tools adaptable to cutting various classes of metals and alloys. Tungsten is the principal controlling element, but chromium is essential and molybdenum and vanadium are often found of value. The steels are forged at a yellow tint, equal to about 1850° F. They are raised to a white heat for hardening, and cooled in an air blast to a bright red. They are then often quenched in a bath of oil.

The first public demonstration of the capacities of high speed steels was made at the Paris Exhibition of 1900. Since that time great advances have been made. It has been found that the section of the shaving limits the practicable speeds, so that, although cutting speeds of 300 and 400 ft. a minute are practicable with light cuts, it is more economical to limit speeds to less than 100 ft. per minute with much. heavier cuts. The use of water is not absolutely essential as in using tools of carbon steel. The new steels show to much greater advantage on mild steel than on cast iron. They are more useful for roughing down than for finishing. The removal of 20 lb of cuttings per minute with a single tool is common, and that amount is often exceeded, so that a lathe soon becomes half buried in turnings unless they are carted away. The horse-power absorbed is proportionately large. Ordinary heavy lathes will take from 40 to 60 h.p. to drive them, or from four to six times more than is required by lathes of the same centres using carbon steel tools. Many remarkable records have been given of the capacities of the new steels. Not only turning and planing tools but drills and milling cutters are now regularly made of them. It is a revelation to see these drills in their rapid descent through metal. A drill of 1 in. in diameter will easily go through 5 in. thickness of steel in one minute.

Machine Tools

The machine tools employed in modern engineering factories number many hundreds of well-defined and separate types. Besides these, there are hundreds more designed for special functions, and adapted only to the work of firms who handle specialities. Most of the first named and many of the latter admit of grouping in classes. The following is a natural classification:

I. *Turning Lathes.—*These, by common consent, stand as a class alone. The cardinal feature by which they are distin­guished is that the work being operated on rotates against a tool which is held in a rigid fixture—the rest. The axis of rotation may be horizontal or vertical.

II. *Reciprocating Machines.—*The feature by which these are characterized is that the relative movements of tool and work take place in straight lines, to and fro. The reciprocations may occur in horizontal or vertical planes.

III. *Machines which Drill and Bore Holes.—*These have some features in common with the lathes, inasmuch as drilling and boring are often done in the lathes, and some facing and turning in the drilling and boring machines, but they have become highly differentiated. In the foregoing groups tools having either single or double cutting edges are used.

IV. *Milling Machines.—*This group uses cutters having teeth arranged equidistantly round a cylindrical body, and may therefore be likened to saws of considerable thickness. The cutters rotate over or against work, between which and the cutters a relative movement of travel takes place, and they may therefore be likened to reciprocating machines, in which a revolving cutter takes the place of a single-edged one.

V. *Machines for Cutting the Teeth of Gear-wheels.—*These comprise two sub-groups, the older type in which rotary milling cutters are used, and the later type in which reciprocating single-edged tools are employed. Sub-classes are designed for one kind of gear only, as spur-wheels, bevels, worms, racks, &c.

VI. *Grinding Machinery.—*This is a large and constantly extending group, largely the development of recent years. Though emery grinding has been practised in crude fashion for a century, the difference in the old and the new methods lies in the embodiment of the grinding wheel in machines of high precision, and in the rivalry of the wheels of corundum, car- borundum and alundum, prepared in the electric furnace with those of emery.

VII. *Sawing Machines.—*In modern practice these take an important part in cutting iron, steel and brass. Few shops are without them, and they are numbered by dozens in some establishments. They include circular saws for hot and cold metal band saws and hack saws.

VIII. *Shearing and Punching Machines.—*These occupy a border line between the cutting and non-cutting tools. Some must be classed with the first, others with the second. The detrusive action also is an important element, more especially in the punches.

IX. *Hammers and Presses.—*Here there is a percussive action in the hammers, and a purely squeezing one in the presses. Both are made capable of exerting immense pressures, but the latter are far more powerful than the former.

X. *Portable Tools.—*This large group can best be classified by the common feature of being readily removable for operation on large pieces of erection that cannot be taken to the regular machines. Hence they are all comparatively small and light. Broadly they include diverse tools, capable of performing nearly the whole of the operations summarized in the pre- ceding paragraphs.

XI. *Appliances.—*There is a very large number of articles which are neither tools nor machine tools, but which are indispensable to the work of these; that is, they do not cut, or shape, or mould, but they hold, or grip, or control, or aid in some way or other the carrying through of the work. Thus a screw wrench, an angle plate, a wedge, a piece of packing, a bolt, are appliances. In modern practice the appliance in the form of a templet or jig is one of the principal elements in the interchangeable system.

XII. *Wood-working Machines.—*This group does for the conversion of timber what the foregoing accomplish for metal. There is therefore much underlying similarity in many machines for wood and metal, but still greater differences, due to the conditions imposed on the one hand by the very soft, and on the other by the intensely hard, materials operated on in the two great groups.

XIII. *Measurement.—*To the scientific engineer, equally with the astronomer, the need for accurate measurement is of paramount importance. Neither good fitting nor interchange- ability of parts is possible without a system of measurement, at once accurate and of ready and rapid application. Great advances have been made in this direction lately.

I.—Lathes

The popular conception of a lathe, derived from the familiar machine of the wood turner, would not give a correct idea of the lathe which has been developed as the engineer’s machine tool. This has become differentiated into nearly fifty well-marked types, until in some cases even the term lathe has been dropped for more precise definitions, as vertical boring machine, automatic machine, while in others prefixes are necessary, as axle lathe, chucking lathe, cutting-off lathe, wheel lathe, and so on. With regard to size and mass the height of centres may range from 3 in. in the bench lathes to 9 or 10 ft. in gun lathes, and weights will range from say 50 lb to 200 tons, or more in exceptional-eases. While in some the mechanism is the simplest possible, in others it is so complicated that only the specialist is able to grasp its details.

*Early Lathes.—*Space will not permit us to trace the evolution of the lathe from the ancient bow and card lathe and the pole lathe, in each of which the rotary movement was alternately for- ward, for cutting, and backward. The curious thing is that the wheel-driven lathe was a novelty so late as the 14th and 15th centuries, and had not wholly displaced the ancient forms even in the West in the 19th century, and the cord lathe still survives in the East. Another thing is that all the old lathes were of *dead centre,* instead of *running mandrel* type; and not until 1794 did the use of metal begin to take the place of wood in lathe construction. Henry Maudslay (1771-1831) did more than any other man to develop the engineer’s self-acting lathe in regard to its essential mechanism, but it was, like its immediate successors for fifty years after, a skeleton-like, inefficient weakling by comparison with the lathes of the present time.

*Broad Types.—*A ready appreciation of the broad differences in lathe types may be obtained by considering the differences in the great groups of work on which lathes, are designed to operate. Castings and forgings that are turned in lathes vary not only in size, but also in relative dimensions. Thus a long piece of driving shafting, or a railway axle, is very differently proportioned in length and diameter from a railway wheel or a wheel tire. Further, while the shaft has to be turned only, the wheel or the tire has to be turned and bored. Here then we have the first cardinal distinction between lathes, viz. those admitting work *between centres* (fig. 29) and *face* and *boring* lathes. In the first the piece of work is pivoted and driven between the centres of head-stock and tail-stock or loose poppet; in the second, it is held and gripped only by the dogs or