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SCREW

[*Encyclopædia Britannica, Ninth Edition, Volume XXI*]

The screw is the simplest instrument for converting a uniform motion of rotation into a uniform motion of translation (see 'Mechanics,' vol. xv, p. 754). Metal screws requiring no special accuracy are generally cut by taps and dies. A tap is a cylindrical piece of steel having a screw on its exterior with sharp cutting edges; by forcing this with a revolving motion into a hole of the proper size, a screw is cut on its interior forming what is known as a nut or female screw. The die is a nut with sharp cutting edges used to screw upon the outside of round pieces of metal and thus produce male screws. More accurate screws are cut in a lathe by causing the carriage carrying the tool to move uniformly forward, thus a continuous spiral line is cut on the uniformly revolving cylinder fixed between the lathe centres. The cutting tool may be an ordinary form of lathe tool or a revolving saw-like disk (see 'Machine Tools,' vol. xv, p. 153).

Errors of Screws.—For scientific purposes the screw must be so regular that it moves forward in its nut exactly the same distance for each given angular rotation around its axis. As the mountings of a screw introduce many errors, the final and exact test of its accuracy can only be made when it is finished and set up for use. A large screw can, however, be roughly examined in the following manner: (1) See whether the surface of the threads has a perfect polish. The more it departs from this, and approaches the rough, torn surface as cut by the lathe tool, the worse it is. A perfect screw has a perfect polish. (2) Mount upon it between the centres of a lathe and the slip a short nut which fits perfectly. If the nut moves from end to end with equal friction, the screw is uniform in diameter. If the nut is long, unequal resistance may be due to either an error of run or a bend in the screw. (3) Fix a microscope on the lathe carriage and focus its single cross-hair on the edge of the screw and parallel to its axis. If the screw runs true at every point, its axis is straight. (4) Observe whether the short nut runs from end to end of the screw without a wabbling motion when the screw is turned and the nut kept from revolving. If it wabbles the

screw is said to be drunk. One can see this error better by fixing a long pointer to the nut, or by attaching to it a mirror and observing an image in it with a telescope. The following experiment will also detect this error: (5) Put upon the screw two well-fitting and rather short nuts, which are kept from revolving by arms bearing against a straight edge parallel to the axis of the screw. Let one nut carry an arm which supports a microscope focused on a line ruled on the other nut. Screw this combination to different parts of the screw. If during one revolution the microscope remains in focus, the screw is not drunk; and if the cross-hairs bisect the lines in every position, there is no error of run.

Making Accurate Screws.—To produce a screw of a foot or even a yard long with errors not exceeding $\frac{1}{1000}$th of an inch is not difficult. Prof. Wm. A. Rogers, of Harvard Observatory, has invented a process in which the tool of the lathe while cutting the screw is moved so as to counteract the errors of the lathe screw. The screw is then partly ground to get rid of local errors. But, where the highest accuracy is needed, we must resort in the case of screws, as in all other cases, to grinding. A long, solid nut, tightly fitting the screw in one position, cannot be moved freely to another position unless the screw is very accurate. If grinding material is applied and the nut is constantly tightened, it will grind out all errors of run, drunkenness, crookedness, and irregularity of size. The condition is that the nut must be long, rigid and capable of being tightened as the grinding proceeds; also the screw must be ground longer than it will finally be needed so that the imperfect ends may be removed.

The following process will produce a screw suitable for ruling gratings for optical purposes. Suppose it is our purpose to produce a screw which is finally to be 9 inches long, not including bearings, and $1\frac{1}{8}$ in. in diameter. Select a bar of soft Bessemer steel, which has not the hard spots usually found in cast steel, and about $1\frac{3}{8}$ inches in diameter and 30 long. Put it between lathe centres and turn it down to one inch diameter everywhere, except about 12 inches in the centre, where it is left a little over $1\frac{1}{8}$ inches in diameter for cutting the screw. Now cut the screw with a triangular thread a little sharper than 60°. Above all, avoid a fine screw, using about 20 threads to the inch.

The grinding nut, about 11 inches long, has now to be made. Fig. 1 represents a section of the nut, which is made of brass, or better, of Bessemer steel. It consists of four segments,—*a*, *a*, which can be drawn about the screw by two collars, *b*, *b*, and the screw *c*. Wedges between the segments prevent too great pressure on the screw. The final clamping is effected by the rings and screws, *d*, *d*, which enclose the flanges, *e*, of the segments. The screw is now placed in a lathe and surrounded by water whose temperature can be kept constant to 1° C., and the nut placed on it. In order that the weight of the nut may not make the ends too small, it must either be counterbalanced by weights hung from a rope passing over pulleys in the ceiling, or the screw must be vertical during the whole process. Emery and oil seem to be the only available grinding materials, though a softer silica powder might be used towards the end of the operation to clean off the emery and prevent future wear. Now grind the screw in the nut, making the nut pass backwards and forwards over the screw, its whole range being nearly 20 inches at first. Turn the nut end for end every ten minutes and continue for two weeks, finally making the range of the nut only about 10 inches, using finer washed emery and moving the lathe slower to avoid heating. Finish with a fine silica powder or rouge. During the process, if the thread becomes too blunt, recut the nut by a *short* tap so as not to change the pitch at any point. This must, of course, not be done less than five days before the finish. Now cut to the proper length; centre again in the lathe under a microscope, and turn the bearings. A screw so ground has less errors than from any other system of mounting. The periodic error especially will be too small to be discovered, though the mountings and graduation and centering of the head will introduce it; it must therefore finally be corrected.

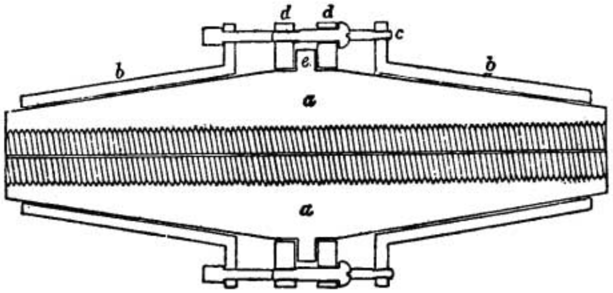

FIG. 1.—Section of Grinding Nut.

Mounting of Screws.—The mounting must be devised most carefully, and is, indeed, more difficult to make without error than the screw itself. The principle which should be adopted is that no workmanship is perfect; the design must make up for its imperfections. Thus the screw can never be made to run true on its bearings, and hence the device of resting one end of the carriage on the nut must be rejected. Also all rigid connection between the nut and the carriage must be avoided, as the screw can never be adjusted parallel to the ways on which the carriage rests. For many purposes, such as ruling optical gratings, the carriage must move accurately forward in a straight line as far as the horizontal plane is concerned, while a little curvature in the vertical plane produces very little effect. These conditions can be satisfied by making the ways V-shaped and grinding with a grinder somewhat shorter than the ways. By constant reversals and by lengthening or shortening the stroke, they will finally become nearly perfect. The vertical curvature can be sufficiently tested by a short carriage carrying a delicate spirit level. Another and very efficient form of ways is V-shaped with a flat top and nearly vertical sides. The carriage rests on the flat top and is held by springs against one of the nearly vertical sides. To determine with accuracy whether the ways are straight, fix a flat piece of glass on the carriage and rule a line on it by moving it under a diamond; reverse and rule another line near the first, and measure the distance apart at the centre and at the two ends by a micrometer. If the centre measurement is equal to the mean of the two end ones, the line is straight. This is better than the method with a mirror mounted on the carriage and a telescope. The screw itself must rest in bearings, and the end motion be prevented by a point bearing against its flat end, which is protected by hardened steel or a flat diamond. Collar bearings introduce periodic errors. The secret of success is so to design the nut and its connections as to eliminate all adjustments of the screw and indeed all imperfect workmanship. The connection must also be such as to give means of correcting any residual periodic errors or errors of run which may be introduced in the mountings or by the wear of the machine.

The nut is shown in Fig 2. It is made in two halves, of wrought iron filled with boxwood or lignum vitae plugs, on which the screw is cut. To each half a long piece of sheet steel is fixed which bears against a guiding edge, to be described presently. The two halves are held to the screw by springs, so that each moves forward almost independently of the other. To join the nut to the carriage, a ring is attached to the latter, whose plane is vertical and which can turn round a vertical axis. The bars fixed midway on the two halves of the nut bear against this ring at points 90° distant from its axis. Hence each half does its share independently of the other in moving the carriage forward. Any want of parallelism between the screws and the ways or eccentricity in the screw mountings thus scarcely affects the forward motion of the carriage. The guide against which the steel pieces of the nut rest can be made of such form as to correct any small error of run due to wear of the screw. Also, by causing it to move backwards and forwards periodically, the periodic error of the head and mountings can be corrected.

In making gratings for optical purposes the periodic error must be very perfectly eliminated, since the periodic displacement of the lines only one-millionth of an inch from their mean position will produce "ghosts" in the spectrum.[1] Indeed, this is the most sensitive method of detecting the existence of this error, and it is practically impossible to mount the most perfect of screws without introducing it. A very practical method of determining this error is to rule a short grating with very long lines on a piece of common thin plate glass; cut it in two with a diamond and superimpose the two halves with the rulings together and displaced sideways over each other one-half the pitch of the screw. On now looking at the plates in a proper light so as to have the spectral colors show through it, dark lines will appear, which are wavy if there is a periodic error and straight if there is none. By measuring the comparative amplitude of the waves and the distance apart of the two lines, the amount of the periodic error can be determined. The phase of the periodic error is best found by a series of trials after setting the corrector at the proper amplitude as determined above.

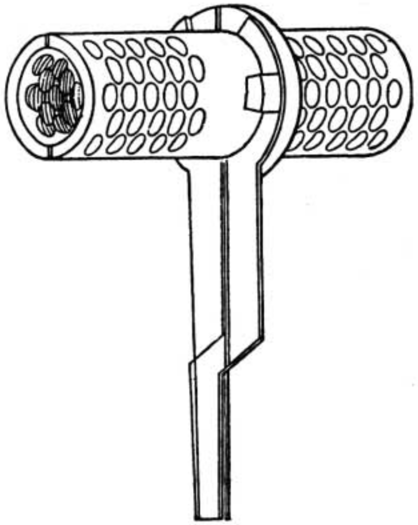

FIG. 2.

A machine properly made as above and kept at a constant temperature should be able to make a scale of 6 inches in length, with errors at no point exceeding $\frac{1}{1000000}$th of an inch. When, however, a grating of that length is attempted at the rate of 14,000 lines to the inch, four days and nights are required, and the result is seldom perfect, possibly on account of the wear of the machine or changes of temperature. Gratings, however, less than 3 inches long are easy to make.

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[1] In a machine made by the present writer for ruling gratings the periodic error is entirely due to the graduation and centering of the head. The uncorrected periodic error from this cause displaces the lines $\frac{1}{300000}$th of an inch, which is sufficient to entirely ruin all gratings made without correcting it.