	1 C.S.	59	62½	3	3	33
III.	Steel HHN.	5.75	4.95	18	27	$\frac{1}{16}$	3	9	do.	62½	62½	1	1	32
IV.	C. Steel HH.	6	5.15	18	28	$\frac{1}{16}$	1	2.25	do.	65	63	2½	1	42
V.	Steel HH.	1.5	1.25	70	27½	$\frac{1}{16}$	½	0.44	do.	62½	62½	3	3	42
VI.	Steel H.	8.35	7.5	5½	12	½	10	15	1½ Mu.	55	52	4	5	35
VII.	Steel H.O.	6.75	6.25	5½	10	$\frac{1}{16}$	18	44	do.	57½	55	8	8	40
VIII.	W. Iron M.	3	2.75	70	55	$\frac{1}{16}$	2	2	1 C.S.	57½	55	3	3	42
IX.	C. Iron	4.95	4.2	18	21	$\frac{1}{16}$	2	3	do.	60	64	1½	1	35
X.	G.M.F.	3.37	3	140	122	0.02	4	1.25	do.	61	64	3	0	35
	HH.	3	2.7	320	251	0.03	6	0.6	do.	61	64	3	0	35
XI.	G. Metal M.	2.6	2.37	320	217	0.03	6	0.6	do.	73	74	2	½	35
XII.	G. Metal S.	3.5	3.25	320	293	0.03	5	0.5	do.	73	74	2	½	35
XIII.	G. Metal F.	2.65	2.45	224	160	0.02	4	0.75	do.	78	78	1	0	35
	HH.													
XIV.	G. Metal F.	2.4	2.125	224	140	0.02	3	0.55	do.	62½	64	3	3	35
	H.													

Very hard material indicated HHH.

Medium hard " " HH.

Hard " " H.

Oil hardened " " O.

Medium " " M.

Soft material indicated S.

Forged " " F.

Nickel " " N.

Mushet " " Mu.

Cast Steel " " C.S.

(concluded from opposite page) TABLE 3.

Operating Angles of Tools.

Lubricant used.	State of Tool-edge after work.			Shavings.		Surface of Specimen after Work.			Material, Index No. and Degree of Hardness.
	Not Damaged.	Slightly Damaged.	Completely Damaged.	Long.	Short.	Smooth.	Rough.	Very Rough.	
Soda Hyd.	—	Yes	—	—	Yes	Good	—	—	I. Steel HHH.
Do.	—	Yes	—	Yes	—	do.	—	—	II. Steel H.
Do. and Soap	—	{ Rough on Edge }	—	—	Yes	do.	—	—	III. Steel HHN.
Do. do.	—	do.	—	Long	—	do.	—	—	IV. C. Steel HH.
Do. do.	Not	—	—	Yes	—	do.	—	—	V. Steel HH.
Do. do.	Not	—	—	Yes	—	do.	—	—	VI. Steel H.
Do.	Not	—	—	Yes	—	do.	—	—	VII. Steel H.O.
Do.	Not	—	—	Yes	—	do.	—	—	VIII. W. Iron M.
Nil.	—	Yes	—	—	Yes	do.	—	—	IX. C. Iron
{ Soda Hyd. }	Not	—	—	Yes	—	do.	—	—	X. G.M.F. HH.
Do.	Not	—	—	—	Yes	do.	—	—	XI. G. Metal M.
Nil.	Not	—	—	—	Yes	do.	—	—	XII. G. Metal S.
Soda Hyd.	Not	—	—	—	Yes	do.	—	—	XIII. G. Metal F. HH.
Do.	Not	—	—	Yes	—	do.	—	—	XIV. G. Metal F. H.

Very hard material indicated HHH.

Medium hard " " HH.

Hard " " H.

Oil hardened " " O.

Medium " " M.

Soft material indicated S.

Forged " " F.

Nickel " " N.

Mushet " " Mu.

Cast Steel " " C.S.

appears to contain an approach to definite laws. The author believes that a careful study of matters relating to cutting angles of tools will fully repay the trouble.

A practical illustration of how beneficial results have occurred, in one place at any rate, may perhaps be of interest, and useful. In a shop which was occupied on repair work, and equipped with a considerable number of lathes, the cutting speeds in general use were very variable, more so than the changes of the work required seemed to warrant. The workmen ground their own tools, and so long as that remained the practice it did not seem feasible to formulate definite instructions as to the cutting speeds at which the men would be expected to work. Machine grinding was introduced, and tools at approved angles were prepared for issue to the men as required. From the data of the experiments, determinations were made for the best speeds for cutting all classes of material in general use, using 1-inch diameter as the constant, and the following letters were adopted to indicate the different classes of material :—

S. V. H. means Steel very hard.	I. C. means Iron cast.
S. H. „ Steel hard.	B. H. „ Brass hard.
S. M. H. „ Steel medium hard.	B. S. „ Brass soft.
S. T. „ Steel tough.	B. F. H. „ Brass forged hard.
S. S. „ Steel soft.	B. F. S. „ Brass forged soft.
I. W. „ Iron wrought.	

A small brass plate was prepared and attached to each machine, bearing figures denoting the determinations referred to of the following form :—

Material.	Revolutions for 1 inch diameter.
S. V. H.	58
S. H.	84
S. M. H.	102
S. T.	107
S. S.	105
I. W.	210
I. C.	80
B. H.	468
B. S.	860
B. F. H.	615
B. F. S.	530

The face of each step on the cone-pulleys was stamped with the number of revolutions the spindle would make when running with single, back, and triple gear. Armed with the information which these permanent markings afford, the adjustments to be made become a very simple operation for the workman; for all he has to do, to at once start his machine at its correct speed, is to divide the number of revolutions for 1-inch diameter by the diameter in inches of the work to be operated upon, which will give him the number of revolutions required, and he can at once arrange his belt on the necessary step of his cone pulley. Besides the advantages accruing from such a method, other benefits may be mentioned; for instance, the foreman in charge can at a glance tell if work entrusted to him for execution is being arranged by the workman at speeds, which will ensure his estimates both for time and cost resulting. Such a display of proof of sound shop administration will be reflected on the workman, and cannot fail to act beneficially on the productions of the shop. The author has referred to the possible charge, that the results of the experiments show a want of finality, which may mar their efficiency; he is fully alive to the possible soundness of such a criticism, but at the same time, hopes that the data offered may yet afford a basis from which others may start in the selection of tool angles most suited to their own special requirements. He believes that variation in practice in individual shops will be found to affect materially the determinations as to the best tool angles. With this in view, he has less hesitation in offering the following Table of margins based upon the experiments, even though their wideness may be considered to almost defeat the attainment of the object in view.

The criticism, that these margins are too wide for practical use, will best be met by the acknowledgment that the author has perhaps endeavoured to compress the variable requirements within too narrow limits, but he would point out that it would unduly prolong the Paper to attempt to embark upon all the possible contingencies, which he believes would arise, when considering the requirements of a particular shop. The large allowance in the margins is also made in order to cover variations in degree of toughness (as distinct from

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TABLE 4.
Limits of Cutting Angles.

	Front cutting.	Side cutting.	Front clearance.	Side clearance.	Horizontal.
	deg.	deg.	deg.	deg.	deg.
For cutting mild steel . .	52 to 60	50 to 60	3 to 8	3 to 8	33 to 43
For cutting medium steel .	54 to 63	63 to 65	3 to 8	3 to 8	33 to 43
For cutting hard steel . .	65 to 78	60 to 70	3 to 8	3 to 8	33 to 43
For cutting soft yellow metal	62 to 74	62 to 74	3 to 8	3 to 8	33 to 38
For cutting medium yellow metal	62 to 74	70 to 75	3 to 8	3 to 8	33 to 38
For cutting hard yellow metal	60 to 80	60 to 80	3 to 8	3 to 8	33 to 38

hardness), variations in depth of cut, speed of material, speed of feed, and form of tool. The author is well aware that the subject could readily be expanded by closer examination of details, but he hopes that the remarks he has made may be the means of raising such discussion as will tend to a closer examination of the principles, which he believes underlie, and matters which depend upon the subject under review, than is, he thinks, generally given to them.

In conclusion, the author desires to express his thanks to all those, especially those in administrative control of departments and shops where the experiments were carried out, and particularly to those who brought special devices and appliances to bear, to assist in the attainment of the desired information.

The Paper is illustrated by Plate 1 and one Fig. in the letterpress, and is accompanied by an Appendix.

APPENDIX.

Some pressure has been brought to bear upon the author to afford some information regarding tests made under his direction with the newer classes of rapid-cutting tool-steels as an addendum to the foregoing Paper; he has much hesitation in doing this, because the experiments were made with a view to the selection of steels most likely to meet the requirements of the work which has to be done on the material generally used, and consequently, it is difficult to avoid reference to the firms from which the steels were procured. He does, however, feel that he cannot entirely refuse the request, as he is fully alive to the great desirability for the widest possible dissemination of information on this subject. He will therefore endeavour to formulate some remarks, which will assist in this direction, to the greatest extent possible without disclosing the names of the makers of the steels with which he has experimented up to the present.

The trials show that a rapid cutting steel tool, which gives excellent results in cutting mild material, is by no means certain to give correspondingly good results if required to cut very hard material. The converse is also true. Consequently, in examining the question, or in selecting a rapid-cutting steel, it is essential to take into consideration the nature of the material to be cut.

Twenty-seven different brands of steel have been tried and in many of these, under several sets of conditions. Table 5 (pages 20-21) shows twenty-four of these, and from them six have been selected as most satisfactorily meeting requirements. Table 6 (page 22) sets out some of the leading features; the brands are indicated alphabetically.

It will be noticed that only two brands are selected for working on hard steel, while four are found suitable for medium or mild steel. This is no doubt due to the fact that, generally speaking, medium or mild steel is dealt with in most shops, and consequently, steel-makers have aimed at supplying general requirements, and it is

TABLE 5 (continued on opposite page).

*Results of Trials of High Speed Tool Steels.
Covering a period from September 1901 to November 1902.*

Name of Steel.	Cutting Speed.	Depth of Cut.	Feed of Tool per Revolution.	Weight of Material Removed per Hour.	Average Time of Cutting.	Travel of Tool.	Condition of Tool after Test.	Order of Merit of Tool.	Nature of Material on which best result was obtained.
	feet per min.	in.	in.	lbs.	hours.	ins.			
W	17	0.25	0.046	20.48	0.116	1.43	{Required regrinding}	—	{Only tried on Cast Steel Soft Steel}
I.	17	0.25	0.046	21.175	2.405	15	Do.	—	Do.
	38.6	0.35	0.1	281	7.6	—	Do.	—	Do.
	13.5	0.5	0.05	—	—	—	—	—	Do.
E	17	0.25	0.046	18.45	1.315	7.3	{Required regrinding}	—	Do.
	33	0.6	0.076	229	7.1	—	Do.	{3rd Soft Steel}	Do.
	13.5	0.93	0.05	80	9	—	Good	—	Do.
B	17	0.25	0.046	20.48	5.8	72	{Required regrinding}	{2nd Hard Steel 2nd Soft Steel}	{Suitable for Soft and Hard Steel}
D	50	0.26	0.1	269.7	8.5	—	Good	—	—
J	13.5	0.93	0.05	148	4.66	—	Good	—	—
K	13.5	0.93	0.05	143.5	4.25	—	Good	—	—
L	13.5	0.93	0.05	128.5	4.8	—	Fair	—	—
N	13.5	0.93	0.05	80	9	—	Bad	—	{Medium Steels}
	39.5	0.228	0.098	176	2.85	—	{Required regrinding}	—	
M	13.5	0.93	0.05	80	9	—	Good	—	{Medium Steel}
	35	0.2	0.1	143	0.106	—	{Required regrinding}	—	
O	37.3	0.215	0.1	179.2	3.95	—	Do.	—	—
R	28	0.15	0.08	78.3	1.62	—	Do.	—	—

(concluded from opposite page) TABLE 5.

*Results of Trials of High Speed Tool Steels.**Covering a period from September 1901 to November 1902.*

Name of Steel.	Cutting Speed	Depth of Cut.	Feed of Tool per Revolution.	Weight of Material Removed per Hour.	Average Time of Cutting.	Travel of Tool.	Condition of Tool after Test.	Order of Merit of Tool.	Nature of Material on which best result was obtained.
	feet per min.	in.	in.	lbs.	hours.	ins.			
A	44.5	0.33	0.1	313	4.12	—	Fair		
S	17	0.25	0.063	25.6	12.5	214	{ Point broke due to accident { Required regrinding }	{ 1st Hard Steel }	{ Cast Steel }
T	17	0.25	0.046	19.98	3.71	41	{ Required regrinding }		
Y	17	0.25	0.046	19.75	1.37	15.5	Do.		
Would not cut at all at these Feeds.									
Q	17	0.25	0.062	25	0.35	6	{ Required regrinding }		
F	39.25	0.244	0.1	196.1	3.04	—	Edge worn away { Cutting edge slightly worn }	{ 4th Soft Steel }	{ Medium Steels }
V	38.5	0.27	0.1	217.3	4.78	—	{ Cutting edge slightly worn }		
X	13.5	0.94	0.05	186.6	2.42	—	Good		
C	13.5	0.94	0.05	166.8	0.83	—	Bad		
H	26	0.1	0.008	4.25	0.25	—	Fair		
G	28	0.2	0.02	24	0.116	—	{ Edge worn off } Tool		
P	42	0.41	0.10	350	13.5	—	{ Required regrinding }	{ 1st Soft Steel }	{ Soft Steel }
	43.75	0.25	0.1	227.3	5.5	—	Good		
	21	0.2	0.047	40	1.34	26.75	{ Required regrinding }		{ Soft Steel }
	42	0.367	0.1	321.7	2.75	—	Do.		{ Suitable for Soft and Hard Steels }
	21	0.2	0.047	39.7	3.64	75.5	Do.		
	35.5	0.15	0.1	114	3.5	—	Do.		
	21	0.2	0.047	39.7	2.42	51			

TABLE 6.—*Rapid Cutting Tool Steel Trials.*

Index Mark of Brand.	Nature of Material Cut.	Cutting Speed.	Depth of Cut.	Feed of Tool per revolution.	Weight of Material Removed.	Average Time of Cutting.	Condition of Tool.
A*	Very hard.	feet per minute. 17·0	inch. 0·25	inch. 0·063	lbs. per hour. 25·6	hours. 12·5	{ Point broke due to accident.
B	Do.	17·0	0·25	0·046	20·48	5·8	{ Required re-grinding.
C	Hard, oil hardened.	42·0	0·41	0·10	350·0	13·5	Do.
D		50·0	0·26	0·1	269·7	8·5	Good.
E		33·0	0·6	0·076	229·0	7·1	{ Required re-grinding.
F		38·5	0·27	0·1	217·3	4·78	Slightly worn.

* Lathe broke down, owing to insufficient power.

therefore easier to get a greater area of supply in grades of this quality. The author does not propose to comment at any length on the foregoing Table, but thinks that he may usefully draw some comparisons, with regard to the weight of metal removed, between these tests and some of the experiments dealt with in the body of the Paper, where the relative degrees of hardness coincide.

The material in specimen I in Table 2 (page 12) was of about the same degree of hardness as was operated upon by tools A and B in Table 6 (page 22). The material removed from specimen I was equal to about $7\frac{1}{2}$ lbs. per hour, while tools A and B removed about $25\frac{1}{2}$ lbs. and $20\frac{1}{2}$ lbs. per hour respectively. Specimen VII would represent equivalent hardness of material for comparison with that operated upon by tools C, D, E, F. The metal removed from specimen VII was about $35\frac{1}{2}$ lbs. per hour, while tools C, D, E, F removed 350 lbs., 269 lbs., 229 lbs., 217 lbs. per hour respectively. This comparison brings out the interesting point that while the new rapid-cutting tool-steels show speeds of work from six to nearly ten times faster than when working with ordinary tool-steels, only about three times faster can be attained when working on the harder qualities of material. It is difficult to account for this, except by the theory that steel-makers have directed their attention more exclusively to meeting the demands for quick removal of large weights of mild or medium hard metal; at the same time, there is reason to think that many steel-makers have not in all cases realised that tools for operating upon very hard material must possess special qualities.

Remarks in the body of the Paper (page 7) have already been made indicating that a round-nosed tool will, other things being equal, give better results in the amount of metal removed than a pointed tool. This is very marked in the case of rapid-cutting tools, for not only are the latter stiffer and stronger but they stand up to their work better and are more durable. No special experiments have been made as to cutting angles for these tools, but experience seems to show that the cutting angles should be a few degrees more obtuse than is required for tools of ordinary steel.

In conclusion, it seems desirable to draw attention to the fact that, in considering the quantities of metal removed in the two sets of experiments, true comparisons are not possible, because in the tool angle experiments no effort was made to test the tool to destruction, while in the rapid-cutting trials such an end was actually aimed at.

Discussion.

The PRESIDENT said the Paper dealt with a subject which was not only of very great importance at the present day, but was of growing importance. If the point raised by the author in the early part of his Paper was considered, that nowadays the whole tendency was towards having tools ground to certain definite angles and supplied to the workmen for their use without giving the workmen the option of changing those angles, it would at once be seen that it was particularly essential that the angles so chosen should be correct, and it was only by careful experiments, such as those carried out by the author, that the necessary angles could be determined and results obtained which would, as it were, compensate for dispensing with the individual skill of the better class of workmen which had hitherto been relied upon. The Institution was indebted to the author for the great trouble he had taken in preparing the Paper. He (the President) felt personally indebted to Mr. Donaldson to a very large extent, because it was chiefly at his request that the author was kind enough to gather together the data which had been embodied in the communication. He was sure the members would feel that the author had done excellent work for them, and he proposed a hearty vote of thanks to him for having written the Paper.

Mr. DONALDSON said he was glad to have the opportunity of saying a few words before the discussion commenced, because the issue of the Paper took place somewhat hurriedly before he was able to correct some details, and therefore there were one or two points which seemed to him to require explanation. For instance, with regard to the Tables in the Appendix (pages 20-22), originally the Appendix contained only one list, Table 6, but during the course of printing he was able to supply Table 5, of which Table 6 was a part. It was a little troublesome perhaps that two Tables should be published containing the same information. Table 6 gave the Table of best results, which were also included in Table 5. There were also some slight errors in the print of Table 1 (page 10). Instead of "Pressure on top in square inches per lb.," he thought it was tolerably evident it should be the reverse, "Pressure on top in lbs. per square inch," and in the next column the actual pressure should be only in lbs. and not per square inch. [These corrections have now been made.]

One of the main difficulties connected with the subject of the Paper was that nearly everybody did the same as was done in his case. The examination of the angles was, as he had said, a part only of another subject, and as soon as sufficient data had been collected the whole of the experimental work, so to speak, was dropped, and the main subject was proceeded with. Consequently the subject was never comprehensively examined. It was one which he thought might, could, and should be extended on its own merits, because there was a great deal of information to be gathered from a closer examination than had, so far as he knew, ever been accorded consistently throughout the whole enquiry to the subject of tool angles.

With reference to the apparatus for measuring the pressure on the point of the tool, Plate 1, so far as he knew nothing of that sort had been tried before. The measurement had never, he believed, been taken directly from the tool, as in this case. If taken in any other way, the possibility of errors of reading was much increased. Experiments to measure a certain portion of the power absorbed by the machine on the tool had been taken upon entirely different lines, and with

(Mr. Donaldson.)

entirely different results. He had hoped that Colonel Holden would have been present that evening, but he had sent a message saying that at the last moment he was prevented from coming. He (Mr. Donaldson) had hoped that Colonel Holden would have said something about a measurement which was taken out for an entirely different purpose, with the idea of testing what would be the effect of taking off cuts with a square-nosed tool in a machine which was now being worked out by a committee appointed for the purpose of preparing a standard leading screw, and a machine which would reproduce those standard leading screws. In parenthesis, he might say that that committee was nearly at the end of its labours, and he hoped at no distant date the machine would be capable of reproducing correctly standard leading screws under the direction of the National Physical Laboratory. That, of course, dealt with another subject, but it was the fact that an experiment had been made on different lines which took in the frictional error to a certain extent of the moving part being cut, and in the examination certain differences had been brought out which at the present time he confessed he was unable to account for; the differences existed, and he hoped they might eventually be able to discover how those differences were caused.

On the question of high-speed steels, Colonel Holden had told him, in answer to a question during a conversation with him that day, that the greatest amount of metal removed by one tool in an hour from oil-hardened steel was 600 lbs., and that he hoped to improve on this performance and get a ton off with two tools. Such a result was by no means impossible.

With reference to the measurement of the weight on the point of the tool, in order to get a common comparison he had taken the cubic inches of the material removed per minute at a given speed, a given feed, and a given depth, and had applied that to the high-speed trials in order to show by calculation, based upon those premises, what sort of pressure was taken by the point of a tool of one of the high-speed cutting steels. Taking the examples given, he found that in the second example of M it was 1,050 lbs. on the point of the tool; in the first of the M's it was 955, while the highest figure

was at F, where 1,580 lbs. on the end of the tool was obtained. He ventured to think that an extension of experiments of that kind might be of great use to machine builders, who were setting out, as he was glad to see some were at present, to evolve machines which would be capable of standing up to the work which the tools, or some of them at any rate, were capable of doing. At present he had broken down some of the machines without breaking the tools.

Mr. H. F. L. OSCUTT thought the Institution was indebted to the author for bringing out the facts contained in the Paper. As Mr. Donaldson said, it was to be hoped it would lead to a development in other shops of further experiments to be carried out on similar lines. He wished, in the first place, to refer to the general importance of investigating the subject, and the necessity for manufacturers to determine upon specific angles, speeds, and feeds by which the greatest product could be obtained from their machines and tools. The author very modestly refrained from bringing out some of those points, and he hoped he would be pardoned if he mentioned one or two very briefly. In the first place, standardizing the tools and definitely fixing the angles would certainly save steel. He thought he had mentioned to the Institution before, that one company had gone into the question of standardizing their angles, and found two tons of useless tool-steel in their works. Every workman had his own kit and his own stock of tools, and a great amount of that steel was done away with; probably it would average 1s. a pound.

Another important point, referring particularly to shop administration, which the author had mentioned, was that standardizing angles and systematizing the grinding of tools assisted materially to maintain order in the shop; he thought order was of great importance in shop administration. Another point was that it made it possible to obtain the maximum product from all the machines by fixing upon the angles, and not allowing the workmen to change them. It saved cost in the actual grinding of the tools, a point to which the President had alluded. A workman who was turning, and who was supposed to be a skilful machine

(Mr. H. F. L. Orcutt.)

operator, ought not to waste his time in sharpening tools; that work should be delegated to a man who did nothing else, because with the aid of the machines now on the market it could be done by comparatively unskilled labour.

In reference to roughing cuts he took occasion to look up the results of some experiments which were made originally by Messrs. William Sellers and Co. who, he believed, were the first to study the matter systematically and thoroughly. They brought out some years ago, as the result of their experiments, a machine especially designed for grinding such tools. He noticed that they mentioned that for roughing cuts a curved edge on the tool was more efficient than a straight edge. He would like to ask the author if he had made any experiments in that direction, because the curve came in as well as the angle. Messrs. Sellers also mentioned that the tool should be arranged so as not to gouge into the work, but rather so that it would have a dragging cut; that also gave greater efficiency. He was sorry the author had not spoken of roughing tools a little more; he seemed to have confined himself principally to finishing work. He thought the roughing tool question was a most important one, for two reasons. The first was that the majority of the hard work of turning tools was the roughing; the finishing was comparatively light work. Another reason was that for a very great deal of the finishing of cylindrical surfaces the lathe disappeared altogether, on account of the increased use of the grinding machine which was now coming in, and the parts prepared for the grinding machine needed mainly to be considered with reference to the roughing tool. Some of the points brought out by the author did not quite agree with Messrs. Sellers' experiments, which were very complete, especially the statement (page 11) that when tools of rapid cutting steel were used there was no doubt that the straight, heavy, round-nosed tool was the best.

Mr. DANIEL ADAMSON said he was very much interested in the subject, on account of some experiments which were being carried out in Manchester at the new Municipal School of Technology under the auspices of their local Association of Engineers; therefore, if he

appeared to criticise the Paper or to ask a number of questions, he hoped the author would understand it was with the idea of eliciting from him further information than was given in the Paper, for which his fellow-members on the committee, and also the tool-steel makers who were helping them in carrying out the experiments by sending tools, would be very grateful.

He would like to ask the author first whether the experiments were confined to lathes. The results given in the Paper appeared to refer entirely to lathes, but possibly in arriving at the deductions given the author might have had other machines in view. One very important omission he noticed, assuming all the experiments referred to work on turning lathes, was that nothing was said of the position of the tool with regard to the centres of the lathe. If that was omitted, or if no notice was taken of it, the information given about angles was, as most of the members would understand, of considerably less value, because the height of the tool in connection with the centres affected the relation of the angles of the tool to the work being cut. The author said (page 7), "even though figures would seem to show that the result should be the same." He could not understand what that meant, unless it was that, although the product of the speed and the area of the cut might by calculation show the same result in the case of a light cut and a heavy cut, the author intended them to understand that a better result was obtained with a heavy cut. There he thought the author was not very clear, because it was certain that if the work or the machine would stand it, more material could be removed by working with a heavy cut at a slow speed.

On the same page (7) the author said that the clearance should be greater as the diameter of the work in the lathe increased. That, he believed, was an error. If the tool was placed in the rest, so that the cutting edge was level with the centres of the lathe, then it was immaterial to the tool what diameter the work was. The work was passing the front of the tool in the vertical direction at right angles to the tool; therefore the clearance was just the same as if the same tool was in use in a planing machine working over a plane surface. If the tool was raised above the centre, as was usual, then the clearance ought to be increased as the work was reduced,

(Mr. Daniel Adamson.)

just the opposite to what was mentioned by the author. Perhaps the author would explain how he arrived at this finding.

The members were asked to compare specimens VI and VII (page 7); in one case the point being rounded off; but later on (page 11) the author asked them to compare No. VI with No. II, saying that the chief difference between the two experiments was the cutting angle of the tools, a difference of 4° . There were, however, other differences between specimens II and VI than the cutting angle. He would also like the author to explain more fully than he had done the meaning in Table 1 (page 10) of "the pressure on top in square inches per lb.," and also "the actual pressure in lbs." On the same page the author mentioned that the deductions possible from investigations in connection with the pressure on the tool under various cuts would be found of great utility; but he (Mr. Adamson) suggested that, for reliable information on the point, heavier cuts ought to have been taken than a $\frac{1}{32}$ -inch feed by $\frac{1}{16}$ -inch cut. Those were particularly small cuts on which to base any calculation as to the amount of pressure that would come on the tool's end, with such cuts as would make the pressure an important amount.

The author also said (page 10) that it was "calculable to compare the power required if a round tool is used." He would like to ask the author to explain how he would advise them to compare the data given for the pointed tool with the round tool, which was in normal use. The author spoke favourably of the round tool; it was therefore unfortunate that he had not given some figures of experiments with round tools. In order to ascertain for himself some idea of the comparison between the tool specified by the author and the round tools in normal use, he (Mr. Adamson) had a tool prepared of the old-fashioned cast-steel—the ordinary water-hardened steel that the author's experiments referred to—in accordance with the particulars (page 9); and the other end of the same tool he had forged into the normal round-nosed shape which was found suitable in their shops. He had the tool run on two forgings, one after the other, with the result that he found the round tool would run twice the length on the same bar, before destroying the cutting edge, than the tool ground to the angles given (page 9) would; from which he

concluded that under those conditions a round tool might be taken to be twice as effective as the pointed tool given in the Tables. He hoped the author would be able to inform them that he had conducted further experiments of the same character which would make that point clearer.

The author mentioned (page 11) that the pointed tool was better for light cuts and fine feeds. That, he believed, was because the pointed tool, however pointed, had a small radius on the point; therefore that small radius when cutting with a light cut was in proportion to the larger radius of the round tool on the heavier cut. The conditions geometrically were similar, supposing one had the small radius on the fine cut and the larger radius on the heavier cut. Further, the pointed tool would not, he suggested, stand with the heavier cuts, while the rounded tool was not suitable for the fine cuts; the ordinary normal rounded tool would not take fine cuts without chattering, the large radius and small depth of cut made the tool act more like a scraper than a tool.

The author said (page 11) that he enumerated only the "best results." In giving the best results he might have given some hint as to the penalty for departing from the angles which gave those "best results," in order that the angles might be appreciated at their true value. Would a slight variation from one angle to another make a serious difference in the "best results," and if so, how much? The author said, "The tests indicate that when working with a high speed of material, a light cut, and a fine feed, different angles are required to those found most suitable for a heavier cut, a slower speed of material, and a coarser feed." The author had only told them that for the harder material more obtuse angles were advisable, but had not given any recommendation as to the amount of variation under these different conditions. In his Table of hardness of different materials (page 12), No. II steel was marked H, and No. V steel was marked HH, which he took to mean that No. V was harder than No. II, but No. II contained twice the amount of carbon on analysis that No. V did, and therefore should be the harder of the two. The manganese in the higher carbon steel was not mentioned; only the carbon was given, therefore the hardness could only be

(Mr. Daniel Adamson.)

judged on the carbon, and according to the carbon the No. II should be harder than the other ; but that might be a clerical error.

It was stated (page 13) " among other good objects, it affords a reasonably sound basis for determining the cutting speeds with which those in authority may be content." Again, he would ask the author, for their guidance in Manchester, how to compare the results named in this Paper with those to be expected from the modern fast cutting steels which were now in use in Lancashire shops. How could they make use of the figures given in the Paper to enable them, as the author suggested, to " determine cutting speeds with which they may be content?" Perhaps he would state his methods of deduction in arriving at that result. A Table showing the " best results " was given (pages 14 and 15). He would like to ask the author how many experiments those " best results " were based upon, in order that some basis might be obtained for judging the value of the results as " best results." Again, were the same tests repeated sufficiently often to ensure that they were the best results, and yet results which could be obtained again under the conditions specified in the Paper? One thing that made him doubtful on that point was the column marked " Lubricant used." If a lubricant was used, it was very important that it should always be applied under the same conditions, and he therefore asked the author to state how the lubricant was applied under the conditions mentioned. Was it pumped on lavishly, or was it dripped on from a can, as was done in the old days? He would also like to ask in regard to the best results whether the cuts were first cuts or finishing cuts. Mr. Orcutt (page 28) had inferred that they were finishing cuts, but it would be advisable to have the point definitely stated. Again, how was it decided that these were " best results ; " according to the statement (page 24), the tools were not run up to the limits of their endurance.

The author referred (page 16) to five varieties of steel, but he did not give much data by means of which it was possible to compare or connect those five varieties with the seven analyses on page 12. He also spoke of four varieties of brass (page 16), and recommended certain speeds (at the foot of the page) for that brass. The speeds

suggested for brass could be increased 50 per cent. with the ordinary tool steels. It seemed to him that Table 4 (page 18) was the most valuable part of the Paper; in fact, the centre round which the whole revolved. The cutting angles for steel agreed with Lancashire shop practice, but with regard to those for cutting yellow metal, he would ask the author to give some analyses of that yellow metal, or something to enable one to connect the *three* varieties of yellow metal (page 18), with the *four* varieties of brass mentioned (page 16), and the *five* varieties of gun-metal (page 12), with their analyses. At present there was nothing in the Paper to connect those various qualities with one another, therefore it was impossible to refer from one part of the Paper to the other with satisfaction. In each case where brass or yellow metal was mentioned, it should be stated whether cast or rolled was meant.

The author mentioned that in cutting hard yellow metal the front clearance should be from 3° to 8° . That, he thought, was an error. A tool for cutting brass must be more approaching a tool for cutting wood, that is, the front clearance must be more like 30° than 3° . The front *cutting* angle appeared to be about correct, so that, if the front *clearance* angle was modified, the cutting tool for brass would be obtained which was used in Lancashire practice, the only practice of which he had knowledge. In Table 5 (pages 20-21) there was nothing to indicate clearly what the material operated upon was. A Table was given showing what certain steels were recommended for, but as neither the steels nor the materials on which the tests were carried out were known, it was not much of a guide. The size of section of tool steel used was not recorded, this was most important. Nor was the subject of the Paper referred to at all, as far as he could see, in that Table; nothing was said about the angles of the tools with which the experiments were carried out; these could easily have been recorded. The comparison between new tool-steels and old tool-steels was considerably over-stated (page 23), the author stating that speeds of work from six to nearly ten times faster could be obtained. Supposing that the old tool-steel cut at 20 feet per minute, which was not a high speed with the old tool-steels, ten times that amount would be 200 feet, an amount which had never

(Mr. Daniel Adamson.)

been obtained with any reasonable cut. That speed was run with a finishing cut of about $\frac{1}{100}$ -inch by $\frac{1}{100}$ -inch; but this was not a cut to be spoken of in testing tool-steels, and again it could be taken at higher speeds than the 20 feet with the old tool-steels. His own opinion, which might be taken for what it was worth, was that with the ordinary mild steels which the Lancashire makers were in the habit of using—they had no experience of the oil-hardened steels used in Woolwich—about four times the weight could be removed under favourable conditions than was done with the old steels. In actual workshop experience that might be modified; for example, machines had been increased in speed two and a quarter times, and then a curious thing happened. Although the machine was running two and a quarter times faster, the man only did about $12\frac{1}{2}$ per cent. more work. The man was told that he was not taking full advantage of the tools and the increased speed offered to him. More expensive tool-steel had been bought for the man, and one would have thought it would have been to his own advantage to increase his output, being on piece-work before and after the change and at same rates; but it was found that if the man was left alone he would do only $12\frac{1}{2}$ per cent. more work, although he was running at two and a quarter times the cutting speed. That was a problem on which another Paper could be written.

In the comparison of cast-iron, about three times the output could be obtained from the new steels.

The tool he exhibited, referred to earlier in these remarks when comparing a pointed tool with a round tool, was cutting forged steel bars containing from 0.25 per cent. to 0.8 per cent. of carbon (which was comparable with the reference No. V, page 12), $\frac{3}{16}$ -inch cut and $\frac{1}{16}$ -inch feed. (He chose this cut and feed because those who were at the Paris Exhibition would remember that the Taylor White tools there shown were being run at the same, and he kept to that figure as a sort of standard with which to compare other tools.) The tool was running on the first cut, that is, removing the skin, at $22\frac{1}{2}$ feet per minute; the diameter of the work was about 9 inches, the pointed tool in one experiment ran $3\frac{1}{2}$ inches along the forging, and on a second similar forging it ran $7\frac{1}{2}$ inches. The round tool forged on

the other end of the tool was hardened and tempered under similar conditions as nearly as possible, and it ran 6 inches against $3\frac{1}{2}$ inches on the first forging, and on the second forging 14 inches against $7\frac{1}{2}$, practically twice as much in each case, and left a better finish. He thought one explanation of having done twice as much on the one forging as on the other, with both of the tool shapes, was that there might be a little difference in the contents or hardness of the two forgings experimented upon.

Mr. J. HARTLEY WICKSTEED, Vice-President, said the Paper, to which he had listened with the very greatest interest, had opened to his imagination long vistas of further enquiry. It seemed to him that the subject was brought before the Institution at a most opportune moment, because at the present time so many manufacturers were removing the tools from under the planing machines and lathe benches and taking them into tool stores. No doubt the man who had been brought up all his life, as an apprentice and as a workman, to the business, and who had just as good brains as the engineer, knew perfectly well how to grind the tool by eye and without any rules to suit the work that he had to do; but if the tool was taken away from him and given to another man to grind, one must of necessity give that man precise directions as to the angle at which the tool must be ground, otherwise it would come back into the user's hands worse than if he had ground it for himself. The apparatus conceived by the author for weighing the pressure on the tool seemed to him to be most admirable; it was direct, easily read, and very fairly sensitive, so far as the author had applied it, but that was only to light cuts. He wished he could be grateful for information to come, as well as for the information already received; he also wished that the author would carry it a great deal beyond the pressure of 160 lbs. or even 200 lbs. He hoped Mr. Donaldson would make an apparatus which would carry the cut up to about 10 tons pressure; because pressure to that amount was very usually provided in large machine tools. Power was given to the belting and gearing which was equal to a pressure upon the tool of 10 tons upon a single cut. He thought that if the author made an

(Mr. J. Hartley Wicksteed.)

apparatus on a large scale for heavy cuts he would benefit by putting the tool into a carrier, and letting the carrier vibrate upon the knife-edge, because then the tool could be securely held in the carrier, and the carrier could not only see-saw upon the knife-edge, but it could also be supported sideways in a line with the knife-edge; whereas if the tool was supported otherwise, one was obliged to go higher than the part which rested upon the knife-edge, and as soon as one went higher than the axis on which the tool vibrated the moment of friction was increased between the side screws, if there was any pressure upon them.

It was stated in the Paper that the side screws were only lightly adjusted. It would not do to have such a light adjustment for heavy cuts, and therefore he thought an apparatus could be made on the same lines which would give equally close results on heavy cuts. He did not think one could infer what the pressure would be on a heavy cut from what it was found to be on a light cut. On a light cut it was very much like cutting, but on a heavy cut it was more like punching, or tearing the metal off. In a heavy cut it might be found that it was not the edge of the tool which had been doing the work at all; after a certain amount of cutting had come off, the face of the tool was found to be quarried, and made rough behind the edge. While the edge remained as smooth as a razor, the part behind the edge had become pitted and made rough, and when that roughness had increased to the extent of producing such an amount of rubbing and friction upon the cutting as to create too much heat, then with the old steels the edge became ruined by the heat of the tool, although for a long time the edge resisted the heat, because it was constantly in contact with the cold metal of the stock which it was touching to clean up.

The author in the Appendix (page 19) had recorded some splendid work on a tool called D. According to his (Mr. Wicksteed's) calculation, about one ton of material had been removed at one setting of the tool. The tool had been working for 8 hours, and 269 lbs. of weight had been removed per hour, so that the one tool at one setting had removed a ton of material in shavings

$\frac{1}{16}$ inch thick, and at the end of that time its condition was still good. That was the class of tool required; endurance was wanted, not short runs. Makers did not want to know how much could be done in 20 minutes; they wanted to know the tool and the speed which would enable them to finish the job, without taking the tool out and without having to re-fix it. There was much more time lost in changing the tools than in running at such a moderate speed as would allow the tool to have the maximum amount of endurance.

There had been so much detailed criticism of the Paper that he would abbreviate any further remarks he had to make. He would, however, just like to ask the author to adapt a somewhat larger instrument to the slide-rest for holding the tool, one which would take off a moderate cut such as had been mentioned, in the case of D about $\frac{1}{16}$ -inch feed and $\frac{1}{4}$ inch deep, and run it at 20 feet per minute, measuring the pressure, and then run it at 80 feet per minute, and again measure the pressure; and then inform them whether they must, in providing for quick cutting, make provision for a greater pressure upon the tool for removing the material quickly than was required for removing it slowly. He did not see why that result should be expected, but he did not think it could be known until the experiment was made. In many cases there was the flow of solids to consider. For instance, if one wanted to punch a nut which was 2 inches deep with a $\frac{3}{8}$ -inch diameter hole, it could be done if the punch was given time, but if one tried to do it quickly the punch would fracture. There were many other cases, where time was an element in the resistance to the flow of solids, but he did not know that they were analogous to a lathe cutting, although there must be some flow of material in a shaving. A shaving which came off a lathe was by no means a strip cut off the material; all the particles were being pushed into fresh positions. It would be an advantage to the trade generally to be informed upon the point, whether, other things being equal, the fact of cutting rapidly put more pressure upon the tool than cutting slowly within the limits of, say, 20 feet and 80 feet per minute.

Dr. H. T. ASHTON said that, as he knew a good deal about the conduct of the experiments mentioned in the Paper, he might say

(Dr. H. T. Ashton.)

that amongst them one of the good results obtained was with a side-cutting tool, a knife tool, in which the angle was such as almost to draw the tool along the bed of the lathe by the dragging action which had been mentioned; a great amount of metal was removed by that means. In regard to the criticism of the second paragraph on page 19, he thought it was evident from the context that what was meant was to compare one rapid-cutting tool-steel with another. The statement that the rapid-cutting tool-steel which was best for cutting mild material was by no means certainly the best for cutting very hard material seemed to him to be reasonable, because some rapid-cutting tool-steels resisted heat very much better than others, while not being necessarily so hard, and there was a much greater amount of heat involved in cutting a large amount of metal off a mild steel than there was in cutting a less amount of metal off a harder steel. In cutting very hard steels a very hard rapid-cutting steel was required, but not necessarily one which kept its temper at such a high temperature.

In regard to the question of gun-metals, he did not think the yellow metals of the Paper could be very well compared with the ordinary commercial yellow metals, because, for the most part, those used were very much harder than the trade brass, and, as he thought the author had pointed out, the experiments were not carried out specially to provide the information which was laid out in the Paper. He thought it was also fairly clear that the experiments detailed in the Paper were all carried out on lathes. From his own information he might supplement the knowledge given therein by saying that the tools were all on the centre of the work. Except as regards the position in which the shafting of the tool was held, provided they accommodated the angles accordingly, it was practically the same thing whether one placed the point of the tool slightly above or slightly below the centre. The same result could be obtained with the tool above or below centre, if the clearance angle and the top angle of the tool were both adjusted.

In regard to Mr. Adamson's query as to the diameter of the work affecting the clearance angle, he thought the statement in the Paper was literally correct, because one wanted to have as little rubbing

surface of the tool and work in compression in contact below the cutting edge as possible. With a small radius of curvature the surface of the work was less in contact with the tool than with the large radius, that is to say, that it could stand a flatter and squarer angle.

A cutting tool was a sort of compromise. It had to do two things, first of all it had to part the material, for which purpose a razor edge would be best, but a razor edge could not be used on steel because the shaving had to be bent at right angles, and the razor edge would be broken away in the process of the bending. If the razor edge was being used, the line of sheer of the material being cut would be radial; on the other hand, if the tool was absolutely square the line of sheer would be tangential; but in an actual cutting-tool there was a compromise between the two, which first of all parted the material and then bent the shaving over. It was in the bending over of the shaving that a large part of the work was done, as was pointed out by a previous speaker. It was no doubt owing to the greater pressure required to bend over the heavy shavings removed by the rapid-cutting tools, that these tools were found in the experiments to work better with a more obtuse cutting angle than that used with ordinary tools working the same material. In regard to the apparatus used for measuring the pressure on the tool, it was a very difficult matter to design any apparatus which would at once efficiently hold the tool and accurately register the pressure on the tool, because a very little movement would spoil the work of the tool. With regard to the apparatus the author had mentioned in his remarks after the Paper was read, he thought perhaps it might make it a little clearer to the members if he stated that that apparatus measured directly, by means of a lever attached to the work, the torsional effort of the face plate of the lathe in turning the work round against the resistance of the tool, thus measuring not only the vertical pressure on the tool, but also the work of bending the shaving round.

Lieut.-Colonel R. E. CROMPTON, C.B., after thanking the author for his Paper, referred to the horizontal angle of the tool as shown

(Lieut.-Colonel R. E. Crompton, C.B.)

on Fig. 3 to be 30° . Here YY was the centre line of the tool viewed in plan. In the Paper nothing was said as to the advantage of increasing or reducing this angle, and he was anxious to hear what the author or other speakers might have to say on this point. It was clear that, as the tool was advanced in the direction of the arrow, the shavings cut from the work by the tool must have a rhomboidal cross-section as shown at C. It appeared to him that the horizontal angle of the tool determined the shape of this section, as, if the horizontal angle was small, the shaving was broad and thin. The question of this angle appeared to be closely connected with that of rounding the nose of the tool, and the question was one

FIG. 3.—Horizontal Angle of Lathe-Tool.

which had never been properly explained, and ought now to be looked into. He offered the suggestion that the advantages of a small angle and of rounding the nose of the tool, either taken together or combined, had the effect of making it easier to get rid of the heat, by spreading over a greater surface the scouring action of the shaving in impinging at a high speed on the top of the tool at a point somewhat behind the cutting edge, and to which Mr. Wicksteed had already called attention. The rounding action would have the effect of making the cross-section take the form D, and it would be seen that the length of the line $d d^1$ was considerably greater than the line $c c^1$. He hazarded this explanation, and would be glad of others' opinion on the point. Personally he had taken great interest

in the cutting angles on machine-ground tools, but he found that the results obtained a few years ago had now to be greatly modified, owing to the advent of high-speed steel. In his own shops two distinct ideas were prevalent. In one shop the stiff straight tool recommended by the author was used, and in the other shop tools forged with a bend, and which were condemned by the author, were used. He believed that many tool foremen would disagree with the author in his condemnation of the bent forged tool.

Turning to another point, he had to thank Mr. Wicksteed for throwing light on a matter which had hitherto been a puzzle to him, that was, it had always been stated that, to get the full advantage from rapid-cutting steel, heavy stiff lathes ought to be used. This appeared to nullify the chief advantage which rapid-cutting steel offered to them, namely to increase the output by increasing the surface over which the cutting point ran in a given time. There was however a second reason, additional to that given by Mr. Wicksteed, why increased speed demanded heavier and stiffer lathes. This was in the case where the material to be removed was from steel castings. At high speeds the shocks due to irregularities in the castings would be considerably increased, and the tendency for all the supports to the cutting point to yield under the action of these shocks would be increased. For this reason only, it would be necessary to use heavier and stiffer lathes when high speeds were used on steel castings.

Mr. ROBERT DUMAS said he did not think the author, in giving the angles of the cutting tools in the Paper, had quite completely defined the tool, because it was clear that with a pointed tool, such as was dealt with in the Paper, the angle on the section line YY, Fig. 1 (page 8) was or might be dependent on the angle to which the non-active edge of the tool KB, Fig. 4 (page 42), was ground.

The diagrams of the tool (page 8) were reproduced in Fig. 4 (page 42), and lettered for reference. If the side clearance on face AK were uniform, the bottom edge of the tool would be shown by a dotted line parallel to the top edge AK, cutting the line YY at the point D. If the face BK was vertical, or if it was ground at

(Mr. Robert Dumas.)

any angle which was less than the side clearance angle, a constant angle of front clearance would always be obtained, which would be greater in amount than the side clearance. If the face BK were ground at a greater angle than the side clearance, it was evident that the front clearance was determined by the angle of clearance on the face BK rather than the angle of clearance on the face AK; so that, in order to define completely the grinding of the tool, some information was necessary about face BK, as well as about face AK. It was evident that if FG (*see* section on XX) was a straight line

FIG. 4.—*Cutting and Clearance Angles of Tools.*
(See also Fig. 1, page 8.)

corresponding with LO in the plan of the tool, then the angle RST (*see* section on YY) must always be greater than the angle NFG, because the point O on the top face of the tool was farther away from K than L.

Referring to Table 3 (pages 14–15): in the case of tool No. II, the front clearance and the side clearance were both given as being 3° , whereas the front cutting angle was 59° and the side cutting angle $62\frac{1}{2}^\circ$. That seemed to him an impossible set of conditions. Either the angles had been incorrectly measured, or the nose of the tool had been rounded to such an extent that the distance OK was

less than OL, though even in that case a very curious form for the top face of the tool would be necessary to get the angles given in the Table.

He would like to make a few remarks upon the horizontal angle referred to by Colonel Crompton (page 40). He was considerably surprised to see the smallness of that angle as given in Table 3 (page 14). He had always found that, with a small horizontal angle, a considerable amount of power was taken in removing the material. There was one reason for that which was fairly clear, namely, that the material was being cut up into thinner strips, and the smaller the horizontal angle was made the thinner these strips became; and under such conditions it seemed to him that more power must be taken to remove a given bulk of material, for the same reason that a milling machine required much more power than a lathe removing the same amount of material by heavy cuts.

As an illustration of the importance of the horizontal angle being large, he might mention that recently, when starting up a new boring machine, it was found impossible to keep the belt on the pulleys, the belt not being sufficiently powerful to drive it. Upon investigation, it was found that the horizontal angle was about 45° ; the tools were replaced by others having a horizontal angle of about 90° , with the result that there was an ample margin of power to drive the machine on the same cut, the strain on the machine being very greatly reduced. He thought there ought to be two or three shapes of tools kept in the tool store for roughing work, in order to get the maximum results. The shape of the tool, as had been pointed out by several speakers, ought to depend on the depth of cut and on the feed. He had drawn three shapes, Fig. 5 (page 44), of which shape (a) was suitable for fair-sized feeds and deep cuts, shape (b) was suitable for medium feeds and medium depth of cut, and shape (c) for very heavy feeds and a small depth of cut; shapes (b) and (c) were in fact transition stages between (a) and the square nosed tool used for scraping cuts at heavy feeds. By using a tool which was really proportioned to the character of the feed and cut employed, it was quite surprising how much the output could be increased. The radius of the nose of the tool should not be less than the feed employed, and it was preferable

(Mr. Robert Dumas.)

if it was slightly more. For general purposes he had found tool of shape (a) best, the angle being 90° or thereabouts. If the radius at the nose of the tool was varied with the feed, very heavy feeds and deep cuts could be successfully dealt with. This shape of tool had the additional advantage that it could be readily forged in a die, and it also lent itself to machine grinding. He was of opinion that, as far as consumption of power was concerned at the cutting tool itself,

FIG. 5.—*Shapes of Roughing Tools.*

the most economical method was to have the radius of the nose of the tool, the depth of cut, and the feed all equal. The best results commercially might, however, be very different.

Mr. DONALDSON, in reply, said he had hoped he had made his position fairly clear when he said in the Paper (page 5) that the experiments detailed were not detailed as experiments upon that particular line, but were taken as applicable for use as a groundwork

from which to start others in investigations. He had all along insisted that there was no finality about the experiments, and it was that want of finality which made him hesitate very much in writing the Paper at all. At the same time he could not but congratulate himself upon the result, in that the discussion had been most useful, which was his object in acceding to the request made to him to write the Paper.

Mr. Orcutt (page 28) referred to the question of whether the cuts mentioned were roughing cuts or finishing cuts. As a matter of fact they were both; most, if not all, of them were roughing cuts, though some of them might be classed as finishing cuts, and he did not think he could say at the moment which was which. At the same time, one important point must not be overlooked, namely, that the experiments, as carried out, were made upon materials in general use, and in many cases the material was such that a heavy cut was an impossibility, and was often so hard that light cuts were essential. For heavy work the round tool had most distinct advantages in the amount of metal which could be taken off. With regard to Mr. Adamson's enquiries, he feared he had missed some of the particular points upon which that gentleman desired information. He could only say that, if he could afford Mr. Adamson and his society information or assistance in the experiments in which he was now embarked, he hoped his services would be commanded; he would be only too happy to show him all the details of the experiments, for what they were worth. They were perhaps not experiments such as he would want, but might be found useful merely as indications.

A question had been asked with reference to the height of the tool above the centre. Practically in all cases the cutting point of the tool was level with the centre. Mr. Adamson had referred to the paragraph (page 7), "A heavy cut and slow speed will be more efficient in production than a light cut and quick speed." Mr. Adamson's idea of what he meant by those words was correct, that if the result was shown to be the same in figures, it did not necessarily follow that the one method would not in fact do more work than the other. At the bottom of the same page, reference had been made

(Mr. Donaldson.)

to the fact that the experiments were all made with pointed roughing tools, though in some cases, notably in specimens VI and VII, the point was somewhat rounded off, and upon that a criticism was based that the circumstances and conditions were not the same. He ventured to think they were sufficiently alike, taking the roundness of the pointed tool and the area of the rounded tool, to be able to obtain to a certain extent, he did not say accurately, some sort of comparison; and as the experiments were not made for comparisons in the way they had been used in the Paper, he thought they must take what they could get in the matter of comparison. Mr. Adamson referred to the lubrication, and asked how it had been applied. So far as his recollection served him, in all cases it was simply dropped on, with a moistening, without such cooling effect as would be done with a pump.

With regard to the question of brass and yellow metal, he was afraid that he must plead guilty to the wording leaving something to be desired. As a matter of fact, what was referred to (page 16) as B.S., B.F.H., and B.F.S., and called Brass Soft, Brass Forged Hard, and Brass Forged Soft, were really the identical metals referred to as yellow metals in the G.M. hard alloy, and so forth. He apologised for calling them brass when they were perhaps something better. Mr. Adamson also referred to the clearance at 3° . He thought that perhaps it depended on which side of the tool the measurement was taken. He had been accustomed to measure it the reverse way to that in which he measured the front cutting angle, and perhaps that accounted for the discrepancy.

Mr. ADAMSON said that that was only for brass work.

Mr. DONALDSON said the brass was hard alloy; he hoped he had made it perfectly clear. What was called brass on page 16 was the same sort of metal as was shown in the Table of analyses (page 12).

Mr. ADAMSON said the point he wished to make clear was that the front clearance for cutting brass ought to be greater than that for the steel.

Mr. DONALDSON said that Mr. Adamson had criticised the speed mentioned (page 23). The use of the words "speeds of work" there were not intended to convey the speed of the travel of the tool, but the speed at which the material was removed, and that he thought was clearly shown as ten times, as he had stated.

He was extremely obliged to Mr. Wicksteed for his suggestion in regard to carrying the tool-holder. Should it be advisable or possible to extend the experiments, of which at the present time he was afraid he did not see much possibility, he would be very pleased indeed to consider that particular suggestion. He was rather inclined to ask Mr. Wicksteed how he measured the 10 tons on the point of the tool of which he had spoken. Was it done electrically, or how?

Mr. WICKSTEED said it was a common thing to allow 150 feet of 4-inch belt to a foot of cut; and if one took the pull of a 4-inch belt as being 2 cwt., and multiplied it by 150 the figure of 10 tons he had mentioned was obtained.

Mr. DONALDSON said it came back to very much the same thing as if it was driven electrically, but there was a long distance in the travel of the power between the belt and the point of the tool.

Mr. WICKSTEED said the figures he had mentioned multiplied to 15 tons.

Mr. DONALDSON said that with reference to the remark about the increase of power if the speed was increased, he was unable to refer at that moment to any experiments, but he believed that if the speed was increased the necessary power of driving was also increased. Colonel Crompton's remark (page 40) on round-nosed tools had been partly dealt with by what Mr. Dumas had subsequently said. In the tool mentioned a longer cutting edge was obtained and the work was distributed over a better supported background. For heavy cuts he thought there was no doubt that the round-nosed tool was the best,

(Mr. Donaldson.)

of course for roughing cuts. As to Mr. Dumas's point in reference to the angle, he was sorry that a gentleman who had intended to be present was not able to do so, because he was in hopes that that gentleman would have described an angle which he had worked out some years ago for boring holes, where the angle so suited the machine, the feed, and the material worked upon that, having started the cut, he was practically able to throw off his feed, to keep the machine running and to have the boring bit feeding itself.

The PRESIDENT thought the members would all share his feeling, when he said he was extremely glad the author did not allow his views as to the want of finality of his Paper to prevent him from bringing it before the Institution. The Paper had elicited a most interesting discussion, and the members were extremely grateful to Mr. Donaldson for all the trouble he had taken.

Communication.

Professor ROBERT H. SMITH wrote that the cutting forces exerted by lathe tool-points had been measured in various series of investigations at various times since 1880, by an apparatus devised by him in that year. In the 1880 series, measurements had been taken under 240 different conditions. These were arranged systematically to show the effects (1) of kind of material cut, (2) of diameter of work cut, (3) of cutting speed, (4) of depth of cut, and (5) of breadth of traverse-feed. In each material all the combinations of four cutting-speeds, four depths of cut, and four traverse-feeds were tested. The effects of variations (1), (4), and (5) were shown clearly in the six diagrams of Figs. 6 and 7 (pages 50-51), which were borrowed from his book on "Cutting Tools," the first edition of which was published by Messrs. Cassell and Co. in 1882. The cutting speeds then experimented on were from 14 to $2\frac{1}{2}$ feet per minute on cast-iron; $9\frac{1}{2}$ to $1\frac{1}{2}$ on wrought (forged) bar; and 6 to 1.3 on forged bar steel. Slightly greater cutting force was needed for the higher speeds, but

the increase was unimportant. Largely different diameters of work were used only in the cast-iron series ; namely, $16\frac{1}{2}$, 7, and $3\frac{1}{2}$ inches. The change in the diameter made but small difference in the cutting force. The steel and wrought-iron bars used were $2\frac{1}{2}$ inches in diameter.

The forces measured on the cutting-tool point ran up to 920 lbs. These were the vertical components of the whole pressure upon the cutting-point. This component alone was the active working force. The two other components, which did not contribute to the horsepower required for the work, were not measured. The amount of possible error in the measurements was determined, the character of the apparatus making this determination easy and accurate. It varied from 1 per cent. on 200 lbs. to $\frac{1}{2}$ per cent. on 600-900 lbs. The ratio of the cutting forces for different metals varied greatly with the thickness of the shaving. Thus wrought-iron took about 50 per cent. more than cast-iron for $\frac{1}{10}$ -inch depth of cut, but for half that depth it took only some 12 per cent. more, while for broad very thin finishing cuts cast-iron took more force to cut it than did wrought-iron. At the greater depth steel took 45 per cent. more than wrought-iron, and at the smaller depth over 100 per cent. more.

In considering these variations, it should be remembered that in most roughing work the traverse-feed was more nearly the thickness of the shaving in the direction in which it was forced to bend than was the "depth of cut." This latter was really the bending "breadth" of the shaving, or was at least proportional to this breadth. The force required to bend the shaving, and break it by bending, must be nearly proportionate to the breadth, and might be expected to be more nearly proportionate to the square of the thickness. But the force needed for this part of the cutting action was by no means the whole. Shear or semi-shear occurred at regular small spacings, and the work spent on this shear was probably proportionate to the first powers of both thickness and width.

These results for what might be termed small work had been confirmed by many subsequent repetitions of a less systematic

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(Professor Robert H. Smith.)

FIG. 6.

*Cutting Forces exerted by Lathe Tool-points
measured by the apparatus shown in Fig. 8 (page 54).*

Steel.

Transverse Breadth of Cut or Feed in fractions of an inch.

Cast-Iron.

Wrought-Iron.

FIG. 7.

Steel.

FIG. 7 (continued).

*Cutting Forces exerted by Lathe Tool-points
measured by the apparatus shown in Fig. 8 (page 54).*

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character, carried out by the writer's college students. They had the advantage of a still better-made measuring apparatus, but their cutting tools were worse. In 1893 he had the good fortune to be allowed to make measurements on very heavy cuts in tearing down a steel ingot in the Sheffield works of Messrs. Jessop and Co. The design of the measuring apparatus was essentially the same as for small work; but, the tool being a solid bar 3 inches square, it assumed much larger proportions. In these tests the depth of cut went up to $1\frac{1}{2}$ inches with $\frac{3}{8}$ -inch traverse-feed, and the cutting-pressure on the tool point went above 10 tons. In measuring the 10 tons, he ascertained that there was not so much as 2 cwts. error. The tool had three straight-edges with corners rounded to about $\frac{3}{8}$ -inch radius, and with top surface level (that is, zero top-rake) and with ample bottom clearance—some 7° or 8° . This shape of tool was used for other reasons than that it was the best for diminishing the cutting horse-power required; it had not a long life under these very heavy cutting strains. He felt sure that a much longer life could be given to it, if the tool-box were differently designed. The strength of the tool and the expense of renewing its cutting-edge were here evidently considerations of paramount importance.

In trials preliminary to the 1880 series of tests, different forms of tool were tried, all of them round nosed, this being known to be the best for getting the metal cut away in quantity, and it was only for this kind of work that enquiry into the forces at action were of practical interest. The rake was practically all side rake, and amounted to 24° for cutting cast-iron and $46\frac{1}{2}^\circ$ for steel and wrought-iron. These were top-rakes and left the two cutting angles 62° and 41° . These cutting angles were much smaller than could be habitually used in ordinary workshop practice. Comparatively few workmen could use such tools without frequent breakages, and still fewer could temper them so as not to have the edges softened after very little work. The tools in question lasted admirably, but they were prepared by a specially clever tool-maker. The smaller the cutting-angle of the tool-edge the smaller was the horse-power required for cutting; but the angle actually required depended upon the necessity of avoiding (1) too frequent breakage, and (2)

overheating and consequent loss of temper in the edges. Thus the limit of smallness of the cutting-angle which was practically useful resulted from (a), the mechanical strength of the tool due to its form and to the quality, especially to the toughness, of the steel, and (b) the tempering quality of the steel. It seemed to the writer that the merit of the new fast-cutting tool-steels, upon which he had had no opportunity of experimenting, mainly depended upon their peculiar power of standing much heating without losing temper. Providing quality of steel was producible that would permit the reduction of the cutting-edge angle with ordinary handling and a reasonably long life, it seemed certain that such reduction of the cutting-angle resulted in decrease of the horse-power needed for driving. It must also not be forgotten that success in this direction accumulated in a sort of geometric or compound ratio; because a reduction of cutting-angle, by diminishing the work to be done, at the same time decreased the amount of heat generated per second at the tool point. In the above experiments no lubricant or cooling water was used, and yet the 41° cutting-edge did two days' almost constant cutting work without regrinding, and was in good condition at the end of it.

It was well known that with a large amount of top-rake there was risk of "digging in." If the depth of cut were small, the work would push the tool outwards from the centre, a push which the tool-clamp must resist. If the cut were deep, it would draw the tool in towards the centre, to prevent which the tool-clamp must exert an outward pull. For each top-rake and for each quality of material cut—perhaps varying slightly with the cutting speed—there was one definite depth of cut, to maintain which steadily the tool-clamp needed to exert no radial force whatever. Similarly with the traverse-feed. He had known turners able to adjust things so that the transverse pressure of the shaving upon the tool-point in the direction of traverse-feed was just able to draw the slide-rest along the bed, giving a steady feed without assistance from either hand or automatic feed-gear. It seemed that this was the ideally perfect condition of things, and that it gave the correct relation between depth of cut and top-rake angle. If so, it suggested the quickest

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and most accurate method of investigating this correct relation ; because it was evidently much easier to discover the depth of cut and amount of traverse-feed that would, with a tool of given angle cutting a given quality of material, produce this result than to proceed conversely to find the cutting-angle that would produce the same result for a given depth of cut in given material.

In Table 3 (pages 14-15) the angles, &c., were given which gave the "best results," but nowhere was it explained by what criteria the

FIG. 8.
*Lathe-tool Cutting-Pressure Measuring Apparatus
as at present used in King's College.*

"best" results were judged. There were so many things desirable and to be aimed at, and what was deemed "best" was so invariably a compromise between losses and gains, that, without the criteria applied being communicated, no criticism was possible, and the given results lost much of their probable value.

In the measuring apparatus used by the writer, the form of which was illustrated in Fig. 8, the tool-bar or tool-holder was supported on a knife-edge as far forward as possible, and behind this its top and bottom surfaces were carefully trued up

parallel by scraping. It lay in a special housing, whose top and bottom inside surfaces were similarly trued up parallel, the depth between them being about $\frac{3}{8}$ or $\frac{1}{2}$ inch greater than the thickness of the tool-bar. The upper and lower spaces between bar and housing were filled up by two hard-steel parallel strips, scraped true and smooth. When both were inserted, both could be moved easily when no upward or downward pressure came upon them, the weight of the tool-bar itself being exactly balanced by an adjustable spring sling arranged above the extension of the bar beyond the outside of the tool-box. These feeling-pieces filled up the tool-housing so completely and perfectly that they allowed no chatter in the tool. In the heavy-cut experiments at Sheffield a slight chatter became sometimes perceptible when the tool-pressure went above about 6 tons. Between 9 and 10 tons it once or twice became threatening, so that the turner withdrew the tool from the cut. When the hinder end of the tool-bar was lifted, the upper feeling-piece became quite tight, and could not be moved by the fingers, while the lower one could be moved with perceptibly greater ease than in the neutral position. Conversely, when the hinder end of the bar was depressed, the upper feeling-strip felt loose and the lower one could not be shifted. The tool-bar was extended outwards in the form of a scale-beam, and this was loaded so as to balance the working pressure on the tool-point. When the balance was perfect, both upper and lower feeling-strips could be moved to and fro by the fingers, and it was easy to detect any slight difference between the resistances to such shifting offered by the two. The balancing load was read from the scale on the beam and the weights in the scale-pan. As already mentioned, this arrangement provided very sensitive means of judging when the balance was correct, and moreover it avoided the introduction of any chattering, which in his opinion would almost destroy the value of any measurement, and maintained perfectly steady and quiet cutting. The special tool-housing was held in place by the ordinary studs of the tool-rest.

In the Paper, the author apparently admitted that the friction of the bearing points at the back end of his tool-bar prevented the free bearing of the bar upon his measuring piston with oil-abutment.

(Professor Robert H. Smith.)

Apparently his tool-bar, Plate 1, had a visible clearance between the upper and lower stops B and C, and he screws down his oil-plunger D until the tool-bar was visibly out of contact with both B and C. Seeing that D had a very appreciably elastic abutment, he failed to see how more or less violent chattering could be avoided, especially at the higher speeds. According to his own experience, the tool-holder must bear both top and bottom against sensibly inelastic and rigid abutments, in order to prevent chattering.

Fig. 2. Method of measuring the Cutting Resistance.