

The above mentioned items are greatly lessened in the machine shown in Figs 7 and 8.

WEAR AND TEAR and MAINTENANCE, 7 per cent. per year on cost of plant.

INTEREST, 5 per cent. annually on cost of plant. (For America say 6 per cent.)

---

## THE FLEXIBLE SHAFT.

---

By GEORGE BURNHAM, JR.

---

There is probably no mechanical invention of the last decade that has seemed, not only to the casual observer but also to the mechanician, to be so entirely novel in its character as the flexible shaft. Great strides have been made during this period, it is true, in all kinds of machinery, but the expert recognizes most of them as extensions and developments of known ideas and methods. So radically different, however, were the principles involved in this tool from those usually employed in machinery, and so unobserved by the world at large had been the stages of its evolution, that when exhibited at the Centennial Exhibition every beholder was struck with astonishment. Almost all machinery is characterized by fixity in certain planes of motion. The whole value of the turning lathe is conditioned upon the maintenance of its centres in a true line, and in all reciprocating machine tools, as planers, shapers, slotters, etc., and also in milling tools, the moving portions of the mechanism are confined to fixed lines and planes. Accustomed as we are to this characteristic of machinery, a device that transmits rotary motion, not through straight lines but through curves, and curves that may be varied at will, is naturally surprising when first seen.

The Paris correspondent of the *London Times*, writing of the Exhibition of 1878, and referring to the flexible shaft, correctly expresses this feeling when he says " \* \* \* it upsets all one's ideas of rigidity. Pharaoh himself could not have been more surprised at seeing Moses' rod turn to a serpent than we were to see this rope-like affair eating into the planks set on all sides for it to work upon." And yet, like all inventions, it has had its history of gradual development from crude beginning to more or less perfect consummation.

The first "flexible shaft" was simply a coil of wire. This was used as a universal joint in sheep-shearing machines, dental engines, and

other light power machines. In the reports of the Paris Exhibition of 1867, however, will be found a description of a Belgian windmill involving a shaft of this character, made of rectangular steel bar, about  $\frac{1}{4} \times 1\frac{1}{4}$ ", coiled into a spiral spring, some six inches in diameter. The limitations of this form of the device are quite evident. The flexibility was obtained at a great sacrifice of strength, to compensate for which the coil had to be made of inconveniently large diameter, about six inches, as above stated, making it equal to a solid shaft of one and one-third inches diameter only.

It was soon found that the angle of torsion was so great in the single coil shaft that it could not be used where positive motion was desirable. One of the first attempts to correct this defect was made in January, 1865, a patent of that date,\* describing a shaft made of a coil of wire wound on a centre of "gum elastic or rolled canvas, or other flexible material." This, of course, was an improvement over the first form only to the extent of the resistance to compression offered by the filling material. The next step, one of great importance, was the substitution of two concentric coils, wound in opposite directions, for the single coil heretofore employed.† By this arrangement the tendency of the outer coil to contract is met by an equal effort of the inner coil to *expand*, while the greater metal section of course increases the strength of the shaft.

It will be seen, however, that some of the flexibility is lost by this construction, since it requires more effort to bend two coils than one.

Up to, and including this stage of its progress, there existed one vital fault in the shaft that confined its use to light power machines. If, in any of the forms heretofore described, the length be over a certain number of diameters, its power-transmitting capacity becomes extremely limited on account of its liability to kink or twist out of line and double up into twisted loops. The effect is easily seen by taking a short piece of rope, fastening one end and twisting the other. The rigidity of the rope will be found to increase to a certain limit, when at some point it will suddenly twist into a loop. Shafts of this form, also, if run at a speed of more than three or four hundred revolutions per minute, vibrate in a very curious manner, the shaft divid-

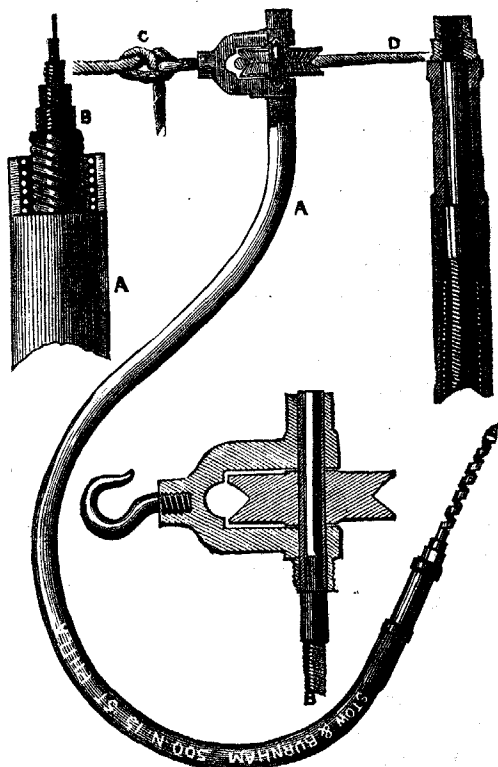
---

\* Thos. Welham, Jan. 31, 1865. Improvement in Universal Shafting.

† Greene V. Black. Patent of Aug. 8, 1871. Improvement in Universal Joints for Shaft Couplings. The title of this patent indicates the restricted use of the principle at that time.

ing into equidistant nodes like the strings of a musical instrument. This action is usually so marked as to interfere with the proper functions of the working tool, giving it a tremulous motion that is difficult or impossible to control. These defects were finally overcome by enclosing the revolving shaft in a flexible *stationary* sheath or case, and at the same time the carrying power of the shaft itself was increased by making it solid all the way through, in the sense that a wire rope is solid.\* The effect of the case or sheath (a hollow coil of wire covered with leather or other flexible material) was to give the revolving core an indefinite number of bearings, in whatever direction it might be placed, thus entirely preventing the tendencies of the naked core to kink and vibrate as described above.

FIG. 1.



Upon reflection it will be seen that this is simply an extension of

\* Nelson Stow. Patent of Aug. 6, 1872. Improvement in Flexible Shafts.

the principle we employ with rigid shafting that is too light to carry its load without vibration; we *increase the number of bearings*, and thus break the shaft into shorter sections. The increased metal section of the "solid" shaft, while enhancing its strength, of course again diminished the flexibility. Since, however, the action of the case permitted the use of much longer shafts than were practicable without it, this loss of flexibility was of comparatively small importance, as the same amount of total curvature could be obtained by making the curve more gradual and increasing its length.

Thus, a shaft  $\frac{3}{4}$  in. diam. (of core), and six feet long, will work in a complete circle or total angle of 360 degrees.

\*As now constructed the flexible shaft is made up of a *core*, a *case*, and appropriate fittings by which the two are joined, and rotary motion communicated to one end of the shaft and delivered at the other. These parts are shown, partly in section, in the annexed cut.

The core is composed of a series of concentric steel wire coils wound hard on each other, the direction of the pitch changing with each layer. The pitch direction of the outside layer is always such that the latter will tend to contract under strain, the shaft always running one way. The case is made of a hollow coil of square wire, with a slight groove on the outer side. This coil is covered with leather, the office of the groove in the wire being to prevent the leather from slipping. The inside diameter of the case is slightly larger than that of the core, and the ends are furnished with iron ferrules to receive the driving pulley and the hand-piece carrying the working tool.

The mechanical action of the shaft may best be analyzed as follows: Imagine two concentric coils of wire bent in a curve as in Fig. 2. On the outer curve the helices are spread or open, while on the inner curve they are in contact or nearly so. Now suppose the coils to be bent in the opposite direction, as in Fig. 3. The parts that were formerly in contact are now separated, and *vice versa*. This change of curvature from the position of Fig. 2 to that of Fig. 3, and back again to that of Fig. 2, is precisely in effect what occurs in the shaft during one entire revolution, except that each successive point on a given helix occupies the top and bottom positions respectively, instead of only two meridian points, as when the coil is simply bent back and forth. At every moment, then, some point in every helix is undergoing a slight

---

\* The Stow Flexible Shaft Co., Limited, 500 N. 15th st., Philadelphia, are the sole makers of the flexible shaft for other than dental purposes.

torsion, whose amount depends upon the diameter of the particular coil in which it is situated, and the curvature of the shaft itself. As long as this torsional strain is kept within the limit of elasticity of the material the shaft will revolve indefinitely without detriment; but should this limit be exceeded the shaft will rapidly give way. If a piece of core be mounted in bearings, and *curved excessively*, it will

FIG. 2.

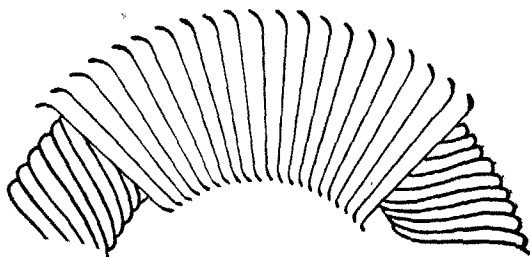
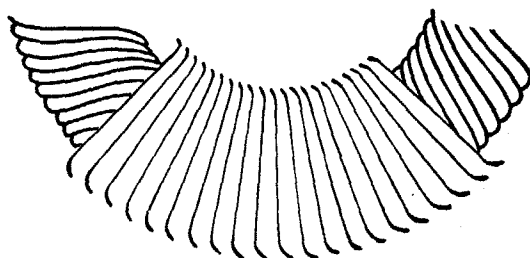


FIG. 3.



soon begin to heat, if set in motion, and will finally break. In practice this contingency is provided for by making the case sufficiently rigid to prevent bending beyond the safe limit. Referring again to Figs. 2 and 3, it will be seen that there must be some slight rubbing action between the wires of the inner and outer coils. The effect of this action is so slight as to be imperceptible, even in shafts that have been a long time in service. The other frictional elements are those common to all machines, viz., the wear of the journals and their bearings, and the wear of the outer layer of the core at points of contact with the case.

Since the flexible shaft is not a special tool for a particular purpose, but a connecting link between a given power source and a multitude of tools, its uses are very varied. The first successful application of this

WHOLE NO. VOL. CVIII.—(THIRD SERIES, Vol. lxxviii.)

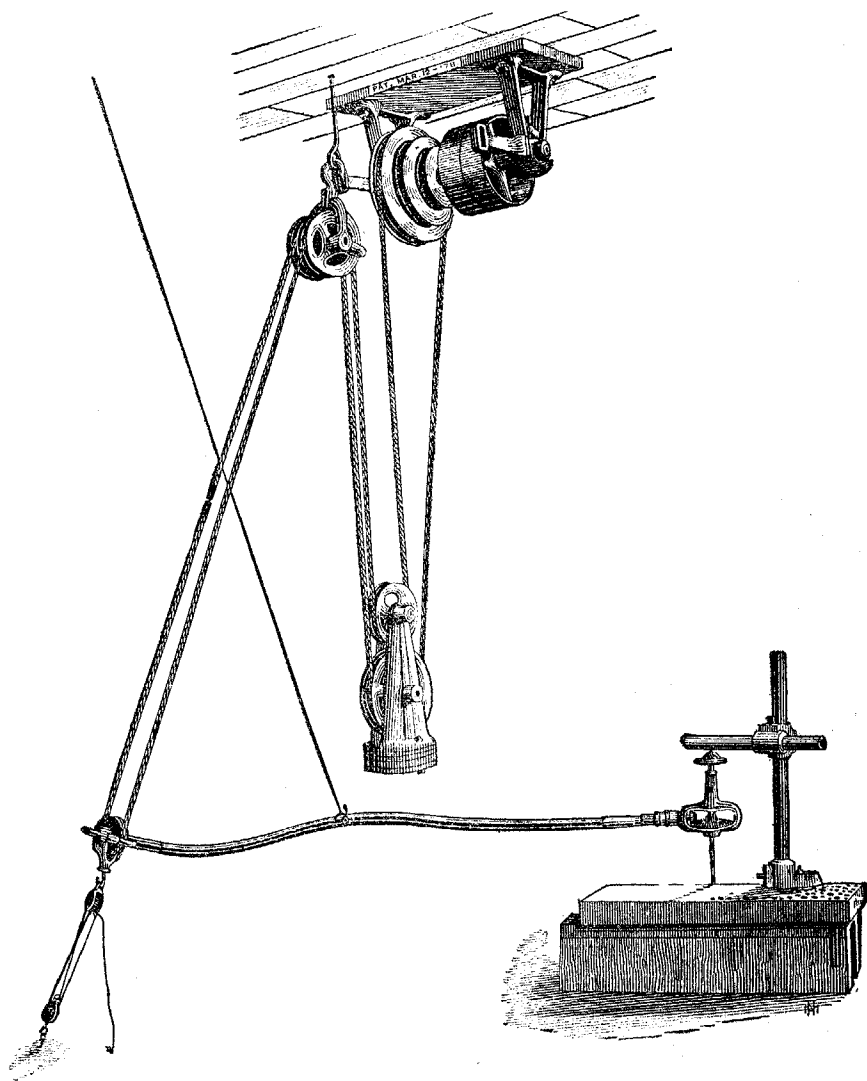
tool was in dentistry, the necessities of the dentist being, in fact, its *raison d'être*. It is needless here to descant upon its use in this line, however, as nearly every one who has need of the dentist's services is familiar with the dental engine and its power of shortening the time of painful operations on the teeth. In heavier operations the leading place occupied by the shaft has been in metal drilling. The usual power drills are no exception to the general rule stated above of *fixity in certain planes of motion*.\*

Even the radial drill only means the ability to drill *vertically* in a cylindrical space a few feet in diameter. Hence the power drill still puts the burden of adjustment on the piece to be worked itself, while the inconvenience of handling the work increases very rapidly with the weight and size of the piece, and soon reaches, in the case of large boilers, for example, a prohibitive limit. For this reason, in every machine shop many holes are still drilled by hand, within sight of the engine, that is willing but powerless to assist. It was soon seen that the flexible shaft would prove a valuable adjunct in such cases, and appropriate tools were made to meet the requirements. Extension is obtained, not by increasing the length of the shaft, which is seldom over eight feet in length, but by increasing the length of the driving rope. Varying directions are obtained; first, by leading the rope through a "transfer pulley," which is simply a pair of idler pulleys mounted one over the other in a light frame, and attached to the floor directly under the counter-shaft. Second, and more conveniently, by a device styled a "roundabout transfer," consisting, first, of a pair of idler pulleys, mounted one over the other in a weighted frame, and, second, of a pair of pulleys in a swivel frame, attached to a hanger adjoining the countershaft. The driving ropes lead from the counter-shaft down to the weighted frame, then over the swivel pulleys, and thence to the pulley on the flexible shaft, as shown in the accompanying cut. With this device the shaft and its drill may be carried at will to any part of the shop, the only limits being the length of rope used and the height of rise and fall at command for the weighted frame. Since both the leading and following ropes are carried down to the weighted frame, and thence over the swivel pulleys, the combinations form in effect a system of one *fixed* and one *movable* pulley; hence

---

\* A notable exception to this is the Thorne Portable Drill, described in the JOURNAL of November, 1871.

FIG. 4.



itself better to irregularities in the surface, while the wear is entirely confined to the joints and gradual abrasion of the ends of the wires. Wheels for sand-papering wood work, made upon the same principle, have been tried and found very effective. The sand-paper is cut into circular disks, which are strung on an appropriate mandril, each disk being separated from its neighbor by a small washer. This arrangement gives the tool great flexibility and at the same time does away with the inconvenience of frequently renewing the cutting surface inherent in the plan of wooden centres covered with sand-paper, since it is effective until worn nearly to the centre.

The shaft has also been found of great utility in stone working operations. The horizontal "lap" that has so greatly expedited the surfacing of small pieces is of no avail for large blocks, on account of their great weight and size; but the shaft enables the lap, on a small scale, to be carried to the work itself. In the apparatus constructed for this purpose, either turned iron disks or frames carrying concentric rings made of zinc, are attached to geared machines (similar to the drill press) on the end of the shaft. The grinding material is sand or emery with water.

The following tables give the results of a series of tests and experiments made in August, 1877. Recent improvements in the make up of the shaft would doubtless change these figures somewhat.

TABLE No. 1.

1	2	3	4	5
Selling No. of Shaft.	Length of Specimen.	Diam. of Specimen.	Proof Strain in lbs. at 1 foot from centre.	Angle at Elastic Limit.
0	3	9.32	4.018	77.
2	3	3.8	9.715	30.3
3	3	1.2	21.109	20.6
4	3	5.8	41.346	29.
6	3	15.16	119.832	10.7

The figures in Table No. 1 are from a series of actual tests made at the Stevens Institute of Technology, Hoboken, N. J.