Johannes Gutenberg's System of Movable Type
c1540-1550

By around 1540 Gutenberg had conceptualized all the elements needed to print with interchangeable type, including an oil-based, fast-drying ink; a durable easy-to-cast metal alloy for making type; and a screw press designed for rapid operation. But the key to his synthesis was an adjustable mold for rapidly casting metal type, enabling him to replicate any given alphabetic character with precision thousands of times, a precursor of the principal of interchangeable parts. Gutenberg's synthesis dramatically lowered the cost of printing, thus contributing to the expansion of literacy and the more rapid exchange and more permanent preservation of ideas. These developments, in turn, facilitated the dissemination of ideas essential for the scientific and industrial revolutions.

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ASME
SETTING THE STANDARD

Gutenberg and Mass Production

The Bible involved a lot of letters

We have become accustomed to regarding machine-made products as essentially identical. We simply expect that new razor blades will fit the razor for which they were designed and that if you need a ¼-20 screw you can get an identical one at the hardware store. Such interchangeability is the hallmark of mass production. Eli Whitney was among the first to introduce the concept in the early nineteenth century when he began using jigs and fixtures to produce functionally identical components for muskets. Henry Ford carried mass production to another level when he introduced the moving assembly line, which was a means of streamlining the assembly of parts and relied on the fact that they were interchangeable. With this background, we have been comfortable in our belief that mass production is a creation of the twentieth century or perhaps the nineteenth. In fact, this conviction misses the mark by about four centuries. The proof is so obvious that, like Poe's purloined letter, we continually look at the evidence and literally don't see it. Any modern publication on "mass production" will be printed on a page that is composed of around a thousand nominally identical letters. This is *real* mass production, and we know that it dates from the time of Gutenberg. He started it all in about 1450.

Gutenberg is generally—if not quite correctly—famed for his invention of moveable type. In fact, long before Gutenberg, the Chinese inventor Bi Sheng in the 11th century developed movable type using porcelain. The tradition persisted in China and diffused to other regions, like Korea, where inventors used metallic, movable type in the 14th century. However, the very large number of logograms in the Chinese language, as well as social conditions, limited the impact of movable type in East Asia. The much smaller number of characters in Western alphabetic languages and different social conditions would enable Gutenberg's system to have much wider and more rapid diffusion and a much greater impact.

Woodblock printing (xylography) for things like printing textiles as well as papermaking had also diffused from China westward during the first millennium. By the mid-fifteenth century, they had come together in Europe resulting in 'block books'—where the whole page, often mostly image but with some set text, was printed in a single impression. Thus, primitive moveable type, usually in the form of wooden text blocks existed in Europe before Gutenberg. Moreover, by 1530 to 1540 some Europeans, like Laurens Janszoon Coster in the Netherlands had begun to experiment with movable type. Coster's type was crudely cast in sand. It was Gutenberg who carried things to the next critical step. His achievement was to break material to be printed down into individual letters and then create the movable fixtures (moulds) which made it possible to cast an unlimited number of copies of each letter rapidly. To do that he fabricated, using hand tools, both the master letter punch and then the variable-space casting hardware, a task which even a contemporary machinist would find challenging.

The usual emphasis placed the movable type itself ignores Gutenberg's real innovation, which was the method of producing unlimited numbers of each letter. Eli Whitney, often credited with the introduction of interchangeable parts shortly after 1800, produced muskets in paltry quantities on the order of a thousand. Gutenberg's first edition of the Bible—a mass produced product—involved something like four million individual letters! Even considering that he ran three presses simultaneously and presumably struck pages and then reused the type, this required an enormous number of individual type characters that could be interchanged.

Gutenberg' process of making type began by hand carving the mirror image of each letter on the end of a soft steel punch, which was later hardened. The punch was struck into a softer metal matrix, usually of copper. The matrix was then used as the base of a mold which shaped an individual piece of type. The type was cast in a lead-tin alloy of Gutenberg's concoction (now called type metal) which, because of an admixture of antimony, had the property of expanding slightly upon setting. It thus exactly reproduced the form of the letter indented in the matrix. Gutenberg's knowledge of this alloy probably grew out of his earlier experience as a goldsmith, since goldsmiths used a similar casting technique for the production of ornaments. His work in jewelry production no doubt required him to develop the manual dexterity he needed to cut punches.

The mold which held the matrix was the real key to mass production, and it was far more complicated than the familiar spherical bullet mold. It had to satisfy a number of requirements. Most fundamentally, a single mold had to be adjustable to accommodate the variations in width of different letters. A comma for example, required a much narrower mold than a "w", although both had to be of the same height. Each mold had to provide a precisely rectangular cross section and had to maintain the vertical position and angle (the "registering") of each letter. The mold had to open quickly to remove the type after hardening and had to accommodate the fact that the dimensions of the matrices were arbitrary. That made it necessary to precisely clamp flat plates of varying dimensions, and at the same time orient them relative to the rectangular mold cavity. Fine tuning of the assembly so that each letter would remain properly oriented and spaced relative to adjacent letters was an art in itself. An entire class of craftsmen (typefounders) specialized in doing nothing other than making these adjustments. An experienced typefounder could cast a piece every ten to twelve seconds.

An example of the molds as they evolved after Gutenberg is shown in **Figure 1**, although this illustration was created three hundred years after his death. Nothing earlier exists, but the principle did not change. The operational details are far from obvious from this drawing, but it can be seen that this is not a trivial piece of machining. **Figure 2** is a much-simplified schematic showing the essentials of the process. Metal is poured into the mold through a wedge-shaped sprue or "tang" which is later broken off. Perhaps the finest mechanical work being done at the time was in making jewelry, and this was Gutenberg's heritage. Clockmaking had by this time developed quite complex timekeepers and astronomical clocks, but nothing on such a small scale as Gutenberg managed to do for typecasting (intricate watches were still half a century away). And to further put it in historical perspective, Columbus did not sail until fifty years after Gutenberg printed his Bible, though already Europeans were venturing out of their near oceans.

The developing art of printing was aided by contemporary innovations in technology. "Burning glasses" were well known as early as the fifth century BCE when Aristophanes mentioned them in a comedy and works on optics in the Greek, Islamic, and medieval period took them for granted, reading glasses were only apparently invented in the thirteenth century, and by Gutenberg’s time were fairly common among scholars and clerks. An even more important factor, without which large volume publishing would have been impossible, was the art of papermaking. Although it had long been known in the East and spread through the Islamic world by the ninth century, papermaking became widespread in Europe only by the end of the thirteenth century, and with it the rise of recordkeeping, writing, copying of ancient texts, as well as commentaries and new authorship —and ultimately literacy itself—all of which created the demand for books and other printing that Gutenberg capitalized upon. Incidentally, the other

thing that printing helped create was capitalism itself, because the investments in the type sets was large to begin with, and in order to produce a print run of 100 or 500 books, the printer needed to purchase all the paper and print the whole print run before he could sell a single completed volume.

The actual form of letters, the "font," is a study in itself. The first fonts duplicated the common form of fifteenth-century handwriting known as Gothic script used by scribes. That must have made early punch cutting relatively easy because the printed letters were being used to counterfeit hand written documents. They were therefore of a size and shape comfortably made by hand. It became common during the late Middle Ages for punch cutters to organize into houses whose product was the embossed matrices. Those were sold to typefounders, who cast the type and then sold it to printers. Around 1500, type making became more demanding when more rounded, complicated letter forms appeared in Italy (known then as 'italic' type, though not yet slanted as we think of it) that reproduced the style of inscriptions on Roman monuments. Specimens of these fonts have endured to present; in fact, many modern fonts have a genealogy which can be traced unbroken back to the Middle Ages. Punch cutting, whatever the font, was regarded as a proprietary art, and the techniques were kept secret, though full type sets were sold across Europe, both new and on the used market as new styles came in. This art has recently been explored in an exhaustive 1996 work which traces all the steps in cutting. *Counter Punch* by Fred Smeijers, edited by Robin Kinross, is not a treatise on boxing. The counter punch is a tool used to emboss the bar that will eventually become a punch. *Counter Punch* documents what was learned by Smeijers, who duplicated the original methods in order to better understand the process. His book also includes detail on the aesthetics of letter forming. There is a real art involved in proportioning letters. Refinements include, for example, slightly adjusting the shapes of otherwise identical letters to retain their character when the size is changed.

The manual skill involved in punch cutting is still truly extraordinary. Until optical or mechanical means of letter forming appeared, which did not happen until the last century, each punch was the handiwork of a single artist. No aids in the form of mechanisms were available until high speed rotating machinery arrived. It is tempting to imagine that some form of reducing pantographs were used, but such machinery did not arrive until the industrial revolution, depending as they did on high speed rotating cutters. That technology did not arrive until around 1814. The most famous pioneering effort to apply modem methods to typefounding was made by Linn Boyd Benton, a now much respected name in typemaking. In 1906 he described a "Delineating Machine" that used a pantograph that traced a large drawing of a typeface and produced a steel punch at a much-reduced scale. That was a very impressive example of precision mechanism design. As a demonstration, Benton was able to cut type in which the lower case letters were .0044" high. Remarkably, cutting was done with a rotating tool .0005" in diameter! He used that as an advertising gimmick on a par with the familiar "Lord's Prayer on the Head of a Pin." Letters as small as .055 inches high ("4 point type") have been produced routinely. Even smaller typefaces are sometime made. Creating these using nothing but hand files and scrapers is a virtuoso performance. Producing a recognizable letter is only the beginning. Each letter must be given a distinctive character by variations of thickness and shape, which require adjustments on the order of .0001 inch.

Johannes Gensfleisch zur Laden zum Gutenberg (1398-1468) was born in Mainz, Germany, to a family which moved to Gutenberg and adopted the name of that city. Little is known about his youth. He apparently learned the skill of engraving, which led to his invention of movable type printing, while he was working with a goldsmith.

Although his name is renowned now, Gutenberg was not a financial success during his lifetime. His first venture in the printing business was to mass produce indulgences, single sheets that were offered for sale that offered remission of various sins or reduction in penances, for the appropriate fee, of course. Although they had been available before as hand-written forms, printing turned them into a big business for the Church (and the printers), which placed a real premium on mass production. Around 150 thousand are known to have been printed of a single indulgence, and many, many different indulgences were printed all across Europe as the printing press spread.

As another example of the influence of technology on history, those printed medieval equivalents of "get out of jail free" cards were one of the major factors that disturbed Luther and prompted him to initiate the Protestant Reformation sixty years later.

Gutenberg's introduction to printing via religion probably led to his decision to produce a Bible as his first major book project. Although that decision was a milestone in human history it did not benefit him personally. The proceeds from his famous Bible printing, which was completed in 1456, went only to his collaborators after he was forced to cede his business to them. He had lost several lawsuits arising from defaults on loans. After the Bible, he was moderately successful publishing a prayer book in 1460.

He died while living on a pension from the Archbishop of Mainz. Gutenberg's fame, which is entirely posthumous, is acknowledged in Mainz, where he printed his Bible, with statues and by the Gutenberg Museum. It is significant that the sculptor of his statue had to work from his imagination, as so little was Gutenberg's fame during his lifetime that no portraits of him, or of his type foundry, exist.

Further Reading

There is considerable interest in preserving the history of printing and typefounding. In Holland. the Plantin-Moretus Museum displays artifacts, dating from 1499, related to one of the first publishing houses that capitalized on Gutenberg's invention.

A discussion of early east Asian printing and its diffusion can be found in He Zhou, "Diffusion of Movable Type in China and Europe: Why Were There Two Fates?," *International Communication Gazette*, 53:3 (1994): 153-173.

A number of modern publications exist that describe early typefounding. Among them is *A Short History of the Printed Word* by Warren Chappell, originally published in 1970 by The New York Times and reissued by Hartley & Marks in 1999 with additions by Robert Bringhurst. *A History of Graphic Design* by Philip B. Meggs was published by John Wiley & Sons in 1998. *A View of Early Typography* by Harry Carter (Hyphen Press, 2002) explores the subject in rich detail. Elizabeth L. Eisenstein's *The Printing Revolution in Early Modern Europe*, published by Cambridge University Press in 1983 provides a very good overview of the broader impact of Gutenberg's innovation, and Adrian Johns' *The Nature of the Book: Print and Knowledge in the Making*, published by the University of Chicago Press in 1998 continues the analysis.

The bible of the typefounding industry, after 300 years, is still *Mechanik Exercises on the Whole Art of Printing* by Joseph Moxon, 2 vols. (London: by the author, 1683-84).

About the author: Robert O. Woods is a Fellow of ASME and a frequent contributor to *Mechanical Engineering*. While visiting Mainz he was given an opportunity to strike a page of print from a replica of Gutenberg's press.

Cover image based on a 19th century steel engraving, online courtesy Wikimedia Commons.

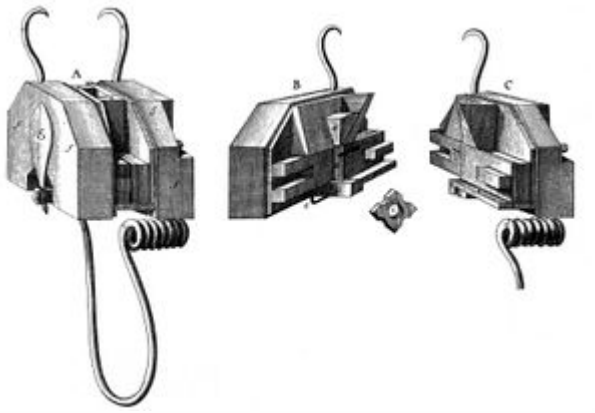

Fig. 1. No contemporary records exist of Gutenberg's type-making tools; he may have used molds like these 17th-century French designs.

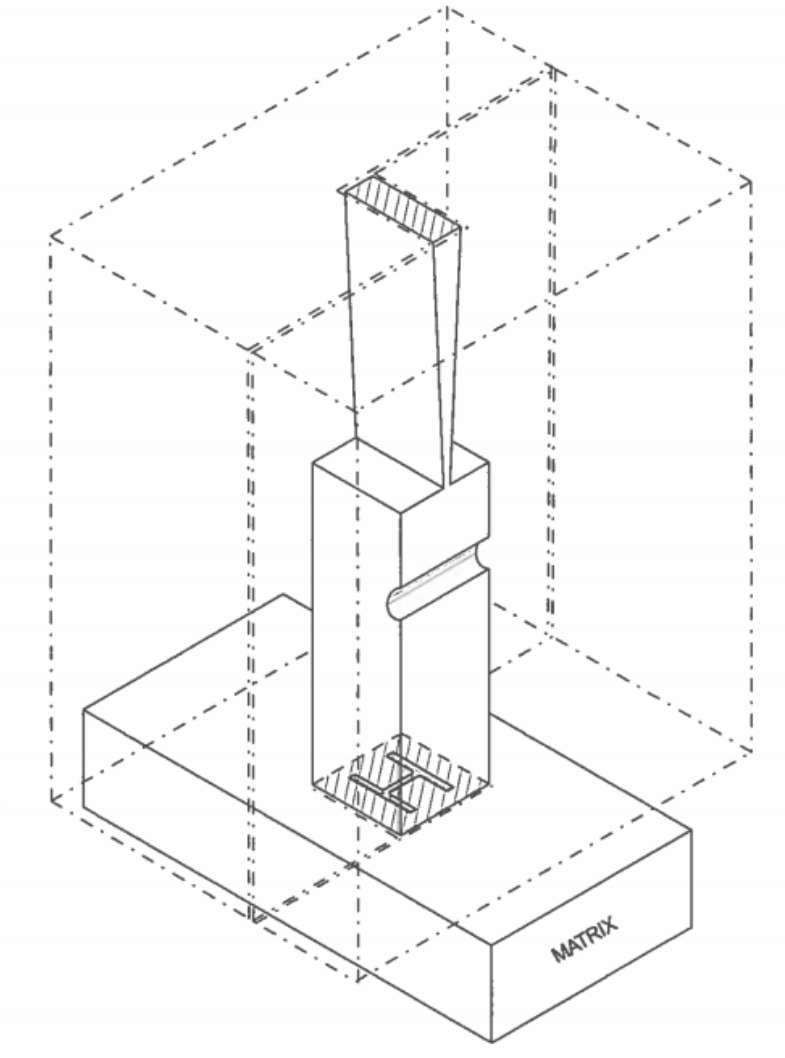

Fig. 2. Conceptual drawing of Gutenberg's method of mass-producing type. In this concept drawing the open-bottomed mold is shown in phantom lines. The mold is shown in place on a matrix of arbitrary dimensions. The letter to be cast (an H in this example) has been heavily embossed into the matrix. Type metal is poured into the cavity shown in solid lines. After the mold is opened, the wedge-shaped sprue is broken off. A line of type will be assembled, guided by a rail which engages the semicircular groove on the side of the completed type bit.

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> *Note: In the following list of names, include any others, if appropriate, who were involved in a significant way with the specific landmark ceremony. The people listed should be incumbent in the position as of the designation ceremony date. Pursuant to ASME guidelines, include, if applicable, the designation P.E. offset by a comma from the name. Exclude any academic or honorific titlles.*

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