How To Run A Machine Shop — A Classic Of Industry

Mechanics

ON THE ART OF CUTTING METALS, by Fred. W. Taylor. An address made at the opening of the annual meeting in New York, December, 1906. Published by the American Society of Mechanical Engineers.

In the early years of this century the ancient battle-ground of capital and labor was being invaded by a new protagonist, which was primarily interested neither in the profits of capital nor the privileges of labor, but in the best method of doing the job in hand. One of the more spectacular leaders in this movement was F. W. Taylor, whose ideas on wage scales appeared as a "Classic" in the Science News-Letter of March 29. Those ideas were worked out in connection with the researches on metal-working tools from which the following quotation is taken. Another by-product of this highly courageous tackling of a very complicated problem was the invention of vanadium tool steel.

THE experiments described in this paper were undertaken to obtain a part of the information necessary to establish in a machine shop our system of management, the central idea of which is:

2 (A). To give each workman each day in advance a definite task, with detailed written instructions, and an exact time allowance for each element of the work.

3 (B). To pay extraordinarily high wages to those who perform their tasks in the allotted time, and ordinary wages to those who take more than their time allowance.

4. There are three questions which must be answered each day in every machine shop by every machinist who is running a metal-cutting machine, such as a lathe, planer, drill press, milling machine, etc., namely:

a. WHAT TOOL SHALL I USE?
b. WHAT CUTTING SPEED SHALL I USE?
c. WHAT FEED SHALL I USE?

5. Our investigations, which were started 26 years ago with the definite purpose of finding the true answer to these questions under all the varying conditions of machine shop practice have been carried on up to the present time with this as the main object still in view.

6. The writer will confine himself almost exclusively to an attempted solution of this problem as it affects "roughing work"; *i. e.,* the preparation of the forgings or casting for the final finishing cut, which is taken only in those cases where great accuracy or high finish is called for. Fine finishing cuts will not be dealt with. Our principal object will be to describe the fundamental laws and principles which will enable us to do "roughing work" in the shortest time, whether the cuts are light or heavy, whether the work is rigid or elastic, and whether the machine tools are light and of small driving power or heavy and rigid with ample driving power.

7. In other words, our problem is to take the work and machines as we find them in a machine shop, and by properly changing the counter-shaft speeds, equipping the shop with tools of the best quality and shapes, and then making a slide rule for each machine to enable an intelligent mechanic with the aid of these slide rules to tell each workman how to do each piece of work in the quickest time.

8. It is to be distinctly understood that this is not a vague, Utopian result, to be hoped for in the future, but that it is an accomplished fact, and has been the daily practice in our machine shops for several years; and that the three great questions, as to shape of tools, speed, and feed, above referred to, are daily answered for all of the men in each shop far better by our one trained mechanic with the aid of his slide rule than they were formerly by the many machinists, each one of whom ran his own machine, etc., to suit his foreman or himself.

9. It may seem strange to say that a slide rule enables a good mechanic to double the output of a machine which has been run, for example, for ten years by a first-class machinist having exceptional knowledge of and experience with his machine, and who has been using his best judgment. Yet, our observation shows that, on the average, this understates the fact.

10. To make the reason for this more clear it should be understood that the man with the aid of his slide rule is called upon to determine the effect which each of the twelve elements or variables given below has upon the choice of cutting speed and feed; and it will be evident that the mechanic, expert or mathematician does not live who, without the aid of a slide rule or its equivalent, can hold in his head these twelve variables and measure their joint effect upon the problem.

11. These twelve elements or variables are as follows:

a. the quality of the metal which is to be cut;
b. the diameter of the work;
c. the depth of the cut;
d. the thickness of the shaving;
e. the elasticity of the work and of the tool;
f. the shape or contour of the cutting edge of the tool, together with its clearance and lip angles;
g. the chemical composition of the steel from which the tool is made, and the heat treatment of the tool;
h. whether a copious stream of water, or other cooling medium, is used on the tool;
j. the duration of the cut; *i. e.,* the time which a tool must last under pressure of the shaving without being re-ground;
k. the pressure of the chip or shaving upon the tool;
l. the changes of speed and feed possible in the lathe;
m. the pulling and feeding power of the lathe.

12. Broadly speaking, the problem of studying the effect of each of the above variables upon the cutting speed and of making this study practically useful, may be divided into four sections as follows:

13 (A). The determination by a series of experiments of the important facts or laws connected with the art of cutting metals.

14 (B). The finding of mathematical expressions for these laws which are so simple as to be suited to daily use.

15 (C). The investigation of the limitations and possibilities of metal cutting machines.

16 (D). The development of an instrument (a slide rule) which embodies, on the one hand, the laws of cutting metals, and on the other, the possibilities and limitations of the particular lathe or planer, etc., to which

it applies and which can be used by a machinist without mathematical training to quickly indicate in each case the speed and feed which will do the work quickest and best.

WHILE many of the results of these experiments are both interesting and valuable, we regard as of by far the greatest value that portion of our experiments and of our mathematical work which has resulted in the development of the slide rules; *i. e.,* the patient investigation and mathematical expression of the exact effect upon the cutting speed of such elements as the shape of the cutting edge of the tool, the thickness of the shaving, the depth of the cut, the quality of the metal being cut and the duration of the cut, etc. This work enables us to fix a daily task with a definite time allowance for each workman who is running a machine tool, and to pay the men a bonus for rapid work.

52. The gain from these slide rules is far greater than that of all the other improvements combined, because it accomplishes the original object, for which in 1880 the experiments were started; *i. e.,* that of taking the control of the machine shop out of the hands of the many workmen, and placing it completely in the hands of the management, thus superseding "rule of thumb" by scientific control.

53. By far the most difficult and illusive portion of this work has been the mathematical side: first, finding simple formulæ which expressed with approximate accuracy the effect of each of the numerous variables upon the cutting speed; and, second, finding a rapid method of using these formulæ in the solution of the daily machine shop problems. Several times during the progress of this mathematical work, the writer, feeling himself completely baffled, has asked the expert assistance of some of the best mathematicians in the country. They all smiled when told that we expected to solve mathematically a problem containing *twelve variables,* and in each case, after keeping the formulæ before them for a longer or shorter time, returned the problem to the writer with the statement that it belonged distinctly in the realm of "rule of thumb" or empiricism, and could be solved only by the slow method of trial and error.

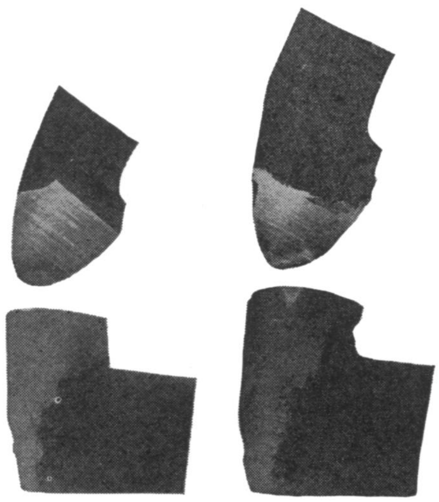
54. In the investigation of an art such as that of cutting metals, and about which at the time our work was started there was so little scientific knowledge, two types of experiments are possible.

55. First, the thoroughly scientific type, in which, after an analysis of all the variable elements which affect the final result, an attempt is made to hold all of the elements constant and uniform, except the one variable which is under investigation, and this one is systematically changed and its effect upon the problem carefully noted.

56. It is to this type that our experiments belong, thanks mainly to the fact that Mr. William Sellers (one of the most scientific experimenters of his day) was president of the Midvale Steel Company when the writer started his work.

57. Second, the type of experiments in which the effect of two or more variables upon the problem is investigated at the same time and in the same experiment.

58. This method is of course much quicker than the thoroughly scientific type, and it is largely for this reason, in the opinion of the writer, that almost all of the other experimenters in this field have chosen it. Several of the experiments of this type have proved most valuable and developed much useful information, and it is with hesitancy that the writer criticises the work of any of these experimenters, since he appreciates most keenly the difficulties under which they worked, and is grateful for the information contributed by them to the art. After much consideration, however, he has decided to point out what he believes to be a few errors made by these experimenters, with the same object which he has in indicating our own false steps: namely, that of warning future investigators against similar errors.



Views of a tool before and after ruining by Taylor investigations. The author states that this drastic measure was adopted because other standards of use "resulted in the impossibility of accurately reduplicating the results obtained. And this after all remains the best gage of the value of experimental methods.... In all cases the earlier standards adopted by us required very close observation and judgment on the part of the experimenter to determine when the tool had reached that state of deterioration which was appropriate to its highest cutting speed. The advantage of our present standard, namely, that of completely ruining the tool, lies in the fact that it is an unmistakable, clear-cut phenomenon which calls for a minimum of judgment on the part of the operator, and thus eliminates one of the sources of human error in the experiments, and enables us to reduplicate our results with accuracy."

In the illustration are shown several views of a tool which has been completely ruined according to this standard.

59. Almost the whole course of our experiments is marked by imperfections in our methods, which, as we have realized them, have led us to go again more carefully over the ground previously traveled. These errors may be divided into three principal classes:

60 (A). The adoption of wrong or inadequate standards for measuring the effect of each of the variables upon the cutting speed.

61 (B). Failure on our part from various causes to hold all of the variables constant except the one which was being systematically changed in order to study the effect of these changes upon the cutting speed.

62 (C). The omission either through oversight or carelessness on our part of some one of the precautions which should be taken to insure accuracy, or failure to record some of the phenomena considered unimportant at the time, but which afterward proved to be essential to a complete understanding of the facts. . . .

64. The effect of each variable upon the problem is best determined by finding the exact rate of cutting speed (say, in feet per minute) which shall cause the tool to be completely ruined after having been run for 20 minutes under uniform conditions.

65. For example, if we wish to investigate the effect which a change in the thickness of the feed has upon the cutting speed, it is necessary to make a number of tools which are in all respects uniform, as to the exact shape or their cutting edge, their clearance and lip angles, their chemical composition and their heat treatment. These tools must then be run one after another, each for a period of 20 minutes, throughout which time the cutting speed is (*Turn to page* 351)

Energy—*Continued*

overcome, quinine can be used to cure the malaria. Instead of using disease to fight disease in the way that was usual before the usefulness of high frequency heating currents was discovered, paresis patients are now raised to high temperature by complex apparatus that consists essentially of a shortwave radio sending set.

Prof. McLennan's new contribution to this treatment is his discovery, made jointly with A. C. Burton, that the heating is dependent upon the conductivity of the material through which the high frequency current is pulsating. Physicians have been reluctant hitherto to utilize the new treatment because they could not be sure just how the patients would heat up. Now through the use of Prof. McLennan's results obtained from tests upon chemical solutions similar to those contained in living things, physicians will be able to tell just what frequencies or wavelengths of current to use to produce a fever in any given part of the body. For Prof. McLennan finds that to heat a material of given conductivity to the greatest degree there is one best frequency or wavelength.

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maintained exactly uniform. Each tool should be run at a little faster cutting speed than its predecessor, until that cutting speed has been found which will cause the tool to be completely ruined at the end of 20 minutes....

66. A change is then made in the thickness of the shaving, and another set of 20-minute runs is made, with a series of similar uniform tools, until the cutting speed corresponding to the new thickness of feed has been determined; and by continuing in this way all of the cutting speeds are found which correspond to the various changes of feed. In the meantime, every precaution must be taken to maintain uniform all the other elements or variables which affect the cutting speed, such as the depth of the cut and the quality of the metal being cut; and the rate of the cutting speed must be frequently tested during each 20-minute run to be sure that it is uniform.

67. The cutting speeds corresponding to varying feeds are then plotted as points upon a curve, and a mathematical expression is found which represents the law of the effect of feed upon cutting speed. We believe that this standard or method of procedure constitutes the very foundation of successful investigation in this art; and it is from this standpoint that we propose to criticise both our own experiments and those made by other investigators.

68. It was only after about 14 years' work that we found that the best measure for the value of a tool lay in the exact cutting speed at which it was completely ruined at the end of 20 minutes. In the meantime, we had made one set of experiments after another as we successively found the errors due to our earlier standards, and realized and remedied the defects in our apparatus and methods; and we have now arrived at the interesting though rather humiliating conclusion that with our present knowledge of methods and apparatus, it would be entirely practicable to obtain through four or five years of experimenting all of the information which we have spent 26 years in getting.

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