machines of this kind, machine taps, which are longer than hand operated taps, being employed in the same machines.

But the smaller screws made in large quantities, and screws which have to be cut on pieces of work on which other operations, as turning, boring, facing, knurling, have to be performed, are made in the numerous capstan or turret lathes, the dies or taps being held in the turrets. Often a cam-operated screwing plate is pulled into line with the work operating independently of the turret head. But in most cases the dies (fig. 8) are held in a chuck which is inserted in one of the holes in the turret and which is better for the cutting of the finer screws. More valuable than any other single improvement is the automatic opening of many dies used in turret lathes, by which the running back of the die over the work is avoided. These opening die heads are of several designs. They are so beautifully contrived that contact with a stop, the position of which can be regulated, arrests the cutting action and causes the dies to fly open away from the screw, so that the turret can be slid away instantly, while the dies close in readiness for the next screw.

*Sizing Taps* are used for the finishing of threads which are required to be finished so uniformly as to be interchangeable one with the other. These are ordinary plug or second taps, generally short in length, and as they remove but a mere trifle of material they retain their size for a very long time. The case of sizing taps is more difficult than that of dies, because a die can be readily compressed to compensate for wear (fig. 8), but a tap has to be expanded. The result is that while plenty of adjustable dies are made, there are few expanding taps. Many nave been designed, but they are used to a much less extent than the dies. A sizing tap is kept true as long as possible by careful use. and when it falls below the limit dimensions it is replaced by a new one.

Screw milling, the latest development in screw-cutting, involves the use of a special machine, something like the lathe in outline, the piece of work to be threaded being rotated in the axis of the machine. The cutter is carried in a head, with swivelling arrangements, to provide for variations in screw angles, and is rotated at speeds suitable for the metal or alloy being cut. The necessary traverse is imparted either to the work or to the cutter, according to the design of machine, by lead screw and change gears. This method is employed to a considerable extent, chiefly for cutting coarsely threaded screws and worms. The great advantage which the revolving cutter possesses over the single-edged tool is its rapidity of action, by which threads may be produced

more quickly than in the lathe.

*Testing Screws.—*The screws cut in engineers’ shops are sufficiently true for all practical purposes. But the fact remains that no guide screw yet made is true, and no true screw can be made apart from the use of devices which are unknown in the machine shop. Actually no screw ever has been, or probably ever will be, made perfect, but the variation from truth has been in some cases only 1/25,000 or 1/30,000 part of an inch. The microscope is brought into requisition for testing standard screws, but commercial screws simply have to pass the test of gauges. A screw 21 ft. long was made by the Pratt & Whitney Co., and tested by Professor W. A. Rogers. A scale, the corrections of which were known to within 1/25,000 in., was mounted parallel with the axis of the screw. A microscope containing a cross bar was mounted on the carriage actuated by the screw. The cross bar was furnished with a micrometer by which the deviations for any revolution of the screw could be measured. A reading was taken for each half inch in length of the screw. Special tests were made at various points by turning the screw through 45° at a time. The maximum error in the entire length of the screw was found to be less than 1/100 in.

The problem of producing a true screw has occupied investigators since the days of Henry Maudslay (1771-1831). The great difficulty is that of attaining accurate pitch, so that the distances between all the threads shall be uniform, and consequently that a nut on the screw shall move equably during the rotation. The importance of this point is felt in the dividing engines of various classes employed for ruling, and in measuring machines used for testing standards of length. The ordinary screw, cut by dies or in the screw-cutting lathe, is found, on applying comparatively coarse tests, to be far from accurate in pitch, while the thread may be wavy or “ drunken ” and the diameter may not be uniform at all points. There are several methods of correcting the errors in screws; the principal one is that of retarding or accelerating the traverse motion of the screw-cutting tool by means of a compensating lever bearing on a compensating bar, which is formed after observations have been made on the degree of accuracy of the leading screw used to propel the tool carriage. The original errors in the leading screw are therefore eliminated as far as possible. The inspection of the screw is done by means of the microscope working in conjunction with a line measure fastened down parallel with the axis of the screw, so that the coincidence or otherwise of the screw pitches with the subdivisions of the measure may be compared. (J. G. H.)

*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 it between the centres of a lathe and then slip upon it 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 it to 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 line in every position, there is no error of run. Where the highest accu- racy 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 in. long, not including bearings, and 1⅛ in. in diameter. Select a bar of soft Bessemer steel, which has not the hard spots usually found in case steel, about 13/8 in. in diameter and 30 in. long. Put it between lathe centres and turn it down to 1 in. diameter everywhere, except about 12 in. in the centre, where it is left a little over 1⅛ in. 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 in. long, has now to be made. Fig. 9 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 in. 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 in., 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 fewer 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.

*Mounting of Screws.—*The mounting must be devised most care-