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THE FELLOWS MACHINE AND CUTTER FOR GENERATING GEAR-TEETH.

[*Being the Report of the Franklin Institute, through its Committee on Science and the Arts, investigating the invention of E. R. Fellows. Sub-Committee.—Wilfred Lewis, Tinius Olsen. Arthur M. Greene, Jr.*]

HALL OF THE FRANKLIN INSTITUTE,
[No. 2025.] PHILADELPHIA, March 1, 1899.

The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, acting through its Committee on Science and the Arts, investigating the merits of Fellows' Machine and Cutter for Generating Gear Teeth, reports as follows:

The Fellows gear-shaper is a machine designed to generate a complete set of interchangeable gears from a single cutter, which is in form similar to one of the gears produced. It consists essentially of a frame or housing adapted to carry the gear blank and the cutter slide in proper relation to each other and connecting mechanism whereby the gear blank and the cutter are caused to roll together on

their pitch lines while the latter reciprocates like a shaping tool and cuts away the material presented to it in the wheel blank.

The gear-shaping machine is the subject of U. S. patent, No. 579,708, dated March 30, 1897, and the cutter and cutter-head thereof are covered by another patent of even date, No. 579,570. As shown and described in the former patent, the gear-shaper differs somewhat in its details of construction from the latest designs, an example of which was examined by the chairman of this sub-committee at the works of W. D. Forbes & Co., Hoboken, N. J., and in its present approved form an idea of the machine can be had from the illustrations shown in the *American Machinist* for December 7, 1897, and in the *Iron Age* for June 2, 1898, as well as from photographs accompanying the inventor's application and engravings published herewith.

The most novel feature of the machine, and that upon which its successful operation chiefly depends, is the cutter. This is essentially one of the gears in the set to be cut, modified as required to adapt it for use as a cutter. These modifications include a certain lengthening of the addendum to provide root clearance in the wheel cut, top rake on the cutter faces and clearance angles on the cutter sides to facilitate the cutting process. Provision is also made for the continued use of the cutter by grinding, after it has become dull in service. It will readily be seen that a cutter thus formed and mounted can be made to produce tooth forms in a wheel blank rolled against it, which will engage the cutter pinion in proper rolling contact, and it may follow as a consequence that wheels which roll properly with the same pinion on the same pitch line will roll properly together. This general proposition must, however, be guarded by two considerations; first, the form of the cutting tooth must be a true odontic, capable of generating a rack with equal congruent branches, and, further, the shaping edge of the cutter must be sufficiently extended to form the actual working face on all the engaging wheels. The principle that one tooth form can be described from another in a mating wheel has been known for half a century at least,

and the process is clearly described in Willis' "Principles of Mechanism," edition of 1850; but it was not until November 16, 1881, that a practical suggestion of the application of this principle in a machine for cutting gear teeth was made. At that time Mr. Hugo Bilgram read a paper before the Franklin Institute entitled "A New Odontograph," in which he suggested for the first time the employment of a rack cutter in a shaping machine for the production of gear teeth in a wheel blank rolled against it.

Previous to this, in 1856, a somewhat similar idea had been advanced in England for the use of a hob in cutting spur gears, but the practical difficulties encountered must have discouraged the pioneers in this field, for, since then, the original idea of a machine for this purpose has been pursued with so little diligence as to have been repeatedly re-invented and re-patented in this country and abroad, and the process still seems to languish without evidence of commercial success. The hob generator differs, however, from the suggestion of Mr. Bilgram, in requiring the use of an expensive cutter with many teeth difficult to maintain in proper shape and working condition, whereas the Bilgram machine contemplated a cutter of the simplest form most easily reproduced. Notwithstanding the fact that the possibility of a practical machine for generating spur gears by means of a rack cutter was thus set forth about eighteen years ago, very little progress in this field appears to have been made since 1885, when a machine of this character was developed and patented by Ambrose Swasey. Here the cutters and gear blank moved together tangentially, and the effect of a continuous rack was obtained by shifting the cutters back to their original position during their return movement. A continuous cutting action was thus obtained, but at some disadvantage in effective construction. Mr. Fellows has extended the idea of a rack cutter to embrace a pinion cutter, thereby permitting a continuous rolling action between the cutter and the gear blank, and the use of the same cutting teeth repeatedly in the production of a gear wheel. The pinion cutter is also applicable to internal gears which are obviously beyond the scope of a rack cut-

ter, and, as an original conception of a practical machine having a large range of usefulness, the Fellows gear-shaper is clearly an invention of unusual promise; but a closer study of the cutter and the machine in general should be made before a definite conclusion upon their merits and possible defects can be reached.

The cutters presented for consideration are of two kinds, one of which appears in patent No. 579,708, as used on the machine there described in a position inclined to the face of the blank for giving the necessary clearance. As the cutter bar advances upon the wheel blank the slide upon which it is carried is made to recede a proportionate amount so that the resultant movement of the cutting edges is vertical. Here the cutting teeth are formed upon a cylinder, and may be ground after hardening to perfect involute form, and the cutting edges may be renewed, as required, by grinding their end faces without causing any change in their form or pitch diameter. The inclination of the cutter is so slight that its effect in distorting the effective shape of the cutting edges may be neglected as inappreciable, and in this form it is believed that the theoretical requirements for a renewable cutter have been practically solved. But the compound movement of the slide and saddle introduces more wearing surfaces to be maintained and more sliding joints to contribute their share of imperfection in the work, and in actual practice this feature has been abandoned in favor of a cutter with ground clearances mounted in a saddle which remains fixed after the proper depth of cut has been attained.

This cutter is described in patent No. 579,570, as "formed as a bevel-gear," the necessary side clearance being obtained by backing off about half a degree on a side. This method of obtaining clearance in the cutter implies a change of shape as the cutting edge is renewed by grinding, and this could not be accepted as meeting theoretical or perhaps even practical requirements, but from the method of grinding the cutters to proper shape, as illustrated and described in the *American Machinist*, referred to, it is believed that the sides of the teeth in the cutter

are really right and left hand spirals of very long pitch, and that they cannot properly be considered as resembling bevel-gear teeth at all. This view of the matter leaves nothing but clearances to be affected by sharpening, and grinding on the face of the cutter can evidently proceed without detriment to the wheels produced until the clearances originally provided are exhausted. The cutter, as thus made, cannot maintain, after grinding, absolutely the same tooth profiles as the cutter first mentioned and described in the patent, but the tooth forms are nevertheless just as true, and differ only in the non-essential element of clearance. Having thus provided clearance on the cutter teeth, it became possible to dispense with the compound slide originally intended for the same purpose, and a decided improvement in the actuating mechanism was thus brought about, giving the whole machine the appearance of greater simplicity, durability and effectiveness in its operation. This cutter combines the advantages of being ground easily and truly to perfect form, after hardening, by special mechanism used in its manufacture, and of afterwards being sharpened by grinding on its face only in an ordinary lathe, and these practical considerations cannot fail to win for it general favor, which it well deserves.

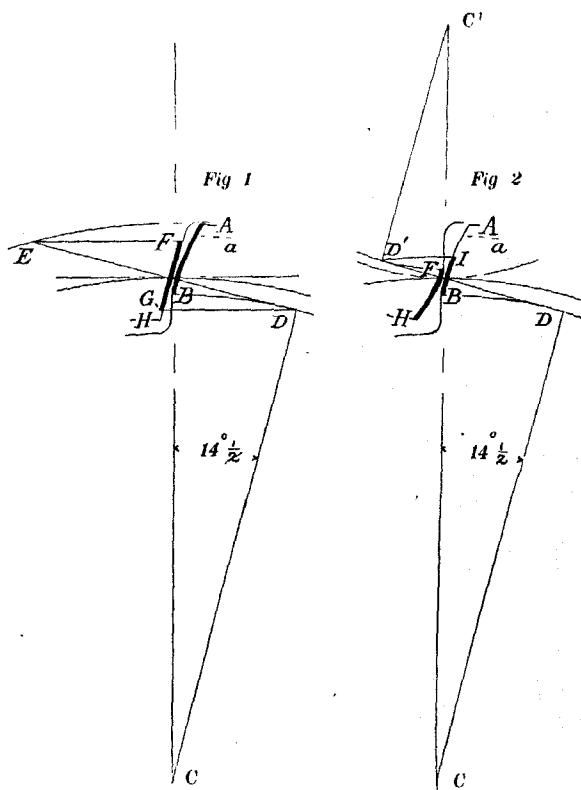
But, before stamping it with the seal of unqualified approval, some examination should be made with reference to its scope and limitations. The principles used in its construction may certainly be applied to an involute cutter having any number of teeth and any degree of obliquity, but attention should first be directed to the cutters actually made and put upon the market. These have twenty-four teeth and they are understood to be made for the production of involute gears in accordance with the Brown and Sharpe standard, $14\frac{1}{2}^\circ$ obliquity. Here the addendum is $\cdot 3183$ pitch, and the question arises whether this cutter of twenty-four teeth and $14\frac{1}{2}^\circ$ obliquity will produce in the Fellows gear-shaper a perfect system of interchangeable gears from a twelve-toothed pinion to a rack; or, only a set of gears approximately correct, which may be run together without practical difficulty. It might at first be supposed that a

cutter generated from a rack by grinding would reproduce the same rack as a rolling cutter, but this does not necessarily follow, as will appear by reference to *Fig. 1*. Here the involute face of the cutter is shown by a heavy curved line BA , from the base circle BD to the addendum circle AE . That portion of the face between the base and root circles may be a straight line terminating in a fillet, or it may be undercut by the corner of the grinding wheel, depending upon how far the rolling of the cutter is continued while grinding; but it does not constitute a part of the true cutting edge of the cutter, and can only be regarded as an undeveloped or clearance edge on the cutter. The involute edge of the cutter acts along the line of action, DE , and generates within this line, the face, GF , on the rack. Between F and the root line there will be a clearance curve, and between G and H the point of the rack tooth will be more or less rounded. If the undeveloped edge of the cutter be left radial, the end of the rack tooth GH will be cycloidal in form, but if this edge be undercut, an important part of the face, BA , near the base circle, will be cut away, reducing the length of the true path of contact. It is not, therefore, possible to reproduce a perfect rack by means of the cutter in question, although it can be itself produced by a rack with equal congruent branches, but it is not denied that the differences pointed out cannot easily be observed in practice. As the number of teeth in the wheel cut is reduced, the rounded end, GH , grows shorter and finally disappears in wheels of thirty-five teeth and under. But another difficulty soon begins to appear in cutting pinions, and this will be understood by reference to *Fig. 2*. The end of the cutter, IA , which, on wheels of thirty-two teeth and over, forms part of the working face, now becomes engaged in cutting clearance below the base circle, and in the case of a twelve-toothed pinion, as shown in *Fig. 2*, the path of contact and the true working faces are very much reduced. The end A of the cutter also cuts away part of the face FH previously formed near the pitch line, and still further reduces the path of contact.

The larger the number of teeth in the cutter, the greater

will be the clearance swept out by the point *A*, and some interference might therefore be anticipated between pinions and large gears; but this danger of insufficient clearance is avoided almost perfectly by the extra addendum on the cutter, which provides root clearance at the same time.

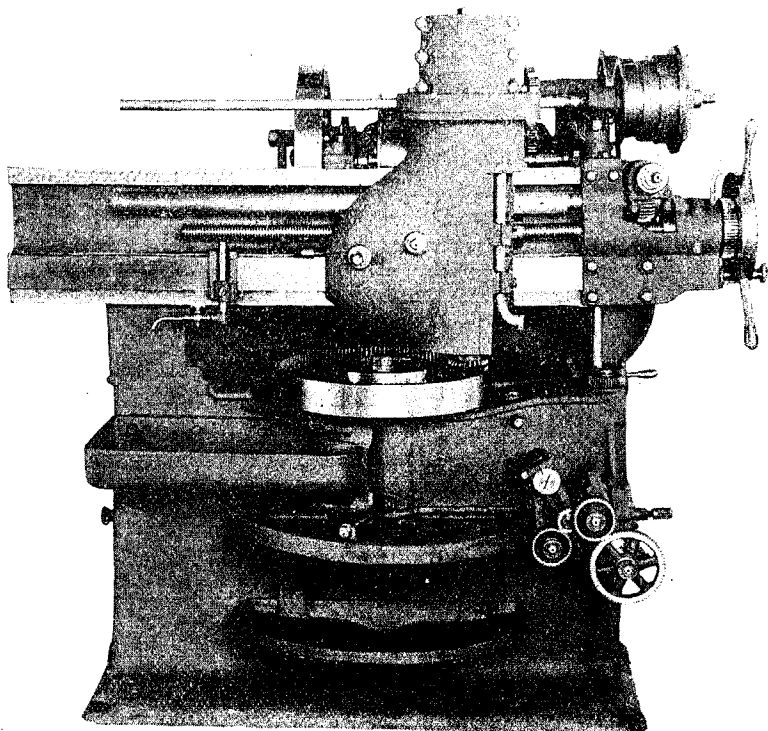
The commercial cutter submitted for examination thus appears to have some slight theoretical defects, but these



defects are inherent in the system to which the adaptation of the cutter is made, and not chargeable directly against the cutter itself, which will undoubtedly cut the teeth, for which it is intended, far better than they can possibly be cut by any set of equidistant cutters in the ordinary way.

The obliquity of the system is clearly at fault, and the

cutter adapts itself as well as possible to the difficulties presented, but as the obliquity is somewhat increased, the defects here noticed rapidly disappear, and the scope of the Fellows gear-shaper as a tool for the perfect formation of interchangeable gears becomes rapidly enlarged. The capabilities of the machine are broad enough to overcome all difficulties, and although cutters can easily be made of any desired obliquity, it has been thought advisable to

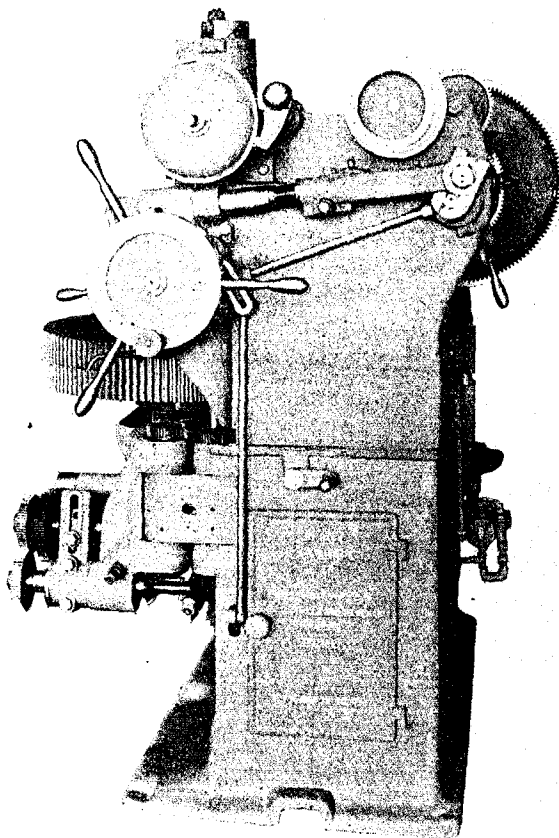


Fellows gear-shaper cutting external gear.

examine critically the cutters now on the market, and ascertain, if possible, the approach to perfection actually obtained in their use.

In the design of the machine throughout great ingenuity has been displayed and close attention has evidently been paid to every detail of construction, reflecting great credit upon the inventor. The cutter is perfectly made

to act on its rising stroke, pressing the blank against a stop on the head itself, thus minimizing the spring in the framework. On the return stroke the wheel blank is drawn away from the cutter to give the necessary clearance, and upon the completion of a wheel the feed is automatically disengaged and a bell sounded to notify the

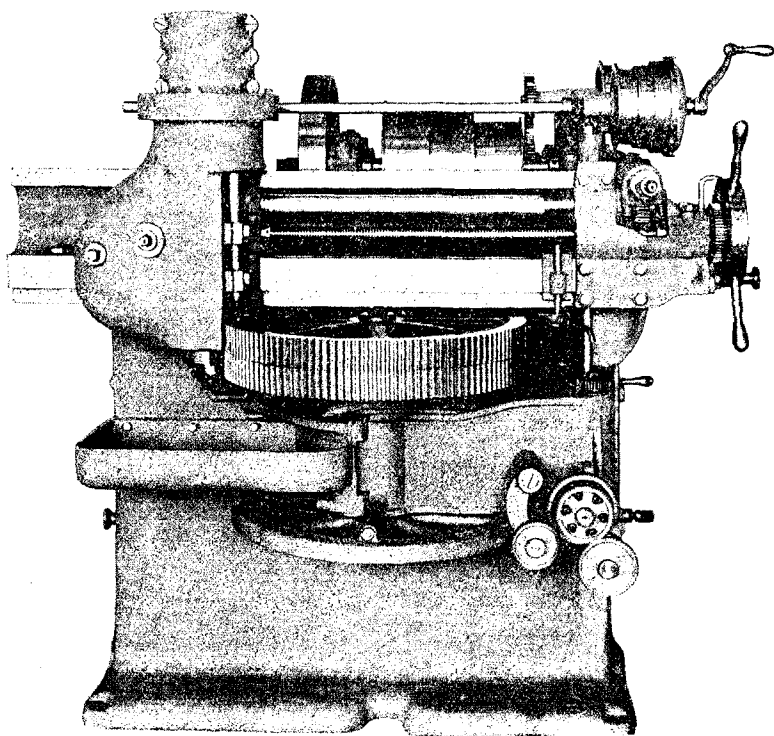


Fellows gear-shaper showing feed motion.

operator, who then removes the finished wheel and places another in position. When properly adjusted, the cutter feeds in automatically to the required depth, where it stops, and the wheel blank and cutter then begin to rotate together.

Although the driving mechanism was not particularly

powerful on the machine inspected and the feeds used seemed rather light, yet results were said to be produced with surprising rapidity, and to the perfect satisfaction of the owner of the machine. The witness, unfortunately, called at a time when the machine was not in operation, but from notes taken on the feeds and speeds in common use, the capacity of the machine was estimated at not less than



Front elevation of gear-shaper.

50 per cent. greater than common practice on gear-cutters in which a milling-cutter is used.

In view of the published articles on file with this application, it is not deemed necessary to encumber this report with further details of construction and operation. Suffice it to say that in design, general appearance and workmanship and in conveniences for adjustment and examination of parts, the Fellows gear-shaper is a very commendable

machine, on which there is little to be said by way of adverse criticism.

Possibly weak points will develop in time, for which the inventor will doubtless find proper remedies. At present, the speed of the machine seems to be limited by the cam mechanism, which moves the blank away from the cutter on the return stroke. This mechanism pounds heavily at moderate speeds, and might well be made the subject of further consideration on this account.

It may also be questioned whether a shaping tool can be pushed as hard as a milling cutter where rapid output is important on account of the well-known difficulty of preserving the edge of the work at the termination of a heavy cut in a shaping machine. On this account, a fine feed seems essential, and rapidity of production seems to be chiefly a matter of cutting speed.

The machine, as it stands, is, however, a well-developed tool, particularly applicable to the production of interchangeable gears, and the cutter used is more accurate in form, more easily renewed and covers a broader range of usefulness than the milling-cutters with which it competes.

Your committee believes that the machine and cutter for generating gear teeth, invented by E. R. Fellows, mark a distinct advance in the art of gear cutting, which should be recognized; and the Franklin Institute therefore recommends the award of the John Scott Legacy Premium and Medal to Edwin R. Fellows, of Springfield, Vt., for his "Machine and Cutter for Generating Gear Teeth."

Adopted at the stated meeting of the Committee on Science and the Arts, held Wednesday, April 5, 1899.

JOHN BIRKINBINE, *President.*

WM. H. WAHL, *Secretary.*

Countersigned by

EDGAR MARBURG,

Chairman Committee on Science and the Arts.