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Development of Machine Tools in New England

BY GUY HUBBARD

The sixth article—Special machines built for manufacturing rotary pumps—Development of the interchangeable system — Advanced sales methods — Working with convict labor

ASAHEL HUBBARD built the first wooden model of his revolving hydraulic engine at his "watermill" near the West Parish of Windsor, and after some experimenting he built one of cast iron, doing most of the work by hand, as he had but little machinery available. The teeth of the bucket wheels of this first pump were shaped by chipping and filing, being afterward ground in with powdered glass and oil.

On account of the lack of the necessary mechanical equipment for the quantity manufacture of the revolving hydraulic engine at Windsor, and because both the local capital and local public interest were all tied up in the similar Cooper invention, Asahel Hubbard journeyed to Proctorsville, Vt., some twenty miles across the mountains west of Windsor, and interested Jabez Proctor in the proposition. Jabez Proctor (1780-1839) manufacturer, capitalist, politician and one of the most honored and influential men in the State, was born at Westford, Mass. He came to Vermont at the age of three with his father, Capt. Leonard Proctor, a Revolutionary officer who founded the village of Proctorsville in the wilderness of the township of Cavendish.

FIG. 30—ONE OF THE ORIGINAL HUBBARD PUMPS

Mr. Proctor installed Ashahel Hubbard, temporarily, in the machine shop of his mill on the Black River in Proctorsville village, and on Oct. 28, 1829, they incorporated The National Hydraulic Co., with a capital of $50,000. This was the beginning of the chain of machine industries which, through various changes of name, has existed unbroken at Windsor for more than ninety years and through which has always run a strong community spirit. In these industries there have been developed some of the most important improvements in the mechanic arts and some of the greatest American mechanics, and from them have sprung no less than thirty other American industries, many of which are leaders in their field today.

Redfield Proctor, son of Jabez, was the founder of the Vermont marble industries at Rutland and Proctor, in the mechanical development of which he was greatly aided by another famous Windsor mechanic, Albert Ball, whose work will be taken up later on in considerable detail.

The First Stationary Steam Engine

The special machines for manufacturing the revolving hydraulic engines and a few of the earliest engines were built at Proctorsville. In a short time Mr. Proctor, through his political influence, succeeded in having Asahel Hubbard appointed warden of the Vermont State Prison at Windsor, at the same time getting the authorities to install a steam engine (with the exception of that on board Thomas Blanchard's steamboat "Vermont," the first in Windsor) and a machine shop at the prison. In 1830, The National Hydraulic Co. removed its machinery from Proctorsville and located in this shop, beginning there the quantity manufacture of the revolving hydraulic engines by the interchangeable system and under a peculiar labor condition. One of the original pumps and some of its parts are shown in Fig. 30.

The manufacture of machinery under this so-called interchangeable or American system consists in making every part of each machine exactly like the corre-

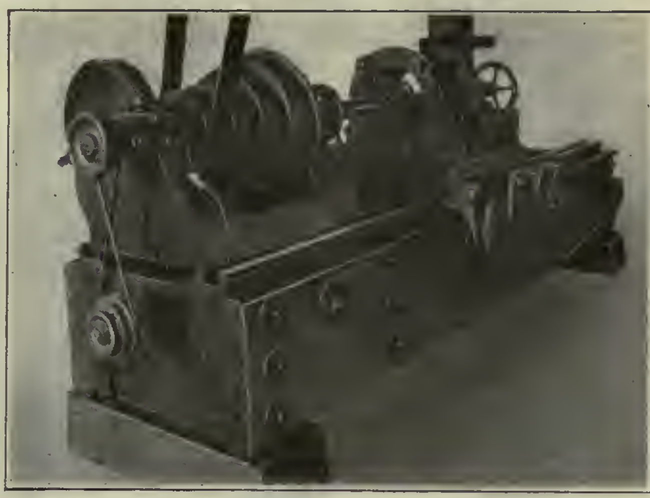

FIG. 31—BELT-FEED ENGINE LATHE, BUILT BY ALVIN JENKS, PAWTUCKET, R. I., ABOUT 1833

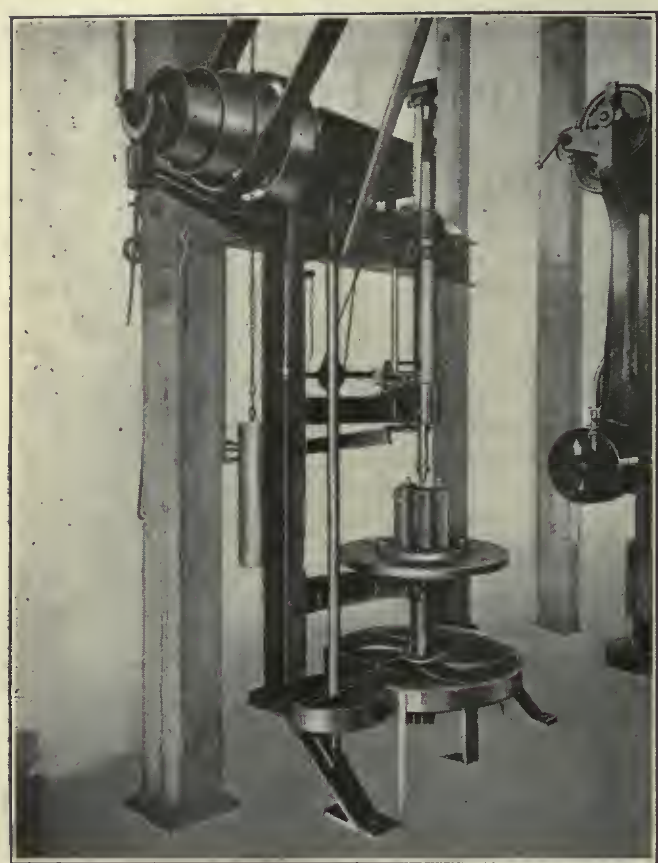

FIG. 32—BORING MILL AND DRILLING MACHINE, BUILT BY ALVIN JENKS, PAWTUCKET, R. I., ABOUT 1833

sponding part in every other machine of the same class and size, so that in assembling the parts no fitting is necessary, by reason of which repair parts can be furnished that will go directly into place. To build machinery upon this plan, it is necessary to either make very careful measurements during every stage of the production of each piece (the tool-room method) or to fit each piece to accurate gages, the drilling and shaping being controlled by accurate work-holding and tool-guiding devices called jigs and fixtures (the manufacturing method). The tool-room method is applied only to small lots of parts such as the jigs and fixtures themselves. In the manufacturing method the skill of the toolmakers who built the jigs, fixtures and gages is reproduced again and again upon the parts for which they are used; the "transfer of skill" it is called by Prof. Dexter S. Kimball in his "Principles of Industrial Organization." Thus the keynote of the interchangeable system is *accuracy*.

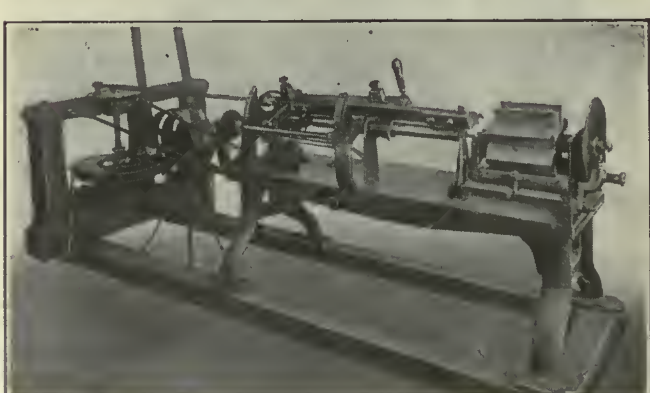

FIG. 33—CRANK PLANER FOR PLANING ROTARY-PUMP BUCKETS, BUILT BY ALVIN JENKS, PAWTUCKET, R. I., ABOUT 1833

The interchangeable system was projected by the armorers in France as early as 1717, but as late as 1785, the attempt of the gunsmith LeBlanc to build muskets by this system did not prove entirely successful, partly on account of lack of funds. The work of LeBlanc came to the attention of Thomas Jefferson, then Minister to France, and being himself mechanically inclined it interested him greatly. In fact he wrote to John Jay and to James Monroe of the possibility of applying the LeBlanc system at the United States Armories. Although he made some moves toward sending the inventor to this country, the matter lapsed at the time but very likely this agitation influenced the later backing given to Whitney by the Government.

Interchangeable Manufacture Abroad

Tackle blocks for ships were made at the Navy Yard at Portsmouth, England, by something approaching the interchangeable system about 1791, by Samuel Bentham (brother of Jeremy Bentham, the great prison reformer) and by Sir Marc Isambard Brunel (who during his exile in America came close to Vermont when he built the Hudson-Champlain Canal). Then in 1806, John George Bodmer, the famous Swiss mechanic, began to manufacture guns by special machinery at St. Blaise in the Black Forest, but in neither of these projects did the system exist in any degree of completeness.

It was in 1798 that Eli Whitney, the inventor of the cotton gin, accepted a contract for 15,000 United States muskets of which he proposed "to make the same

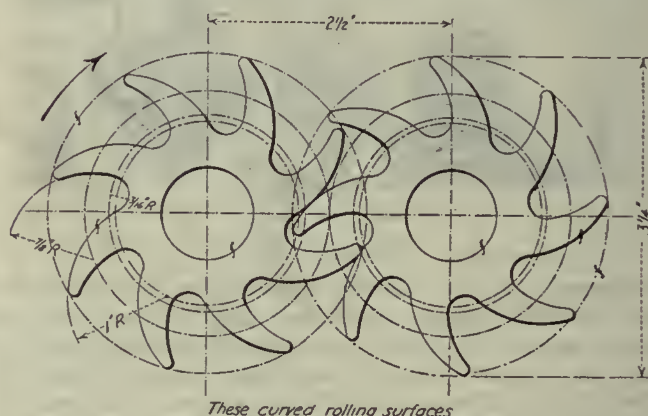

FIG. 34—DIAGRAM OF BUCKET WHEELS OF HUBBARD'S ROTARY PUMP, 1828

parts of different guns, as their locks for example, as much like each other as the successive impressions of a copper-plate engraving." In 1800, Whitney built and equipped his armory outside of New Haven and of his work Jefferson said in a letter to Monroe in 1801: "He has invented molds and machines for making all the pieces of his locks so exactly equal that take 100 locks to pieces and mingle their parts, and the 100 locks may be put together by taking the pieces which come to hand." Thus was this system first completely practiced at Whitneyville, Conn., and became known as the American system. It has since spread to all parts of the world.

Although the interchangeable system had thus early been applied to the manufacture of firearms (where its value was self-evident), its application to machine building did not immediately follow and the revolving hydraulic engine was unquestionably one of the first instances in which it was applied in this connection. Upon the early application of this system and its subsequent development, rests not only much of the success of the Windsor machine builders (who, with the exception of Eli Whitney, in the early days probably did more to develop and spread this system than any others) but also that of American industry in general.

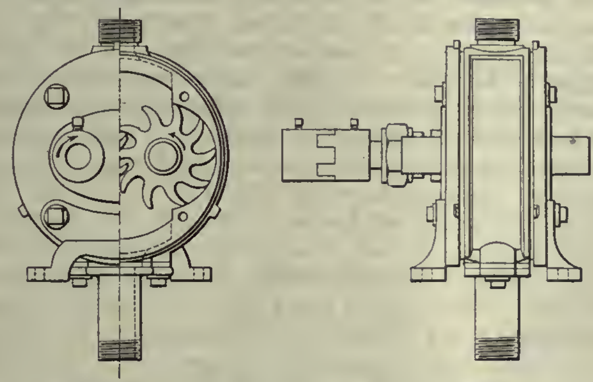

FIG. 35—DIAGRAM OF HUBBARD'S ROTARY PUMPS FOR HOUSEHOLD USE

The experiment in regard to labor at the prison touched both the free mechanics and the convicts who were employed by The National Hydraulic Co. The life of a mechanic in those early times of twelve-hour days and "bound-out" apprentices was not a rosy one, and the life of a convict in the days of damp cells, balls and chains, and whipping posts was much less so. The National Hydraulic Co., however, began to treat its free workmen, not like servants, but as fellow craftsmen and it made a special effort to send out its convict labor with self-respect and with a useful trade learned. At the same time the prison became a source of revenue to the State, instead of being a drain upon it.

Early Office Systems

The old books of the National Hydraulic Co., which are in the possession of the writer, show that it had excellent "systems," much like those used today in machine shops. List of jigs, fixtures, patterns, castings, operations, etc., were kept, as well as a record of each pump manufactured, showing its number (which was stamped upon all its parts), its test results, and to whom it was sent. All letters and orders were copied and filed. Quite accurate time was kept on the work in the shop, from which costs were figured, and records were kept of the quality of the work done by the various men. Entries in these ancient books show that when the more efficient convicts were pardoned or otherwise released, they were either kept on as free men or were fitted out with tools, new clothes and recommendations, so that they could start life anew elsewhere as useful citizens.

An apprenticeship system was also developed, by which likely boys were taken in at what was then a fair living wage ($100 per year and board) and were taught all branches of the business during a period of three years. These points go to explain why, years later, the workmen in their turn stood by the Windsor industries during periods of depression, for it is not beside the point to say they felt much the same toward these industries as graduates of a modern engineering college feel toward their *alma mater*.

The National Hydraulic Co. built pumps and fire engines, ranging from small cast-iron, brass or pewter hand pumps, to industrial pumps of more than a thousand gallons per minute capacity. The several small pumps which are still in existence prove them to have been strictly interchangeable. Following distinctly modern policies, the company began extensive advertising and sent salesmen out from Windsor who penetrated even as far as Northern Mexico. It also established agencies in all parts of the country.

The First Water Works

In 1829, Mayor Daniel D. Page and the Board of Aldermen of St. Louis, set on foot a movement to build the first water-works for that rapidly growing city and a firm of contractors, Wilson & Fox, undertook the work. Through Charles Manser, its agent at St. Louis, The National Hydraulic Co., in 1830, was given an order to build a revolving hydraulic engine of 20 hp., capable of raising water from the Mississippi and forcing it through 1,300 ft. of iron pipe into a 230,310-gal. reservoir. The reservoir was located on top of one of the mounds on the east side of what was later called Broadway, near the residence of Gen. W. H. Ashley, and was 104 ft. above the normal level of the river.

This "huge pump" was built at once and under the direction of the inventor was taken to St. Louis, being transported by wagon over the Green Mountains at Albany, by canalboat from Albany to Buffalo, by lake steamer from Buffalo to Chicago (then only a small settlement) and by wagon and riverboat from Chicago to St. Louis. This journey lasted for several weeks

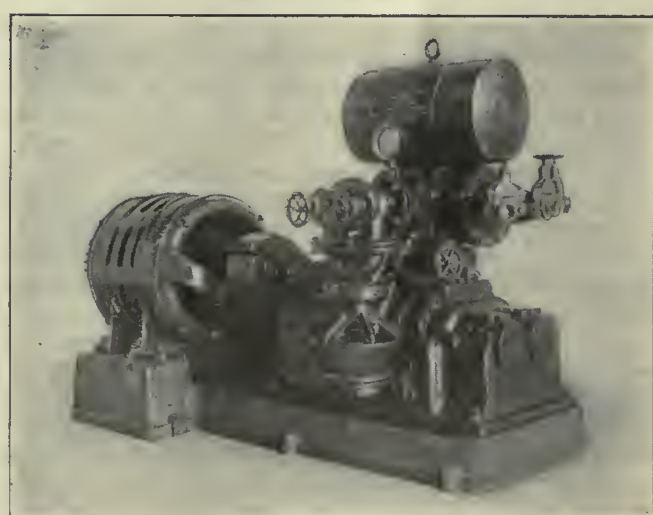

FIG. 36—A 750-GAL. HUBBARD ROTARY FIRE-PUMP, FALES & JENKS MACHINE CO., 1917

but both the inventor and the pump arrived safely at the then "far western" city. Under Asahel Hubbard's direction the pump was attached to a steam engine built by Francis Pratt of Pittsburgh and coupled to the mains which had been cast by Vanleer & Co. and Woods, Stacker & Co. at their iron works in Tennessee.

The pump worked very satisfactorily, but when it came to settling the bill, it was discovered that the water company did not have sufficient money on hand to pay for it. A committee of citizens, forerunners of the very progressive St. Louis Chamber of Commerce, then took up a collection but still there was a deficit, so these patriotic citizens presented the inventor with a fine, pure-white saddle horse. Asahel Hubbard, who was by that time anxious to return home, was glad to accept this as payment of the balance. Taking the cash in gold in a money belt, he rode the horse to Davenport, Iowa, where he had other business and from there he and the horse journeyed back to Windsor by the same route and method by which he had gone west. His arrival in Windsor on his St. Louis horse was an event long remembered by the old residents.

The revolving hydraulic engine remained in use at the St. Louis Water Works, with another type of pump later added, until 1848, when it was replaced by a new steam pump of 150 horsepower.

Orders from Far Off

The National Hydraulic Co. began to receive orders from all over the country, a large order coming from far-away Matamoros in Mexico, and about fifty men, some convicts and some free, were employed. After the St. Louis trip, Asahel Hubbard spent most of his time traveling, going to all parts of the country from Canada to western Florida in the interests of the business. When away he left his son Colman, who had learned the machinists' trade under him, in charge of the prison and of the shop at Windsor.

On account of the difficulty of shipping large pumps from Windsor, the inventor, in 1833, sold his patent rights for the State of Rhode Island to David G. Fales and Alvin Jenks, who in 1830 had founded a machine business at Central Falls under the name Fales & Jenks. Mr. Jenks, a brilliant mechanic himself, was a member of a famous mechanical family and a descendant of Joseph Jenks of Hammersmith, England, who settled in Lynn in 1642 and who was, according to Lewis in his "History of Lynn," the first founder who worked in brass and iron on the "Western continent." Fales & Jenks, who had begun by building cotton machinery, immediately made Hubbard's patent rotary pump a prominent article of its manufacture, especially in the form of stationary fire-pumps for large buildings. After ninety years, the Fales & Jenks Machine Co. continues to build them in sizes varying from small bronze chemical pumps driven by hand, up to huge electric fire-pumps of a thousand gallons per minute capacity. The design is practically unchanged and it is now one of the oldest mechanical products continuously built by one concern in the United States. In the plant at Pawtucket may still be seen, in running order, some of the machines built by Alvin Jenks in 1833, which will give a clear idea of those used by The National Hydraulic Co. in the pioneer days at Windsor.

Special Machinery

One of these machines is a heavy engine lathe for boring the pump cases, shown in Fig. 31. It has a massive wooden bed with cast iron ways bolted to it and is fitted with a reversible carriage having a rack feed, operated by an ingenious endless belt arrangement on the front of the bed. The boring is done by an adjustable tool, held on a bar between the lathe centers and the cases are held in a fixture in which they can be quickly shifted by means of a slide, so that first one side and then the other may be bored at one setting.

Another ingenious machine is a combination boring mill and drilling machine, Fig. 32, which was designed primarily for boring the centers of the cast bucket-wheels for the steel shaft (an improvement in construction introduced in the pumps by Mr. Jenks). This machine is used as a boring mill by fixing the spindle with a sliding key and throwing the table into gear so as to revolve. As a drilling machine, the table driving-gear is thrown out of mesh, the table clamped in place and the key removed from the spindle, which is then thrown into gear. This machine has a speed-changing gear box and an adjustable power feed.

The third machine of this historic group, is a gear tooth generator for automatically shaping the rolling faces of the teeth of the bucket wheels, see Fig. 33, upon the accuracy of which the efficiency of the pump so greatly depends. In 1828, planers and milling machines were very rare in New England and probably had been scarcely heard of in Vermont. Plane surfaces, or special curved surfaces which could not be cut in the lathe, were produced by chipping and filing, just as were the teeth of Asahel Hubbard's first cast-iron bucket wheels. In fact the special machinery by Mr. Jenks was built by this method, the labor of chipping and filing (which by the way is almost a lost art among mechanics) being reduced to a minimum by providing raised "spottings" upon the castings where the plane surfaces were required. One of the first special machines built by the National Hydraulic Co. was a sort of hand planer in which the cutting tool was guided by a form to follow the curve of the tooth as it made its progressive strokes. As is the case of most early gearing, the tooth curve of the bucket wheels of these pumps was an arc of a circle which approximated the true epicycloidal form, as shown by the accompanying diagram, Fig. 34.

Planer with Forming Attachment

Alvin Jenks greatly improved this planer by making it power driven, by relieving the cutting tool on the back stroke, by providing a power feed with automatic stop and by making the machine adjustable to different sizes of bucket wheels. This machine, which Prof. Joseph W. Roe believes to be the original gear tooth generator, is primarily a crank shaper, with the ram sliding upon a round rod and about which it is also fitted to swing. The radius of the swing is adjustable by raising or lowering the slide by screws, and the swing or feed is controlled by pinions meshing into quadrants fastened to the body of the slide. The pinions are turned step by step by a ratchet wheel, which is kicked by a dog on the toolslide at the end of each return stroke, the motion of the ratchet wheel being communicated to the pinion shaft by bevel gears. This mechanism is adjustable for coarse and fine feeds. The bucket wheel is held between centers in an adjustable fixture having an index plate like a milling machine. The relieving of the tool is accomplished by a wedge, a sort of slide within the toolslide, which forces the tool up to the cut when the stroke is forward but lifts it slightly when the stroke is to the rear. Automatic stopping is provided by lifting a pin clutch in the drive mechanism, by a lever operated by an arm on the toolslide, when the toolslide has traveled through the required arc.

To operate the generator, a bucket-wheel casting which has been turned, bored and pressed on its shaft, is mounted in the fixture with the proper index plate in place. By means of a gage, the center of the gear-tooth arc is lined up with the center of the rod on which the toolslide moves and the radius of swing of the tool is set to the radius of this arc. With the tool beginning to cut at the bottom of a tooth, the machine is started, and at each return stroke the tool moves a step toward the top of the tooth, gradually swinging on the proper curved path. When the tooth is completely planed, the machine automatically stops, the operator indexes the gear to another tooth, sets the toolslide back and starts the machine. This cycle of operations is repeated for each tooth, the operator meanwhile tending to other machines.

Although the Fales & Jenks Machine Co. has a complete equipment of modern machine tools and cuts the teeth in its standard pumps in a powerful milling machine with formed cutters, these ancient machines are by no means idle, being frequently called into service to make repair parts or during the construction of special pumps. As there was no general public water supply in Providence until subsequent to 1870, hundreds of the small pumps such as shown in the diagram in Fig. 35, were sold to the householders of that city to draw water from wells and cisterns. Of late years, The Fales & Jenks Machine Co. has developed automatic electric fire-pumps for large buildings, the largest of which, Fig. 36, will deliver a thousand gallons per minute for high-pressure fire service. From its original and somewhat sacrilegious test upon the steeple of the South Meeting House in Windsor Village in 1828, Hubbard's Rotary Pump was developed under Fales & Jenks, to a point where it threw a powerful stream almost to the pinnacle of the Tribune Building in New York City, in a test made some fifty years later.

Practical Notes on Speeds and Feeds

By Ernest K. Steiner

It has been my experience to find that only a small percentage of job-setters and foremen really know how to check the speed and feed of the machinery over which they exercise supervision.

For convenience we will use the term "Surface Speed" to designate what is variously called surface speed, peripheral speed, rim speed, cutting speed and circumferential speed. Surface speed is the number of feet on the surface which passes a given point in one minute and on a lathe, where the work is revolving, it is the number of feet of surface revolving past the tool. On a milling machine, where the cutter revolves, the surface speed of the cutter is taken.

For a circular object revolving about a center, the surface speed is found by multiplying the circumference of the object in feet by the r.p.m. of the machine. The circumference in feet is found by multiplying the diameter in inches by 3.1416 and dividing by 12, which gives the following formula:

$$\text{Surface speed} = \frac{\text{Diam. in in.} \times \text{r.p.m.} \times 3.1416}{12}$$

$$= 0.2618 \times \text{diam. in in.} \times \text{r.p.m.}$$

The more important elements which determine surface speed are the kind of material being machined, the type of machine being used, the condition of the machine, the kind and amount of cooling liquid available at the surface of the work, the kind and condition of the tool, and the amount of cut being taken. The table of surface speeds herewith has been compiled through years of experience and the data is given for high-speed tools with the exception of those designated in the note below the table. The grinding speeds were determined from wheels of various makes.

STANDARD SURFACE SPEEDS IN FEET PER MINUTE

Operation	Material						
	C. R. Steel	D. F. Steel	Cast Iron	Mall. Iron	Aluminum	Brass	Bronze
Drill	120	110	140	110	300	300	120
Grind	6,000	...	6,000	...	6,000	...	...
Gear Cut	100	100	125	100	.....	300	200
Mill	200	200	250	175	800	500	225
Profile	200	200	225	175	700	500	225
Turn	175	175	100-R *300-F	*190	1,000	250	175

* Stellite.

These figures represent standard surface speeds that should be used with ideal conditions prevailing, but condition of machine, lubrication, depth of cut, etc., also affect the speed and make it necessary at times to use a slower speed than shown in the table.

According to the table a surface speed of 300 ft. per min. should be used when finishing cast iron with a stellite tool on a lathe. Assuming that the work is 5 in. in diam., the proper r.p.m. can be determined by transposing the formula given above.

$$\text{R.p.m.} = \frac{\text{Surface speed}}{\text{Diam in in.} \times 0.2618}$$

$$= \frac{300}{5 \times 0.2618} = 229, \text{ approximately.}$$

If the diameter of the line shaft pulley is not great enough to give a sufficiently large r.p.m., a larger pulley should be placed and its diameter may be found as follows:

$$\text{Diam. of line shaft pulley} = \frac{\text{diam. of machine pulley} \times \text{r.p.m. of machine}}{\text{r.p.m. of line shaft}}$$

For instance, if a grinding wheel is to run at 750 r.p.m., has a 4-in. pulley, and is to be driven from a line shaft at 250 r.p.m., the diameter of the line shaft pulley required will be $\frac{4 \times 750}{250}$, which equals 12 inches.

The feed of a machine is equally as important as the surface speed but is of such a nature that it can not be tabulated, since the finish required on a piece governs the thickness of cut to be taken. Feed should always be given as a certain fractional part of an inch per revolution of work on cutter.

Practically all production machines have lead screws with plenty of adjustments for any desired feed, but if not, it is a comparatively simple matter to figure the gearing required between spindle and lead screw for a given feed.

Choosing Feed Gears

For example, assume that a feed of 0.0625 in. per rev. of spindle is required, and that the lead screw has 6 threads per inch. It is evident that the lead screw must make $\frac{6}{16}$ or $\frac{3}{8}$ rev. for one revolution of the spindle and this is, therefore, the gear ratio required. It is only necessary to choose gears whose tooth numbers have this ratio and in this case a 24-tooth gear would be placed on the spindle with a 64-tooth gear on the lead screw.

For drilling feeds, 0.004 to 0.007 in. per revolution will be satisfactory for drills under $\frac{1}{2}$ in. in diameter and 0.005 to 0.015 for the larger sizes.