An Early Home-Made Spring Calculation Slide Rule

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Introduction

After repeatedly coming across a posting online for a "Vintage Wood Wooden Spring Weight Calculator Slide Rule" over several months, I finally purchased the rule for a reasonable price mainly to look at its use of two adjacent slides and also because it was literally just a few miles down the road from my home in Illinois. The on-line images were not very sharp and so it was hard to tell what all the scales were, but it appeared to be hand-drawn and, although the advertisement indicated otherwise, I had assumed it to be of length 10 inches or so. I was surprised when I got my hands on it and it was actually 17 inches in length. Talking to the antique dealer in Elmhurst, IL, she was not sure where the slide rule came from as it was found in a box of items traded between dealers and hence, she was not familiar with its history.

The stock of the slide rule is made from three-ply plywood, 0.75 inches thick, with a total width of 2.5 inches. The device has no cursor, nor any sign of accommodation for one. The front side of the rule has two side-by-side slides, while the back side also has a totally separate slide, thus three in all. The scales are on paper glued to the wood, and the scales and labels appear to have been written by hand, though rather carefully drawn. A composite image of the slide rule is shown in Figure 1.

FIGURE 1. Early Spring Calculation Slide Rule

It is interesting that the slides of this apparent home-made rule have been cut from the stock in a dovetail fashion. The two adjacent slides have been formed by a single dovetail cut through the stock, and then a single square cut being used to form two pieces. This arrangement guarantees that these two slides only fit one way, yet stay snugly in place when the rule is turned over. A detail of the end of the slide rule is provided in Figure 2.

The slide rule at hand has scales that are used to evaluate the following two equations, which are written on the upper and lower stock of the rule:

$$P = \frac{0.196\quad {}^3S}{r} \qquad \text{and} \qquad f = \frac{64NPr^3}{d^4G}.$$

The slide rule has an error in the printing of the second equation (d rather than d^4), though the scales themselves perform the correct calculation.

FIGURE 2. Right-Hand End of Slide Rule.

Additionally, I have used the symbol G above rather than E_s which is used in the equation on the rule, since closer inspection showed that the symbol G is used to label the relevant scale on the rule, rather than E_s.

But most significantly, when I finally took out the slides to inspect the construction of the rule I was surprised to find engraved in the well of the front side (see Fig. 3): "R. K. Baetzmann, 1941".

FIGURE 3. The Two-Slide Construction, and the Front Well with Slides Removed.

Some Background

From Michael Konshak's comprehensive JOS article in 2006,[1] the earliest spring design calculators appeared as slide charts in the mid-1940s, generated by companies that manufactured springs. Recent communication indicates that this conclusion has not changed in the past 16 years.[2] The article has examples of slide charts from as early as 1943 sold by the Wallace Barnes Company, a division of the Associated Spring Corporation (ASC) in Connecticut. These slide charts were manufactured by the J.B. Carroll Corporation of Chicago, and J.B. Carroll eventually sold a plastic slide rule that contained a patented 1952 scale set, also designed for ASC. The riveting used in its construction is very similar to that of the 1943 slide charts. Eventually slide rules for spring design calculations were made by major manufacturers, perhaps most notably by Pickett in Chicago, who used the same patented 1952 design in their model 1025 for ASC. Spring slide rules by Acu-Rule Manufacturing Company in Mt. Olive, IL, (Acu-Math) are also noted by Konshak, but date to around 1960. From all of this it appears that our wooden slide rule pre-dates these early examples of the known slide rules and slide charts of this genre from the major slide rule and spring manufacturers.

R. K. Baetzmann

A simple on-line search revealed that Robert Kristian Baetzmann was born in 1908 and grew up in Chicago, Illinois. Records show that he studied Mechanical Engineering at the University of Illinois in Urbana-Champaign, graduating in 1932.[3] The search also revealed that Mr. Baetzmann was a member of a three-person group that received a patent, submitted in 1946 and granted in 1952, for a positioning control system.[4] The patent shows that Baetzmann was working at the Askania Regulator Company in Chicago at the time the patent was submitted. The lead author of the patent, also of Askania, is Herbert W. Ziebolz, one of the pioneers in the field of automatic control and who was responsible for many patents in such areas as jet pipe regulators and signal devices, translator chains, and pneumatic safety devices.[5] The third author, Daniel T. Gundersen, is known for his 1948 patent of the electric arc furnace control system,[6] and several others. It appears very likely that Baetzmann would have been working for Askania at the time his slide rule was made, and such a rule would have been very helpful in the design work being pursued by the Askania group.

Following his work with Askania, Mr. Baetzmann was later employed for many years at the Metropolitan Sanitary District of greater Chicago and eventually retired from his position there, according to his obituary. He passed away in Elgin, IL, in 2004. Beginning in 2005, the College of Engineering at the University of Illinois began to offer the Robert K. Baetzmann Scholarship for undergraduate study in various engineering disciplines.

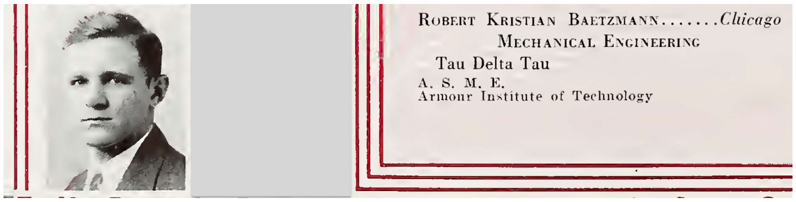
ROBERT KRISTIAN BAETZMANN.......*Chicago*
MECHANICAL ENGINEERING
Tau Delta Tau
A. S. M. E.
Armour Institute of Technology

FIGURE 4: Excerpt from University of Illinois Yearbook, 1932

Spring Calculations

A few of the more general parameters for basic spring design calculations involve properties of the material being used, in particular its torsional modulus of elasticity, G, and its safe shearing stress, S; the diameter, d, of the wire used in making the spring; the radius, r, of each coil of the spring, and the number of coils, N, used to make a complete spring.

With these parameters, one can compute the load P, in pounds, that the spring can safely support, according to

$$P = \frac{\pi}{16}\frac{d^3 S}{r} \qquad (1)$$

Additionally, one can compute the *rate* for the spring, the deflection of the spring per unit of load or, alternatively, the deflection f directly through the relationship

$$f = \frac{64 N r^3 P}{d^4 G} \qquad (2)$$

Slide rules constructed a decade or more later incorporated calculations of other design features and corrections (such as square *vs.* circular wire cross section, *etc.*). However, the early slide rule we have here is designed to analyze the two basic relationships shown above.

The Scale Set

The uncommon side-by-side double-slide front of the rule and the single-slide back side of the rule contain the following scales, using our above notation for the relevant variables:

Front: P [d r] [G N] f
Back: S [r d] P

where P is in pounds, d, r, and f are in inches, and G and S are in pounds per square inch. The quantities within a bracket are found on a slide. Each of the scales on the rule are logarithmic in nature, and a quick set of measurements provides the length of a decade on each. This scaling is slightly different on the two sides of the rule for values of r and d as shown in Table 1.

As this appears to be a one-off in-house slide rule, let us examine how the scales might have been developed. Starting with the back of the rule, these scales are used to evaluate Eq. 1, which can also be re-written as

$$S/r = P/d^3 \times 5.09.$$

Matching up a value of r on the slide with a value of S on the stock is equivalent to finding S/r. Doing the same at the bottom interface, lining up numbers on d on the slide with numbers of P on the stock is taking the ratio of P/d^3. So, if $P = d = r = 1$, then, within factors of 10, we should find $S = 5.09$, which is indeed the case.

Looking at the front side, with two slides, the scales are used to evaluate Eq. 2, which can be factorized as

$$f/N = (P/d^4) \times (r^3/G) \times 64.$$

A quick check on the slide rule can be made if we move the two slides so as to line up $d = 1$ on the top slide with $P = 10{,}000$ on the top stock ($P/d^4 = 10^4$), then line up $G = 10{,}000{,}000$ on the bottom slide with $r = 1$ on the top slide ($r^3/G = 10^{-7}$). Doing so we find that $f = 6.4$ on the bottom stock is opposite $N = 100$ on the bottom slide and $f = 0.64$ is opposite $N = 10$, i.e., $f/N = 0.064$ ($= 64 \times 10^{-3}$) as required. Maximum reasonable ranges for the important parameters, like r, d, P, and f are used to set the

TABLE 1. Scale Variables

Front	**Range**	**Distance (1 Decade)**	**Unit**		***Back***	**Range**	**Distance (1 Decade)**	**Unit**
P	0.1 - 10K	(5.9 cm) log$P$	lb		S	20K - 300K	(5.9 cm) log$S$	lb/in^2
d	0.03 - 1	(23.6 cm) log$d$	in		r	0.01 - 5	(5.9 cm) log$r$	in
		= (5.9 cm) logd^4			d	0.015 - 1	(17.7 cm) log$d$	in
r	0.028 - 5	(17.7 cm) log$r$	in				= (5.9 cm) logd^3	
		= (5.9 cm) logr^3			P	0.1 - 10K	(5.9 cm) log$P$	lb
G	5M - 20M	(5.9 cm) log$G$	lb/in^2					
N	1 - 300	(5.9 cm) log$N$						
f	0.1 - 100	(5.9 cm) log$f$	in					

overall extent of the scales, and likely helped to determine the overall length of the slide rule itself.

Comments on Accuracy

A close inspection of some of the lines marked on the slide rule provides evidence of a hand-drawn system and questions the accuracy of the device. If the distance between decades along a logarithmic scale is L_0, then the value x on the scale is at a distance $L = L_0 \log x$. An error ΔL in the printing, reading, or setting of a mark on the rule will give an error in the value of x provided by $\Delta L = L_0/\ln 10 \cdot \Delta x/x$, and so the error in the calculation Δx will scale like

$$\frac{\Delta x}{x} = \frac{\ln 10}{L_0} \cdot \Delta L.$$

For the hand-drawn lines on the Baetzmann slide rule, the length of the standard decade is L_0 = 59 mm, or $\Delta x/x = \Delta L/(25.6 \text{ mm})$ for this rule. A marking error of, say, 0.1 mm or so would give an error in the evaluation of about 0.4%. Four to six scales each with 0.1 mm marking errors could add up to produce an error of a few percent.

It is easy enough to check the computations of the slide rule against modern technology. A total of 16 random calculations were performed using the slide on the back of the rule, and compared with results from using a laptop computer. This gave a typical absolute error of about 2.0-2.5%.

On the front side, we have more variety in the parameter combinations, but a similar exercise was performed for a similar number of combinations. I found that the typical error in the evaluation of Eq. 2 compared to a computer-generated result is again about 2.5%. Though certainly not an exhaustive error analysis, this shows that typical calculations on the rule are expected to be accurate to the few percent level which is arguably consistent with a hand-drawn system.

Final Remarks

Our example here is a very early spring design calculation slide rule, earlier than the common slide rules produced by major manufacturers for this application. Its unique three-slide feature made from a single stock makes it especially interesting as an example of a multi-parameter calculation device.

In creating and/or overseeing the manufacturing of his slide rule, Robert Baetzmann of Chicago was perhaps influenced by the city's local slide rule makers and distributors such as Pickett, Dietzgen, Post, Keuffel and Esser, and others who had headquarters and other major offices in the city. Or, perhaps it was the other way around. As an engineer working in metropolitan Chicago, it begs the question as to whether Baetzmann and his Askania colleagues had early interactions with companies like Associated Spring and with the local Chicago slide rule makers, helping to influence the early development of a set of slide rule scales for the industry through the development of his own slide rule. On the other hand, it is equally likely that Baetzmann found it easier and more satisfying to simply build his own slide rule for his needs, and that's that.

Whatever the story behind the man, the Baetzmann slide rule is a piece of history, showing that spring design calculations had become commonplace enough to demand their own special slide rule in the early 1940s, and demonstrating what a good Midwestern engineer will do to get the job done. (No bias here, of course.)

Notes

1. Konshak, Michael, *The Spring Design Slide Rule Calculator*, Journal of the Oughtred Soc. 15:1, 2004.
2. Michael Konshak, private communication.
3. *The Illio 1932*, University of Illinois yearbook. See https://archive.org/details/illio193239univ/mode/2up.
4. United States Patent Office, No. 2,613,502, "Positioning Control System For Remote Elements, Including Hydraulic Transmission Units", Herbert Ziebolz, Daniel T. Gundersen, and Robert K. Baetzmann, Chicago, IL.
5. Slater, L.E., A. S. Iberall, and H. M. Paynter, *On Herbert W. Ziebolz*, Journal of Dynamic Systems, Measurement, and Control, Transactions of the ASME, 1975.
6. United States Patent Office, No. 2,447,066, "Electric Arc Furnace Control System", Daniel T. Gundersen and Paul Glass, Chicago, IL.