Taylor, Taylorism, and Machine-time Slide Rules

Dieter von Jezierski and Rodger Shepherd

Introduction

Machine-time slide rules are an interesting group of special-purpose slide rules that played an important role in industrialization during the Twentieth Century. They were based on pioneering work by Frederick Taylor.

Taylor and Taylorism

Frederick Winslow Taylor, the efficiency expert and inventor, was born on March 20, 1856 in the Germantown district of Philadelphia, Pennsylvania. He died on March 21, 1915 in Newport, Rhode Island. [1]

He received his early instruction from his mother. This was followed by two years of schooling in France and Germany, and extensive travels in Europe. At Exeter Academy he prepared to attend the Harvard Law School. After two years he terminated his studies at Exeter, and he learned pattern making and machining at a pump factory in Philadelphia. For a while he was a simple laborer at Midvale Steel Company. Over the next ten years he worked his way up to be Chief Engineer. During this time he attended night school and earned a degree in mechanical engineering at Stevens Institute of Technology, Hoboken New Jersey. From 1890 to 1893 he was the general manager of the Manufacturing Investment Company, Philadelphia. In 1893 he opened his own consulting office.

By this time he had worked many years and had the opportunity to study many different manufacturing methods and conditions. During the rest of his life he devoted himself to the task of achieving the maximum possible increase in human efficiency. He was the founder of the "system" named after him. It was an approach that created admirers (who called it the Taylor System) and enemies (who scornfully referred to "Taylorism"). Taylor believed that, "by scientific study of every minute step and operation in a manufacturing plant, data could be obtained as to the fair and reasonable production capacities of both man and machine, and that the application of such data would, in turn, abolish the antagonism between employer and employee, and bring about increased efficiencies in all directions." He had in addition worked out a comprehensive system of "analysis, classification, and symbolization to be used in the study of every type of manufacturing organization." [1]

The effect of his system was pivotal in the industrial development of the USA. His system also was accepted enthusiastically in other countries. Among them were Germany, where it was called the Refa System (Refa was an acronym for Reichausschuss für Arbeitszeitberechnungen), and France, where it was called the Bedaux system. For Germany after WWI the application of the Refa System offered a good chance to become competitive again in the marketplace. The Taylor system was comprehensive, but this article will focus on the application of slide rules to the calculation of machining time. In the case of machine tools, these slide rules became an essential aid to achieving one of Taylor's axioms, i.e. the establishment of maximum efficiency. Taylor's exhaustive study "On the Art of Cutting Metals" [2,3] offered guidance which made it possible for the machine-tool industry to make better and more efficient use of machines and tools.

Taylor was among the first (along with Karl G. Barth and H. L. Gantt) to develop and introduce a slide rule for machine-time calculations. For example, in 1904 Taylor was granted a US patent for such a device. At that time he was working exclusively for Bethlehem Steel. A drawing of this slide rule exists [3]. The slide rule consisted of a stator with six slides. (Figure 1) The rule was probably very difficult to operate and required considerable experience to use. This same slide rule was also attributed to Bethlehem Steel Co. [4]

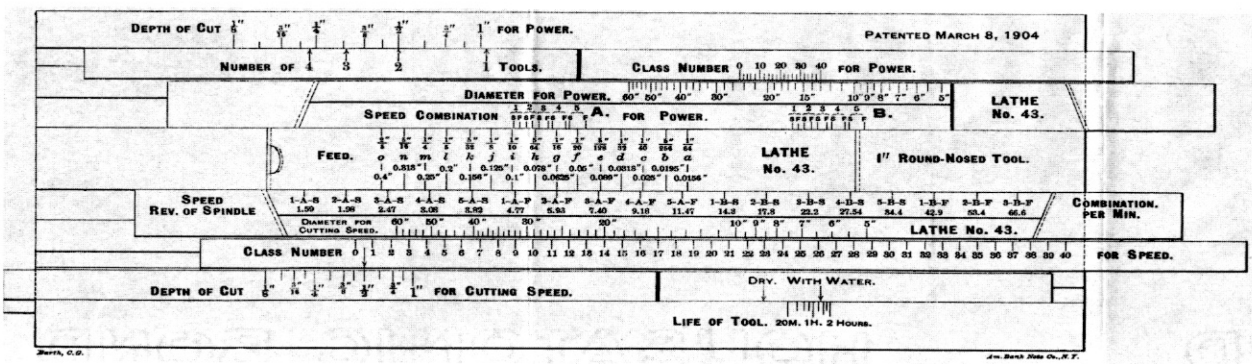

Figure 1. The Taylor side rule as depicted in *On the Art of Cutting Metal.*

The development of the scales of this slide rule was, for the people involved, an extraordinary challenge. The machine-time slide rule was not at all like the usual slide rule whose scale can be calculated and arranged according to well-known mathematical relationships. Taylor mentions twelve variables that must be taken into consideration in machining. These variables include, for example, the characteristics of the metal to be worked, the elasticity of the piece being shaped, the rotation and advance speeds that were possible with the particular lathe, etc. [5] The values for all these variables had to be ascertained by practical experiments (the so-called Bethlehem experiments) which lasted over 25 years. Also, the variables had to be transformed into logarithmic scales, a task at which Carl G. Barth excelled. In this connection, Taylor wrote "That we carried out the task with such perfection is largely due to the tireless efforts of Mr. Barth, who was the best mathematician among us." [3] Indeed, it was the effort to incorporate the painstakingly measured values of all twelve variables that led to such a complicated slide rule with six slides. [6]

Taylor wrote that no machinist could keep track of twelve variables in his head. Also, it was probably asking too much of a machinist to use such a highly developed slide rule as Taylor's. (Actually, as a result of experience with the Taylor slide rule, all the subsequent machine-time slide rules were designed to be much simpler.)

Around the same time (1902) in the USA Barth's Time Slide Rule was introduced and used. Cajori's list of slide rules [4] includes "#178. Barth's Time Slide Rule. A circular slide rule designed by Carl G. Barth, of Swarthmore, Pa., and Fred W. Taylor in the shop of Bethlehem Steel Co." (See Figure 2.) Thus we have reason to believe that Taylor also collaborated in the development of Barth's circular Time Slide Rule.

As can be seen from Figure 2, Barth's circular slide rule had a much simpler system of scales than did the Taylor slide rule. For this reason Barth's slide rule was easier to use, and, for example, it was even used widely in Germany.

After a surprisingly long interval, we see the appearance (around 1918) of a Russian slide rule that appears to belong in this same group. This characterization is presumed to be correct, but it is not certain, since the scales and notation are in Russian and difficult to decipher. [7] As already mentioned, after WWI there were sufficient reasons to justify aids for the calculation of machine-time, and, at least in Europe, the well-known slide rule makers offered such models.

Some Machine-time Slide Rules

Table 1 lists some machine-time slide rules. The list is not exhaustive, but it does provide some idea of the market for machine-time slide rules. In addition to the slide rules listed in Table 1, machine-time slide rules of cardboard and celluloid were offered in England, the USA, and other countries as promotional items.

The claims that makers made for machine-time slide rules are also informative. For example, the Dennert & Pape catalog of 1919 offers the following regarding model #29 (of Friedrich and Hippler):

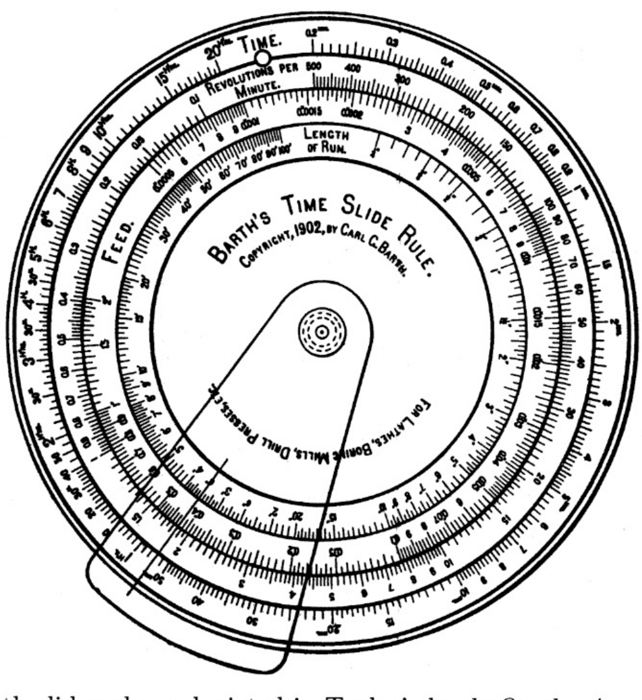

Figure 2: The Barth slide rule as depicted in Taylor's book *On the Art of Cutting Metal.*

> "The new slide rule for high speed cutting and turning is used to determine the most efficient settings for machine tools. It replaces the Taylor slide rule in the German shop and is simpler to operate.
>
> The slide rule also serves to determine the most favorable values for cutting speed, advance, and cutting depth with wet or dry methods for various metals. It can also be used to determine energy expenditure and working times. It is also suited to estimating these variables in advance.
>
> With this slide rule it is possible to make the best use of the machine tool without overworking it."

The Dietzgen catalog 22D from 1955 includes the following regarding model #1751, the Industrial Slide Rule for time and motion study (See Figure 3):

> "An outstanding development in Industrial Slide Rules it is actually two slide rules in one. A Duplex slide rule, having two faces, the Industrial Face (Front Face) is designed for solving mechanical and industrial problems: the Numerical Face (Back Face) has all of the most useful scales found on conventional slide rules.
>
> While other special purpose slide rules have been proposed and designed, they usually have two or more slides—making it necessary firmly to hold the slide not in use to prevent mistakes. The distinct advantage of the Dietzgen Industrial Slide Rule is that it is operated in exactly the same manner as conventional slide rules. Most of the industrial and mechanical problems can be easily solved with only one setting of the slide. It is, therefore, very easy to use."

The Dietzgen catalog goes on to list some typical problems that could be "quickly and easily solved" with the Industrial Slide Rule:

Drilling – distance, RPM, time, peripheral speed, number of pieces

Turning – cutting speed, feed, length of cut, RPM, time

Milling – cutting speed, diameter, time, feed, RPM

Grinding – cutting speed, diameter, RPM, time

Shaping – time, cubic inches

Horsepower

Gearing

Maker	Country	Year Begin	Year End	Model	Form*	Slides /Disks	Material	Comments
Bethlehem Steel	USA	1902		?	circ 4"	4	celluloid	Barth's circular rule
Bethlehem Steel	USA	1903		?	linear 15cm	6	celluloid	Barth's time slide rule
Air Equipment	USSR	1917		?	duplex 25cm	3	wood,brass	System D.N. Fedotova
Dennert & Pape	Germany	1919		27	linear 25cm	1	mahog,cell	System Friedrich and Hippler
Dennert & Pape	Germany	1925	1936	27/28	linear 25cm	1	mahog,cell	System Kresta.
Faber-Castell	Germany	<1931		348	linear 25cm	1	pearwood	"piecework" rule, Syst. Winkel
Faber-Castell	Germany	<1931		348e	linear 25cm	1	pearwood	System Winkel with English units
Faber-Castell	Germany	1935	1936	1/48/348	linear 25cm	1	pearwood	
Faber-Castell	Germany	1937	1956	1/48	linear 25cm	1	pearwood	
Faber-Castell	Germany			1/48e	linear 25cm	1	pearwood	English markings and units
Faber-Castell	Germany			1/48fr	linear 25cm	1	pearwood	French markings
Faber-Castell	Germany	1956	1972	111/48	linear 25cm	1	plastic	
Faber-Castell	Germany	1956		111/48e	linear 25cm	1	plastic	English markings and units
Faber-Castell	Germany	1956		111/48fr	linear 25cm	1	plastic	French markings
Nestler	Germany	1925	1931	26	linear 25cm	1	mahogany	System Friedrich and Hippler
Nestler	Germany	1931	1947	26	linear 25cm	1	mahogany	revised
Nestler	Germany	1955	1973	0260	linear 25cm	1	plastic	The "Mecania". Until 1973. Fr, Eng. Ital
Reiss	Germany	1923	1929	1146	linear 25cm	1	mahogany	System Rath.
AWF	Germany	1932	1952	701				
AWF	Germany			701M				
IWA	Germany	1920's		338	linear 20cm	1	wood,cell	(marked Fried. Krupp)
IWA	Germany	1920's		SR 701	linear, 19cm	?	card,cell	
IWA	Germany	1930's		SR 701 M	linear 19cm	2	card,cell	designed by Bahlecke
IWA	Germany	1930's		SR 701 Zf	linear 19cm	2	celluloid	Staehely. Machine-time and gear milling
IWA	Germany	1960's		01168	linear 15cm		plastic	Bruetsch-Ruegger.
IWA	Germany	1970's		01265				
IWA	Germany	?		01171	circ 11cm	2		
Dietzen	USA	1941	1959	1751	duplex 25cm	1	wood, cell	
Skala	Poland	1956	1976	SLPG	linear 25cm		beechwood	
Logarex	Cech.	1957	1976	601	linear 25cm		plastic	similar to F-C 111/48
Gamma	Hungary	1954	1975	Robot	linear 25cm		cherrywood	
Schacht & West.	Germany	1925?	1936?	?	circ 6.5cm	2	brass	System Thomas
Fearns	UK	?			circ 7.5"	4	plastic	"Maching Time Calculator"
Krebs	Switz.				circ 11cm	4	cardboard	

Table 1. Machine-Time Slide Rules

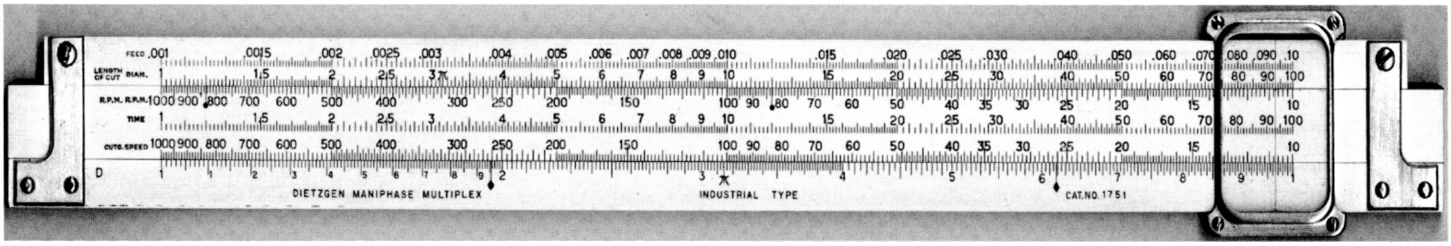

Figure 3: The Dietzgen Industrial Slide Rule, (Model 1751). The scale configuration on the reverse is L,A/B,CI,C,/D,K. (Specimen from the collection of Bobby Feazel.)

Arrangement of the Scale Systems

All the machine-time slide rules have the same basic general-purpose scales, i.e. A/B,C/D, usually with an effective length of 10cm. These four scales are used for the standard purposes and also for the special machine-time calculations.

The special scales on the Faber-Castell model 348 are representative. These scales can be seen in Figure 4 and in the schema presented below:

Working time in minutes and hours
Working diameter or stroke
Feed path (in inches)
Cutting speed: feet per minute
Feed: inches per revolution
Settings for the type of operation, e.g. grinding, planing, milling etc.
Revolutions or "work and return" in strokes per minute

It is important to mention that, to be useful, the special scales on machine-time slide rules had to adapt over the years to changes in technology, i.e. to changes in machines and materials that were used by machinists. For example, in 1939 W. Haustein, an engineer, wrote to Faber-Castell, "For years I used your slide rule with System Winkel with great success. Unfortunately I have been forced to add my own markings to your slide rule because the scales no longer correspond to modern times. Machine tools now employ cutting edges of such new harder metals ... (and) ... higher cutting speeds are applicable." [archive, the author]

Faber-Castell had to respond to this trend and lengthen the scales to include cutting speeds of 100 to 500. The scales for rotation speeds had to be extended to include 300 to 600 revolutions per minute. These scale extensions were actually small but necessary.

"Tables of Standard Values" ("Richtwerttafeln")

As mentioned before, Taylor had attempted to incorporate all twelve variables in his slides, and, in the process, he made his slide rule too complicated to use. After the 1920s most machine-time slide rules were made in the single-sided form with one or two slides. As indicated above, Dietzgen offered a double-sided slide rule (model 1751).

In order achieve the versatility of the Taylor slide rule but retain the portability of the simpler slide rule, most of the simpler models were furnished with so-called "tables of standard values" (Richtwerttafeln). These were either printed on the back of the slide rule or provided on separate strips that would fit with the slide rule in its case. These tables incorporated some of the twelve variables that Taylor had forced into his six slides. Thus the user of more modern machine-tool slide rules did not have to carry books of tables; he had the most important standard values at hand thereon, or with, his slide rule. These tables showed cutting speed v in m/min, feed or advance s in mm/revolution, and advance s′ in mm/min for all the important metals such as carbon steel (CSt), fast cutting steel (Sst), and hard metal (HM) under such working conditions as turning, planing, drilling, and reaming on various machines. With the help of such a table, the user could make the appropriate settings on the slide rule and solve a particular machine-time problem.

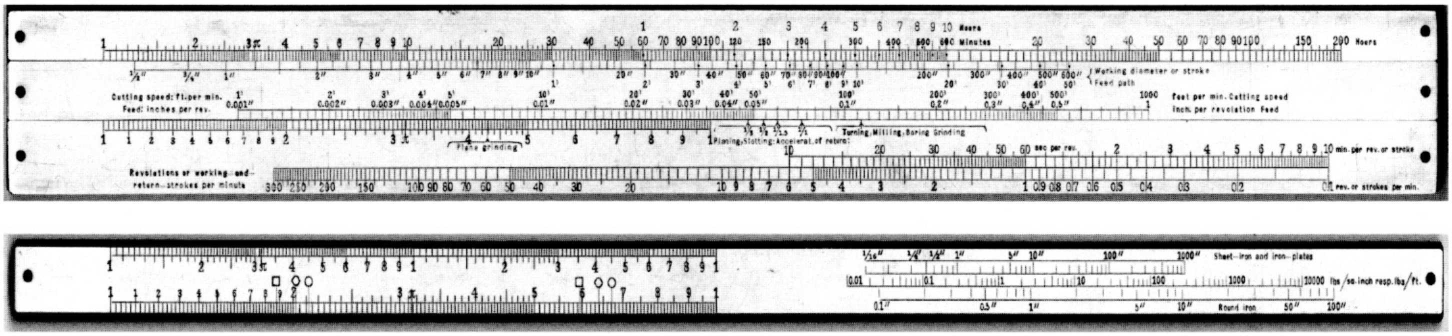

Figure 4: Faber-Castell model 348 (System Winkel) including reverse of slide.

The above description was based on the table provided with Faber-Castell model 1/48. In somewhat shorter form the same thing is described in Dietzgen catalog 22D about model 1751: "The table contained in the slide rule case presents some constants of practice in common use. It shows cutting speeds in feet per minute of machining operations, indicating the necessary variation obtainable when cutting tools of different materials are used in the fabrication of various kinds of metals."

Conclusion

Machine-time slide rules were an important part of a larger movement to increase industrial efficiency. These slide rules were complicated to develop, but they were eventually widely used. Taylor, who began the development of the machine-time slide rule, concluded that, "The benefit of the machine-time slide rule is far greater than all of my other inventions combined." [8] Taylor's own appraisal of the machine-time slide rule is even more impressive when one considers that Taylor was the owner of over 100 patents and that he designed and constructed the largest successful steam hammer in the USA at that time (US Patent 434939, April 1890).

Acknowledgements

Günter Kugel kindly provided source material about System Kresta, as well as a book by A. Wallich and a report by W. Hippler. Heinz Joss provided information from his own collection about 12 models that would not have come to our attention otherwise. Colin Barnes helped with information about English models. Bobby Feazel kindly loaned us his Dietzgen Industrial slide rule.

References and Footnotes

1. These details about Taylor and Taylorism and many of those that follow are drawn from the *Dictionary of American Biography,* edited by Dumas, Malone. London. Humphrey Millbord. Oxford University Press. New York, Charles Scribner Sons. 1936.

2. Seubert, R., *Aus der Praxis des Taylor-Systems mit eingehender Beschreibung seiner Anwendung bei der Tabor Manufacturing Company in Philadelphia,* Auflage, Berlin, Verlag von Julius Springer 1919, p.103.

3. Wallichs, A., *Über Dreharbeit und Werkzeugstähle-Autorisierte deutsche Ausgabe der Schrift,* (*"On the Art of Cutting Metals"*) von Fred. W. Taylor, Philadelphia, p. 229. (Taylor's original English version of *On the Art of Cutting Metals* was presented at the Annual Meeting of the American Society of Mechanical Engineers in December 1906 in New York. The American Society of Mechanical Engineers subsequently published at least three editions of the entire report, which includes 350 pages of text and 148 tables.)

4. Cajori, Florian, *A History of the Logarithmic Slide Rule and Allied Instruments.* Reprint publ. by Astragal Press, Mendham, N.J. 1994, p. 98, rules No.175 and 178.

5. Taylor's full list of variables that affect cutting speed is as follows:

   The hardness of the metal being worked

   The diameter of the work

   The absolute depth of cut or metal to be removed per pass

   The depth of cut relative to the diameter of the work

   The elasticity of the work and the tool

   The shape or contour of the cutting edge together with its clearance and lip angles

   The chemical composition and heat treatment of the tool

   Whether a heavy stream of water is used to cool the tool

   The durability of the cutting edge, i.e. the time that the cutting edge must last under pressure of the shaving without being reground

   The pressure of the chip or shaving on the tool

   The changes in speed and feed possible with the lathe

   The pulling or feeding power of the lathe at various speeds

   (From Taylor, *On the Art of Cutting Metal,* 1906, 3rd ed., revised, page 70)

6. The complexity of the problem can be illustrated by the following formulas for some of Taylor's twelve variables:

$$V = 90/T^{1/8}$$

$$V = \frac{11.9}{F \times 0.665 \times (D \times 48/3)^{0.2373+2.4/(18+48\times D)}}$$

$$P = 45000 \times D^{14/15} \times F^{3/4}$$

   Where

   V = cutting speed in feet per minute

   T = length of time that the tool will last before it must be reground

   F = thickness of feed or advance of tool in inches per revolution

   D = depth of cut in inches

   P = pressure of the chip on the tool in terms of pounds per square inch of sectional area of chip

   (Taylor, *On the Art of Cutting Metal,* 1906, 3rd ed., revised, pages 163 and 207)

7. Maack, Dennis, OSJ Vol. 8, No. 2 , Fall 1999. P. 20-26.

8. Hippler, Willy, "Ein Rechenschieber für die Werkstatt zur Einstellung der Werkzeugmaschine auf wirtschaftlich höchste Leistung", Zeitschrift *Die Werkzeugmaschine,* 1919.