History of Mechanical Computing Machinery

GEORGE C. CHASE

Foreword

I. Bernard Cohen
Victor S. Thomas Professor of the History of Science
Harvard University

George C. Chase's survey has long been admired by those in the know as a most attractive personal view of the development of machines for mechanical computation. Originally presented in May 1952 as a slide show during the ACM National Meeting in Pittsburgh, Chase's presentation is notable for its genial style, its wealth of information, and the author's personal reminiscences. Chase was particularly well informed about the activities of many inventors or manufacturers of the late nineteenth and early twentieth centuries, a number of whom were personal friends and acquaintances. Thus, Chase introduces Carl Friden **(22)** as "my good friend," who "was a lover of fine horses." Furthermore, Chase knew how these machines actually functioned and, for example, could state easily and authoritatively that the "Friden machine is a Thomas, or polyphase, nonreversible cycle type."

Chase's association with calculating machines goes back to the early years of the century, when he and his brother were selling "Millionaire" calculators in Massachusetts. He records **(38)** how one of these was sold to the astronomer Percival Lowell, who hoped to use this machine to simplify his calculations of the perturbations supposedly produced by an as-yet-undiscovered planet (Pluto) on the motion of Uranus. Chase became interested in mechanical calculation when, in 1904, he worked as a salesman for his brother, Louis Chase, who had an office appliance shop (then in North Adams, later in Boston). He became a sales agent for an office calculator called the Mechanical Accountant, manufactured by the Mechanical Accountant Company in Providence. Chase had difficulty selling the device because it was "clumsy and inadequate,"[1] but before long he had devised such practical improvements that he became a member of the firm; he was general manager until 1917, a tenure marked by many inventions and patents and a series of improvements.

After the Monroe Calculating Machine Company attempted unsuccessfully to purchase the Mechanical Accountant, Chase joined Monroe where he became director of research. Among his innovations at Monroe was the motorization of calculators and a degree of automation. In a statement prepared in February 1953 for the American Society of Tool Engineers, Chase's career is described as follows:

"Born in Worcester, Massachusetts, Mr. Chase received his early education in that city. Keenly interested in mechanical devices, his business career started in the field of computing machinery and he has never engaged in any other. As a young man he began his work on key-driven adding machines and in 1906 completed his first experimental models of mechanisms applicable to machines of that type. Continuing his study and experimentation in the following years Mr. Chase visualized and perfected a fundamentally new mechanism for a key-driven machine that he placed on the market in 1915. Its underlying principle is now in use in many different types and makes of adding and calculating machines.

"In 1917 Mr. Chase joined the Monroe Calculating Machine Company. With Jay R. Monroe he worked closely with Frank Stephen Baldwin whose achievements, as early as 1875, marked the beginning of the calculating machine industry in the United States. After Mr. Baldwin's retirement his principles were carried forward and added to by Mr. Chase's inventions. New features developed by him have not been limited to any single make or type of machine, for many manufacturers both in the United States and Europe now use mechanisms in their machines which have been patented by him.

"In May 1932 the Franklin Institute of Philadelphia awarded the Monroe Company the John Price Wetherill Medal in recognition of the consummation of completely automatic operation in the four basic rules of arithmetic: addition, subtraction, multiplication, and division as attained through Mr. Chase's inventions."

Chase's presentation of the historical record is published here essentially as it appeared in the *Pro-*

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[1] Information kindly supplied by Myrna K. Chase, George Chase's daughter-in-law, in a personal letter, March 20, 1980.

ceedings of the Association for Computing Machinery in 1952, with a few minor corrections. I have appended a few notes (in brackets), amending or revising an occasional statement that may no longer square with our knowledge or one that may be a slip. At the time of the lecture, Chase had a collection of older calculators **(8)**, which were displayed "in my exhibition adjacent to the registration desk." I do not know what has become of this collection.[2]

The reader will observe that Chase devised a means of classifying the early mechanical calculators according to function **(19)**. Among many interesting observations is the remark that "many of the machines developed in the United States had their beginnings in or near St. Louis." Chase found this to be surprising, "since no adding or calculating machines are manufactured in that city at the present time."

Some readers may find it odd that Chase did not mention several computing pioneers, such as Presper Eckert, John Mauchly, George Stibitz, John Atanasoff, or Konrad Zuse. Chase may have limited himself to his own personal contacts and experience.

Perhaps the most remarkable topic in Chase's presentation is the concluding discussion of Howard H. Aiken and Mark I **(56)**. Chase described an interview with Aiken on April 22, 1937, in which Aiken "outlined to me his conception... and explained what it could accomplish in the fields of mathematics, science and sociology." Chase described some of the proposed features of Aiken's invention and concluded: "What he had in mind at that time was the construction of an electromechanical machine, but the plan he outlined was not restricted to any specific type of mechanism; it embraced a broad coordination of components that could be resolved by various constructive mediums."

On February 24, 1973, I had a copy of Chase's article with me on the occasion of a taped interview with Howard Aiken in his home in Ft. Lauderdale. This interview, conducted by Henry S. Tropp and me, was part of the oral history project sponsored by AFIPS and the Smithsonian Institution to record the personal experiences of computer pioneers.[3] In the course of the interview I pressed Aiken to explain why he had chosen to build Mark I out of electromechanical parts. He replied that he had been aware that to make his computer a reality would require "money and a lot of it." It had seemed to him more feasible to "build the first machine out of somebody's existing parts," rather than to have to invent or construct parts. Electromechanical relays and step switches were already in wide use, teletype had been developed, and there was punched tape or punched cards for input. "The tape," he said, "was harder to edit and you couldn't sort with it, but nevertheless it would work and it had advantages." These "different techniques—printing telegraph techniques, telephone switching techniques, computer industry techniques—were all grist for my mill." At that time Aiken was "largely a promoter, trying to find out where to get these pieces so that the machine could be put together." His "first step" was to go to "the Monroe Calculating Machine Company." Aiken could not at once recollect "the name of the charming man I met there." "Mr. Chase," I told him—George Chase. The only reason I knew about Chase was that I had found and read his account of Aiken's visit.

I read aloud the paragraph I have just quoted about Aiken's plans, whereupon Aiken commented, "He's just saying what I said a moment ago, only much better." Then, "I went to Chase, and I did just what he said."

Aiken continued, "Chase was Chief Engineer at Monroe, and a very, very, scholarly gentleman. He took an almost immediate interest, and we kept up an association for quite a few years thereafter. He wanted, in the worst way, to build Mark I. He would supply me with the parts and we would collaborate and do it together, that's what he wanted to do.

"He also foresaw what I did not. I did not foresee the application to accounting as coming out of it, and he did. He went to his management at Monroe and he did everything within his power to convince them that they should go ahead with this machine because, although it would be an expensive development, it would be invaluable in the company's business in later years.... Chase could see this. His management, however, after some months and months of discussion turned him down completely."

It was Chase who suggested that Aiken turn to IBM. When Aiken asked him, "Whom should I see at IBM?" Chase told him (Aiken recalled), "Why don't you see Professor [Theodore] Brown? He's at the Business School at Harvard. He's right there." Brown was a sensible choice. An applied mathematician (Ph.D. at Yale in celestial mechanics under Ernest William Brown, famous for his studies of the moon's motion), Ted Brown had long been interested

[2] Myrna K. Chase (see note 1) writes as follows: "At the time of his death, the Monroe Company (Litton?) was offered some of his papers and machines, but I do not remember, now, what the outcome was. We no longer have any of historic value."

[3] The tape of this interview and an unedited transcript of it are in the archives of the Smithsonian Institution. Henry Tropp and I hope eventually to publish a version of this interview, together with supporting documents concerning Aiken and his role in the development of the computer.

in business machines and in the potentialities of mechanical calculation; he also had had personal contact with Thomas J. Watson, Sr. Brown, according to Aiken, "came to life" and sent him on to see Harlow Shapley at the Harvard College Observatory. And Shapley, in turn, "came to life" and made the successful contact with IBM.

A little later in the interview, I returned to the subject of why Aiken had chosen to have Mark I built of electromechanical components—why he had not made use of vacuum tubes. I mentioned that this had always seemed astonishing to me in view of the fact that Aiken had been a student at Harvard of E. L. Chaffee, under whom he had written his doctoral dissertation; Chaffee's specialty was vacuum tubes and vacuum tube circuits. To be specific, I asked, wasn't there some thought given at one time to having quenching circuits in Mark I, using vacuum tubes? Aiken replied, "Yes. But your question really is: since I had grown up in 'space charge' in a laboratory like Cruft [at Harvard], why wasn't Mark I an electronic device? Again, the answer is money. It was going to take a lot of money. Thousands and thousands of parts! It was very clear that this thing could be done with electronic parts, too, using the techniques of the digital counters that had been made with vacuum tubes, just a few years before I started, for counting cosmic rays. But what it comes down to is this: if Monroe had decided to pay the bill, this thing would have been made out of mechanical parts. If RCA had been interested, it might have been electronic. And it was made out of tabulating machine parts because IBM was willing to pay the bill."

Which came first, the chicken or the egg? Did arithmetic give birth to the mechanical computing device? That seems to be the general impression. But let us look deeper than the mere words and sentences of recorded history by using those words and sentences to paint pictures of conditions and things as they were, with dates in true perspective. When this is done, I think it becomes clear that mechanical computing devices gave birth to arithmetic. I refer to the arithmetic we know, based on the Hindu-Arabic numeration that was born in the ninth century and gradually came into use in Europe during the next two or three centuries. Roman numerals and the countless other systems of number notation fell short of the needs of arithmetic, which must, of necessity, include the four cardinal rules: addition, subtraction, multiplication, and division.

Let us picture the situation before the ninth century. In their struggle for number comprehension, primitive races passed through the eras of finger counting, notched sticks, knotted strings, and other devices. Then came the abacus, by the use of which people doubtless first learned multiplication and division, but remained unable to formulate these advanced branches of mathematics in terms of decimal notation until the Hindu-Arabic system of numeration came into use. During the Roman-numeral era in Europe, the theory of multiplication and division was taught only in the highest institutions of learning, and mathematicians who could solve problems in multiplication and division without resorting to an abacus were regarded with awe and as possessing supernatural powers.

The abacus appears to have been the first computing device providing fixed decimal orders; the conception of the cipher to indicate an empty order doubtless resulted directly from widespread use of the abacus.

The conception of the cipher gave birth to the Hindu-Arabic system of numeration, and this, in turn, lifted the teaching of the four rules of arithmetic out of the highest institutions of learning and placed them in primary grade schools.

Weird and awesome were the many systems of numeration in use by different peoples prior to the Hindu-Arabic notation. The Egyptians expressed the digits 1 to 9 by one to nine staves or vertical lines; 10 was a U or a circle; 100 was a coiled rope; 1,000 was a lotus blossom; 10,000, a pointed forefinger; 100,000, a tadpole, and 1,000,000 was expressed by a man with arms stretched toward heaven in amazement. For 3,647,543, they had to show

3 amazed men,
6 tadpoles,
4 pointed forefingers,
7 lotus blossoms,
5 coiled ropes,
4 hoops, and
3 staves

I have a question. How many men should be shown with arms outstretched toward heaven in amazement at our national debt?

The history of mechanical computing machinery in its essence is the story of the numeral wheel and the devices that rotate it to register digital and tens-carry values.

Ignoring a zero-setting mechanism, which clears the numeral wheels to zero after a calculation is completed, two fundamental elements rotate the numeral wheels:

1. Digital value actuators, which rotate the wheels one to nine steps to register the digits 1 to 9.
2. Tens-carrying mechanisms, which advance or retract the next higher order wheel as a given wheel passes through ten units of registration.

The basic classification to be considered relates to the digital value actuators, which may be divided into two major groups: (1) rotary digital actuators and (2) reciprocating digital actuators. We often speak of rotary or crank-type calculating machines, referring specifically to the machines that perform multiplication and division by rapidly repeated cycles of operation. Even though motor-driven, such machines are still sometimes referred to as "crank-type machines."

Reciprocating digital actuators first came into general use in the so-called adding-and-listing machines, such as the Burroughs, and in key-driven machines, such as the Comptometer.

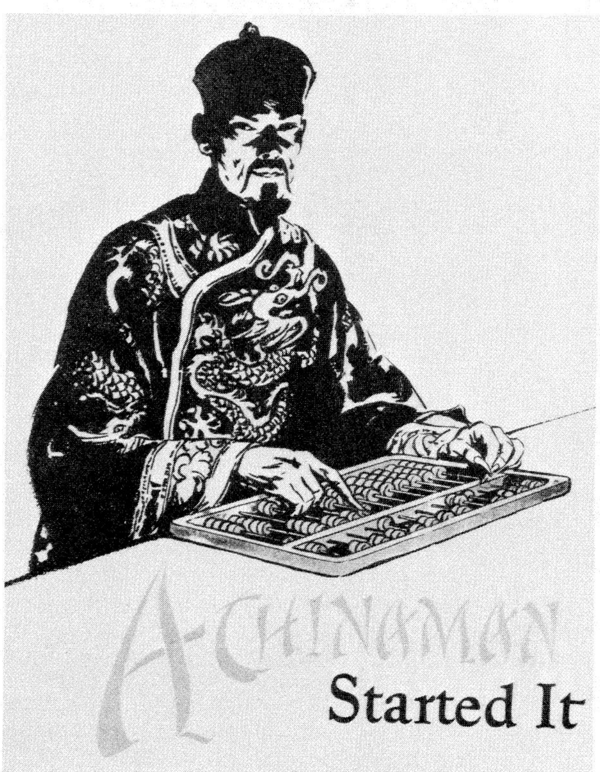
While rotary actuators are inherently capable of making repeated cycles of registration more rapidly than reciprocating actuators, the rotary mechanism does not lend itself readily to the operation of printing values entered in the machine, and totals.

Some of the earlier calculating machines, such as the Grant and the Mercedes, which did multiplication by repeated additions, were equipped with reciprocating actuators driven by a rotary drive; more recently, some of the reciprocating actuator listing machines, such as the Remington, have been fitted with automatic controls that facilitate multiplication and division by repeated additive or subtractive registrations.

Another species of numeral wheel-actuating mechanism has been developed; it may be classified as a partial-product actuating mechanism.

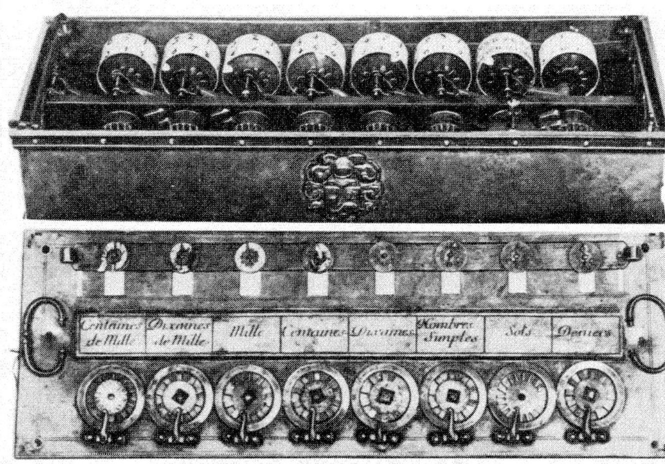
These devices do not require that 7 shall be added six times to multiply 7 by 6, but provide for the turning of the lower of two adjacent numeral wheels two steps, or figures, and the higher wheel four steps, thereby registering the partial product 42. Such machines are usually equipped with reciprocating actuators. The Millionaire calculating machine and the Burroughs Moon-Hopkins billing machine are the best known of this species.

We are now ready to view some of the machines and mechanisms that have played a major role in the history of mechanical computing machinery.

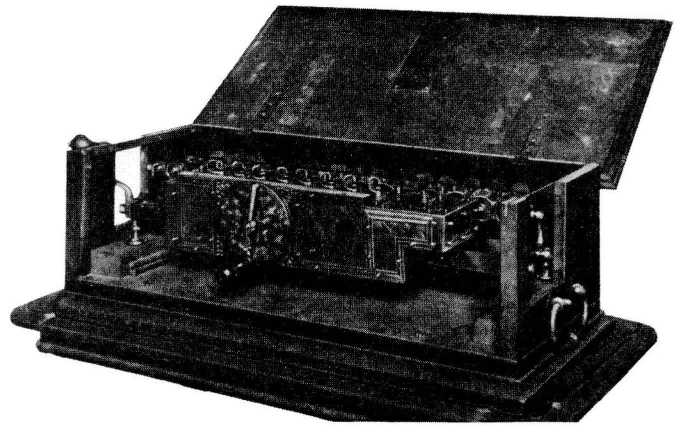


1 "A Chinaman Started It"
I expect the caption of this picture, "A Chinaman Started It," to start an argument. One may say the Babylonians started it. Another may say the abacus drifted to China from India. But I like the picture, which I clipped from an old-time Sundstrand advertising leaflet, because it was a Chinaman who started it with me. This picture clearly shows the two-bead section known as "Heaven" and the five-bead section known as "Earth." The Japanese abacus has but one bead in each order of "Heaven."

2 Chinese Laundry
The abacus was the first computing device I ever saw. As a lad in the Gay Nineties when men's daily attire was a shirt with a stiffly starched bosom and an equally stiff detachable collar, one of my weekly chores was to fetch my father's laundry from the Chinaman. What he could do with his abacus amazed me. He tried to show me how it was done, but could not explain it in any terms of arithmetic I could understand. He knew nothing of the arithmetic I had learned in school, and could not do with pencil and paper the examples he could solve on his abacus skillfully and accurately. Later, I learned he had been taught in China to operate the abacus as his forefathers had been taught, before Hindu-Arabic numeration was known.

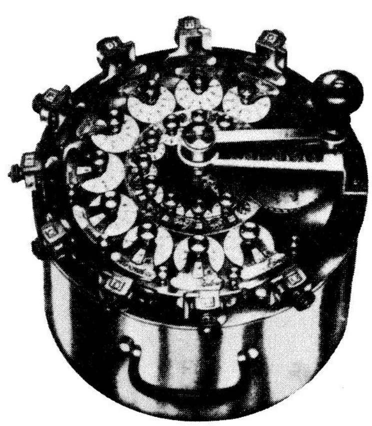


3 Pascal and His Machine
The first known numeral wheel register was made by Blaise Pascal of Paris, in about 1642. Pascal's father was a superintendent of taxes; and the boy was inspired to build a machine that would be helpful to his father in his figure work. By the age of 19, Pascal had experimented with several models. Of the seven that have been preserved, none give dependable results because of deficient mechanical construction. [Since Chase produced this survey, information has come to light concerning an earlier digital calculator than Pascal's. Designed by Wilhelm Schickard, it was intended for use in the laborious calculations then being performed by the astronomer Johannes Kepler (1571–1630). The single prototype was destroyed in a fire, and Schickard never undertook to build another. With respect to Chase's sentence about "dependable results" and "deficient mechanical construction," it may be doubted that Chase's judgment was based on the same firsthand experience with the Pascal calculators that he had with the others described later in the article. Pascal's machine, it may be added, used complement arithmetic for subtraction. In fact, the two distinctive features of the Pascal machine were a mechanical means to effect a carry and the use of complement arithmetic to perform subtraction without having to reverse the operation of the machine.]



4 Leibniz and His Machine

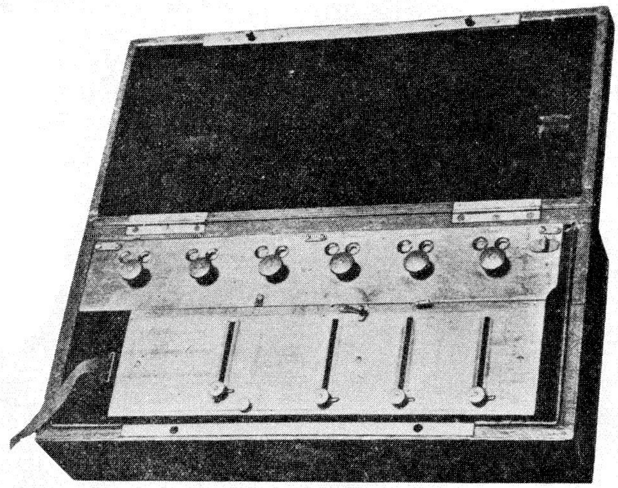
The next important advance toward the development of a numeral wheel calculator was that of Gottfried Wilhelm Leibniz, the illustrious philosopher and scientist who shares with Sir Isaac Newton the credit for the development of calculus. Like Pascal, Leibniz's incentive to develop a calculating machine was to facilitate the work of his father, who was actuary of the University of Leipzig. It is believed that Leibniz built two machines, but only one has been preserved (in the possession of the State Museum [Niederesachsichen Landes Bibliothek und Archiv] in Hannover); it is known to have been completed in 1673. The Leibniz machine attracted widespread notice, and although its operation was never dependable, it was exhibited before the Royal Society in London and the Academy of Science in Paris.



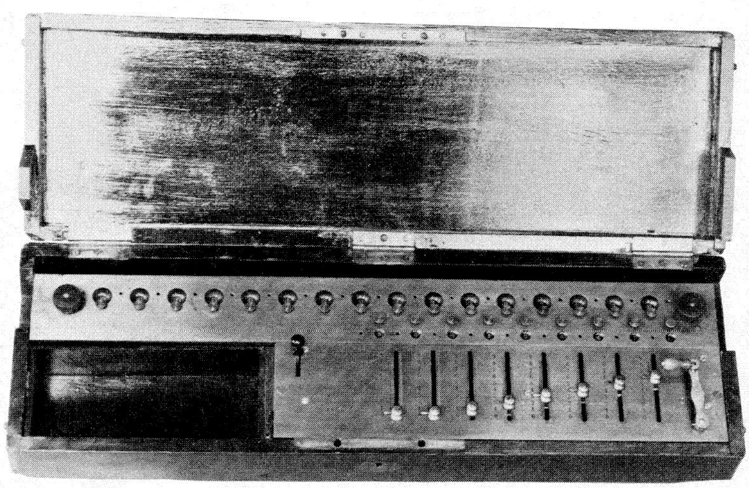
5 Hahn and His Machine

About 100 years after Leibniz completed his machine, a churchman and mathematician, Philipp Mathäus Hahn, built a machine. Hahn used the stepped cylinder originated by Leibniz to make the first dependable four-rules calculating machine.

6 Thomas de Colmar
The honor of first establishing the manufacture of calculating machines as an industry goes to Charles Xavier Thomas of Colmar, France, or Thomas de Colmar, as he is more commonly known. Like Hahn, Thomas used the stepped cylinder invented by Leibniz as his digital-value actuator.



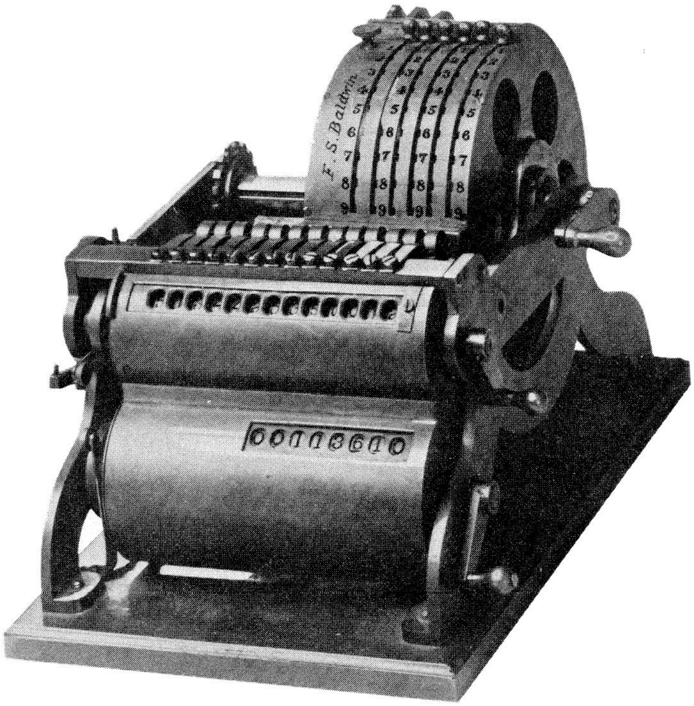
7 Thomas Machine of 1820
Construction of the first machine built by Thomas is said to have started in 1820 and ended in 1822. The machine provides for four digits in the multiplicand and six in the product. The first model did not have a hand crank for rotating the actuators, as did all of Thomas's subsequent machines; it was driven by pulling on a belt, which may be seen protruding from the lower left corner.



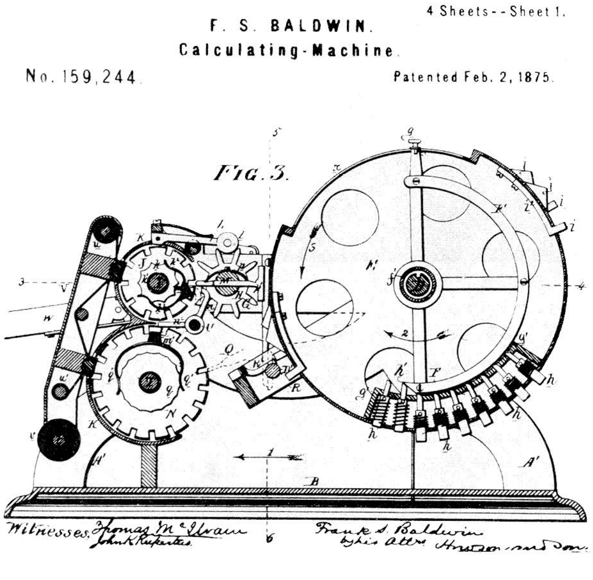
8 Thomas Machine of 1870
Several Thomas machines came to the United States. This one, built in about 1870, was in use for many years at Yale University and may be seen in my exhibition adjacent to the registration desk. The fundamental principles of the Thomas machine have been used in scores of different makes of calculating machines placed on the market during the past 70 years. Machines based on these principles became known as "Thomas-type machines." [The machines built by Thomas are usually known as arithmometers or *arithmomètres*.]

9 Frank Stephen Baldwin
A basically different principle was developed by Frank Stephen Baldwin, a resident of St. Louis. Baldwin's conception of the machine was complete in 1872, when he filed a caveat in the United States Patent Office.

Having completed his first machine in 1873, Baldwin moved to Philadelphia where he rented a small shop and started the construction of his first lot of 10 machines.

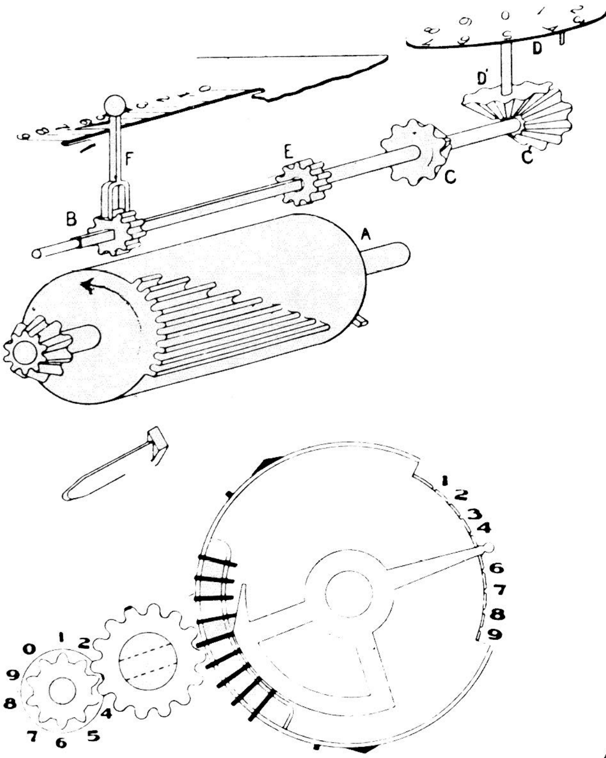


10 Baldwin's 1875 Machine
This marked the beginning of the calculating machine industry in the United States and the development of the second fundamental principle in rotary four-rules calculators, which became known as the "Baldwin principle." During the 75 years that followed, the number of manufacturers of Baldwin-type machines equaled or exceeded the number of manufacturers of Thomas-type machines.



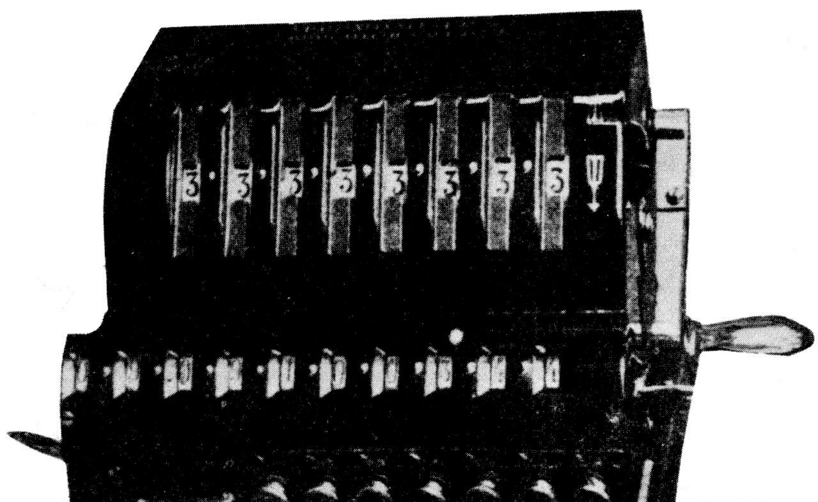
11 Baldwin Patent
Although Baldwin completed his design in 1872 and his first machine in 1873, it became known as "Baldwin's 1875 machine" because during that year his patent was issued and he was awarded the John Scott medal by the Franklin Institute.

I have seen the statement in print that Baldwin did not know of the Thomas machine at the time he made his invention, but I find the following in Baldwin's memoirs: "In the office of a life insurance company in St. Louis, I had seen the Thomas type of calculating machine, devised by C. X. Thomas of Colmar, France, about 1820. I contrived the plan of substituting one cylinder for the nine cylinders in that machine, making a working model which is now in the Patent Office at Washington."

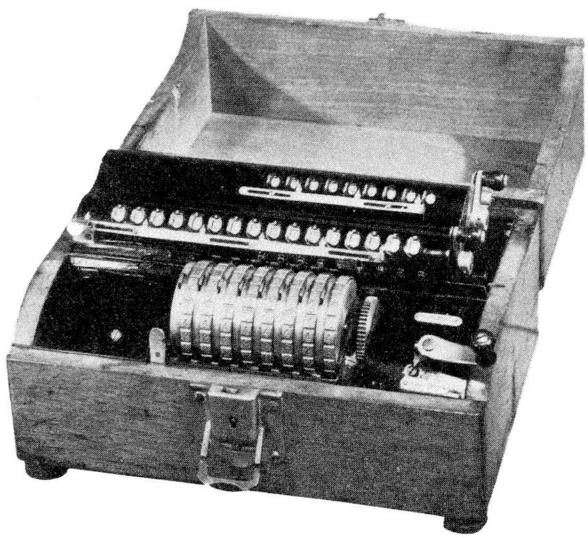


12 Thomas and Baldwin Diagrams
The outstanding characteristic of the Baldwin invention was not, however, the substitution of one cylinder for the nine of Thomas. These diagrams illustrate the fundamental difference between the Thomas and Baldwin actuators. The upper one shows Thomas's stepped cylinder. These cylinders are rotated in the same direction for subtraction as for addition. Additive or subtractive registration is effected by shifting the bevel gears C–C′ to rotate the numeral wheels in the appropriate direction. These gears must be properly set before the calculation is started.

In the Baldwin machine several orders of radially extendable teeth are provided within the single cylinder for the setting of digit values. This diagram shows an actuator set to register the digit 5. Five teeth stand projected so as to rotate the numeral wheel five steps at each revolution of the actuator. The outstanding advance by Baldwin was the elimination of the reversing gears between the actuators and the numeral wheels, and the lever for setting those gears, by providing that the actuator may itself be rotated forward for addition and in reverse for subtraction.

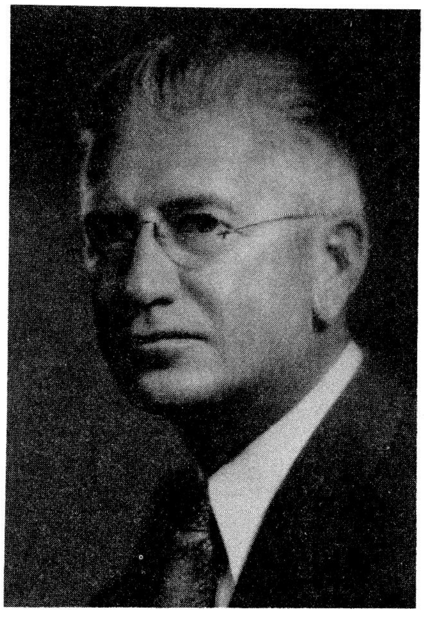


13 Odhner and His Machine
In about the year 1878, Willgodt Theophil Odhner developed a machine fundamentally like that of Baldwin. For many years European historians of the art credited Odhner as the first inventor of the principle used by both Baldwin and Odhner, but Odhner did not make that claim; in his earliest United States patent he conceded that he was not the originator of that principle. The term *Odhner-type machine* was used in Europe, however, where copies of his machine were eventually made and sold by many manufacturers; it is now recognized that the terms *Baldwin type* and *Odhner type* are synonymous.

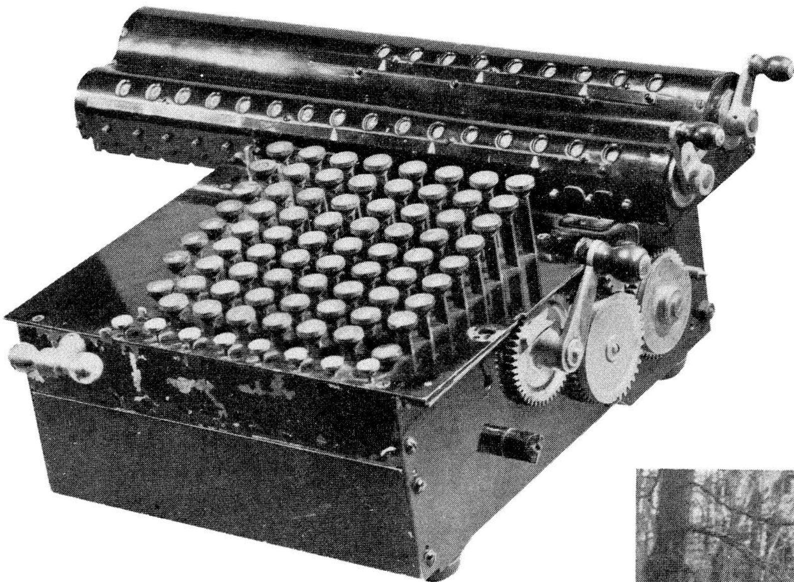


14 Baldwin's 1902 Machine
Baldwin's next venture in his effort to commercialize his invention was a machine placed on the market in 1902. The first Baldwin machine I ever saw was like this one. It was demonstrated and explained to me by an actuary of an insurance company in Springfield, Massachusetts, in 1904. The day marked the beginning of my interest in the study and development of adding and calculating machines.

15 Baldwin's Recording Calculator (1907)
Even though Baldwin's 1902 commercial venture did not yield a profit, he did not quit. In 1908 he was granted a patent on his "Recording Calculator" (United States patent number 890,888), a working model of which was completed a year or two earlier. This machine retained the Baldwin principle, but embodied a revised construction of the digital actuators that installed values through a keyboard and printed them.



16 Jay Randolph Monroe
In 1911 Baldwin showed the 1908 machine to Jay Randolph Monroe, who was then an auditor with the Western Electric Company. Recognizing the merit of Baldwin's inventions, Monroe made a deal with Baldwin whereby they would develop a more compact machine and put it on the market in a big way.



17 First Monroe Calculator
The first machine built by their combined efforts, entirely handmade, was completed in 1912. It was patterned after Baldwin's recording calculator, but the printing feature was omitted. The Monroe Calculating Machine Company was organized, a factory was established, and duplicates of this machine were sold in volume—with profit.

18 Baldwin and Chase
In those years Baldwin was frequently referred to as "a man who achieved success after 80." I became associated with Monroe and Baldwin in 1917, at about the time Baldwin was planning to retire. Baldwin was affectionately known as "Dad" to those of us who were closely associated with him. This picture was taken during "Dad's" eighty-fifth birthday party, April 10, 1923. He is on the left; I am on the right.

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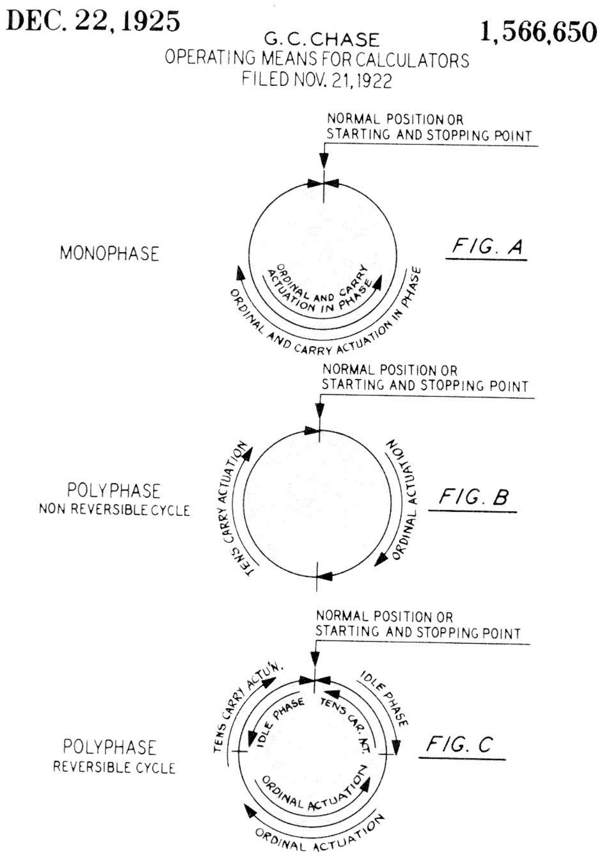
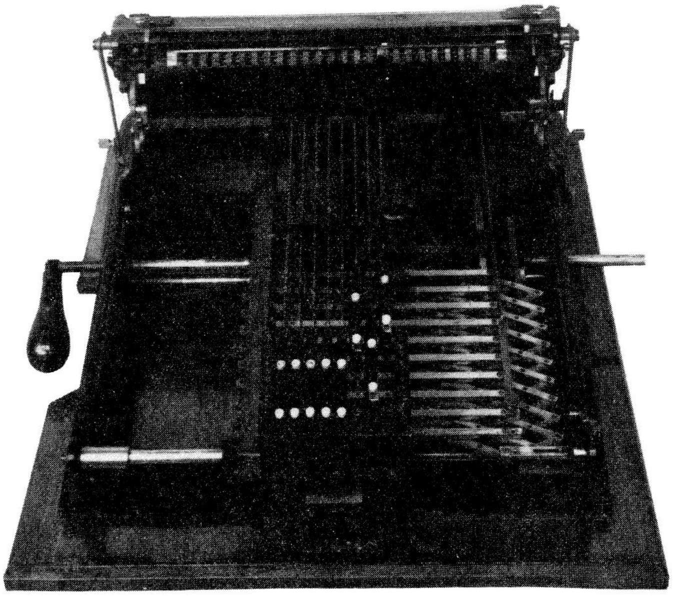


19 Classification of Species

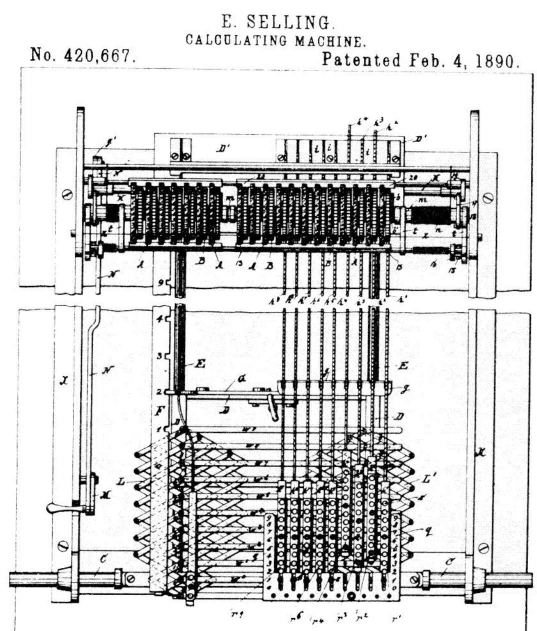
I have so far followed the invention and commercial development of two basic types of rotary calculating machines: the Thomas type and the Baldwin type. These types were first identified in Germany where the Thomas type was known as *Staffelwalzenmaschinen*, meaning "stepped-drum machines," and the Baldwin type was known as *Sprossenradmaschinen*, meaning "sprocket-wheel machines." As the art expanded, these designations became inadequate because some Baldwin-type machines embodied the stepped-drums of Thomas, and the so-called sprocket-wheel of Baldwin was usable in Thomas-type machines.

While drafting patent claims in 1922, it became necessary for me to designate these types more definitely, so I developed the classification shown in this picture. The middle circle illustrates the cycle of operation in a Thomas-type machine. The cycle comprises two phases of registration—the ordinal or digital actuation phase, followed by a phase of tens-carry registration. The arrows indicate that the sequence of the phases is unidirectional. I designated such machines as "polyphase, nonreversible cycle." They are characterized by reversing gears between the actuators and numeral wheels to provide reverse rotation of the wheels in subtractive registration. The lower circle illustrates the three-phase cycle in Baldwin-type machines, which I designated "polyphase, reversible cycle." The two direction arrows indicate that the phase sequence of the cycle is reversible, a tens-carry phase following the digitation phase in each direction.

The upper circle represents a third species of four-rules calculating machine that I have not yet mentioned. I designated it the "monophase cycle machine"—that is, a machine in which digital registration fills the cycle, and in which tens-carrying action must merge with digital registration.

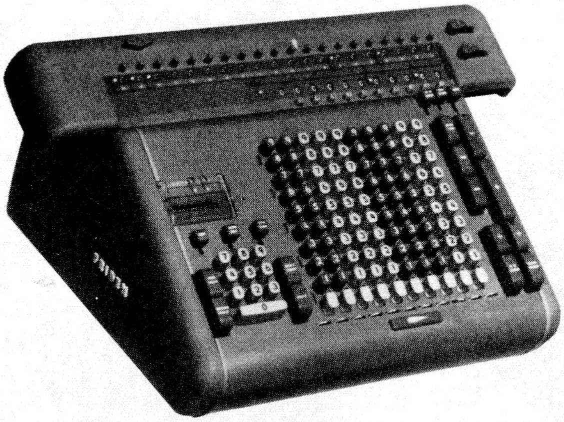


20 Selling Machine of 1886
This is the best known of the early monophase cycle machines. It was built by Dr. Edward Selling, Professor of Mathematics and Astronomy, at the University of Würzburg in 1886, and is now preserved in the Deutsches Museum at Munich. In this machine, Selling used reciprocating actuators driven by "lazy-tongs," but the monophase type of registration is better adapted to rotary actuation. Selling's reciprocating actuators differ from those I have previously mentioned in that they are longer and may be driven in one direction through several cycles of registration. Instead of turning a crank six revolutions to multiply 7 by 6, Selling moves an actuating handle six steps in a straight line, registering 7 during each step, or cycle.



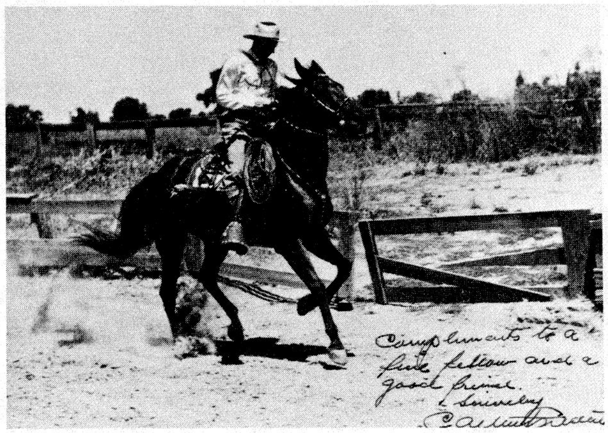
21 Selling Patent
United States patent 420,667 was issued to Selling in 1890. It clearly shows the "lazy-tongs" that drive the reciprocating actuators through one or more cycles of registration. To merge the tens-carry with digital registration, Selling used a crawl, or gas meter, type of carrying mechanism.

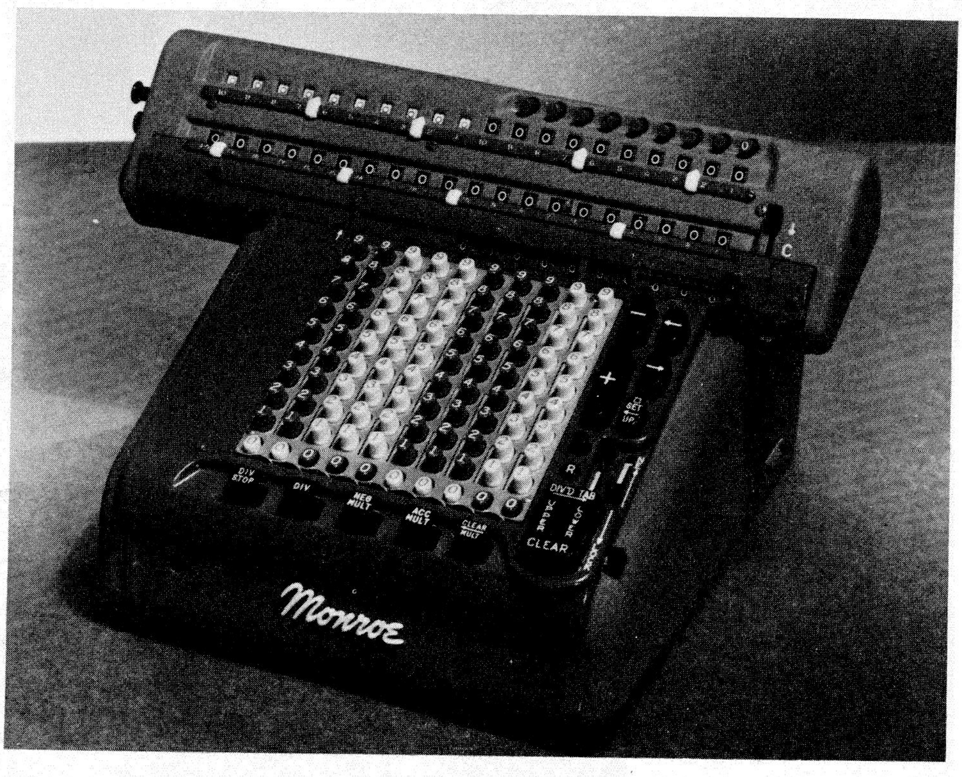
Selling built several machines, some of them considerably more advanced than the one illustrated here. It is recorded that a few of his machines were used in commercial work.



22 Friden Machine
Having completed my review of the three basic types of rotary calculating machines, it is interesting to note that of the three rotary calculators now manufactured in the United States, there is one of each type.

The Friden machine is a Thomas, or polyphase, nonreversible cycle type. It was developed by my good friend, the late Carl Friden, who, aside from being a great calculating-machine inventor, was a lover of fine horses.

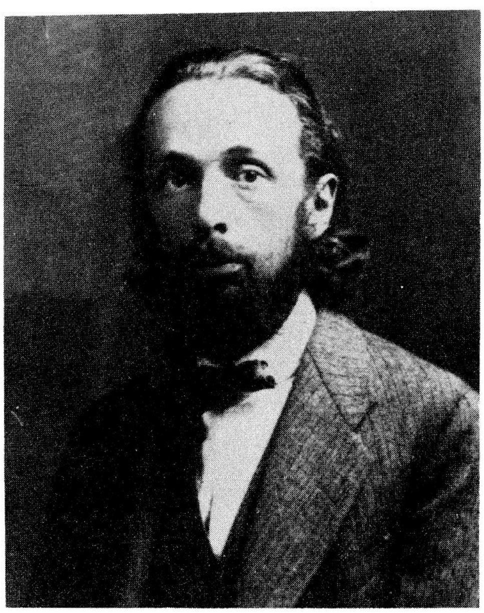




23 Monroe Machine
This is the present-day Monroe, which is still a Baldwin-type, or polyphase, reversible-cycle machine.

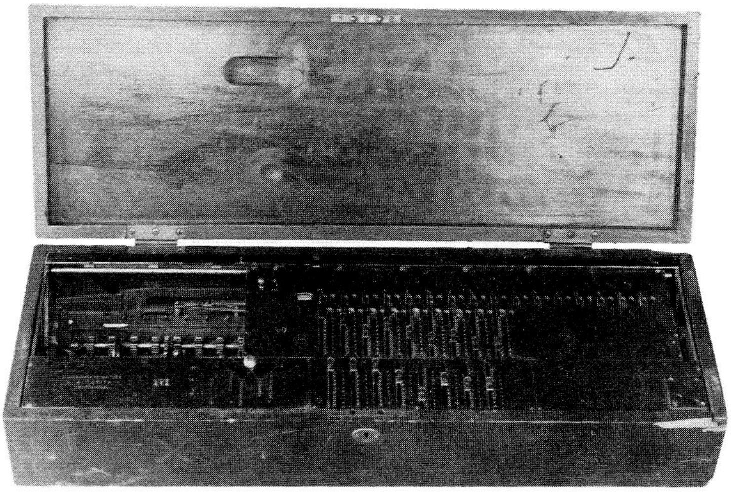
24 Marchant Machine
The Marchant is illustrative of the present-day embodiment of the monophase cycle machine.

25 Harold T. Avery
It was invented by another very good friend, Harold T. Avery.



26 Alexander Rechnitzer
At this point I shall digress long enough to trace the history of the development of automatic division in rotary actuator calculating machines.

That was first developed by Alexander Rechnitzer, a citizen of Czechoslovakia and a resident of Germany, who built his first experimental model at the age of 19.

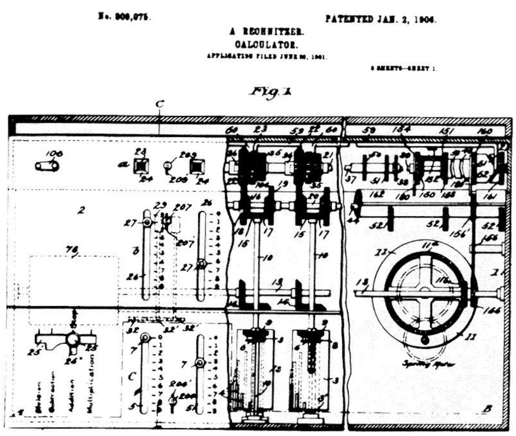


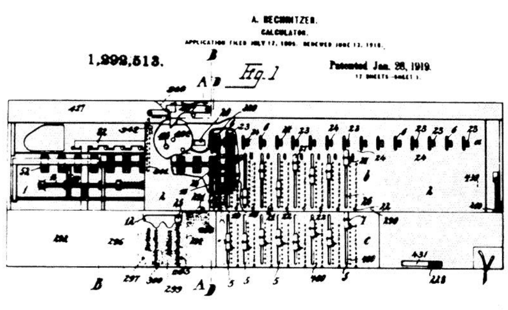
27 Rechnitzer's Autarith

This is a picture of what I believe to be the world's first motor-driven calculating machine; it was also the first machine to embody full automatic multiplication and division. This machine was built about the year 1902. It is patterned after the Thomas machine and was named "Autarith."

Multiplication was done by setting the multiplicand in the lower setting slides, the multiplier in the upper slides, then moving the control lever to the "multiply" position, causing the machine to complete the calculation automatically.

Division was done by setting the dividend in the numerical wheels, the divisor in the lower setting slides, then moving the control lever to the "divide" position, whereupon the machine would automatically complete the calculation.

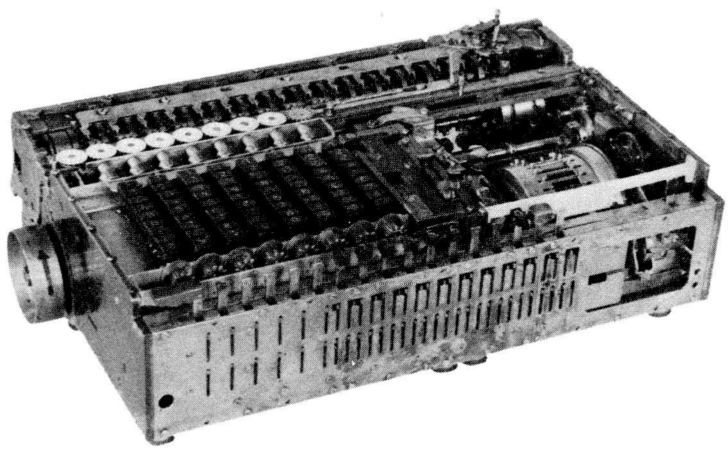




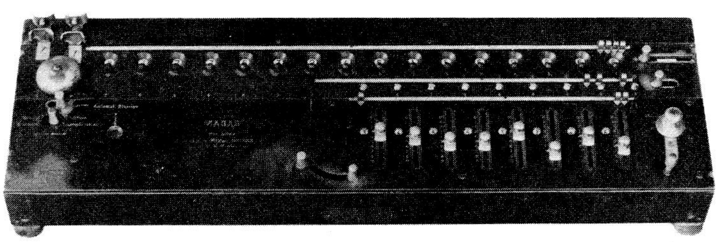
28 Rechnitzer Patents

This picture shows figures taken from Rechnitzer's two earliest United States patents, 809,075 and 1,292,513. The earlier patent shows the construction of his first model, except that it was driven by a clockweight instead of by a spring motor as shown in the patent. The later patent shows the construction of the machine I have been talking about.

Rechnitzer's system of division control was to subtract to an overdraft and to make one cycle of addition to correct the overdraft in the computation of each digit of the quotient.

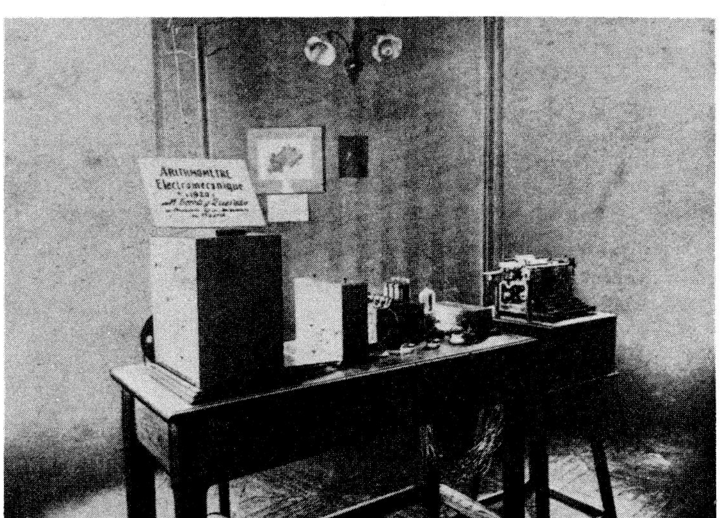


29 Rechnitzer's Last Machine
This picture shows Rechnitzer's final effort to produce a salable automatic four-rules calculating machine. He started the construction of this model in 1912. The pulley on the left end provided for a belt drive. This machine can do automatic shortcut multiplication and full automatic division, and it contains a "memory" mechanism. I can operate the machine in my collection slowly by a hand crank; I have never dared to drive it by a motor. The memory makes it possible to install a second multiplicand and multiplier while the machine is making the last preceding multiplication, and to install a new dividend during the computation of the last preceding division. Although departing widely from the Thomas construction, this machine is of the polyphase, nonreversible cycle type. Rechnitzer died in despondency in 1922; his body was found in New York's East River. But his life was not a failure; his inventions have been widely commercialized by others.

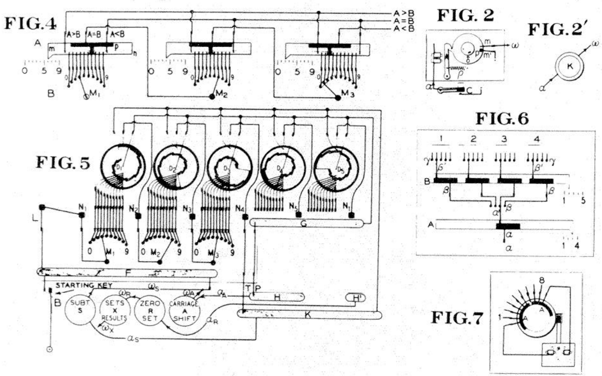


30 Madas Machine
The first commercial machine to embody the division-controlling mechanism invented by Rechnitzer was the Madas, which came on the market about the year 1914. In this machine the Rechnitzer principle of division control was refined and improved by Edwin Jahnz of Zurich, where this machine was manufactured by the same company that produced the Millionaire.

Many other manufacturers have adopted Rechnitzer's system of automatic division control—or variations of it.

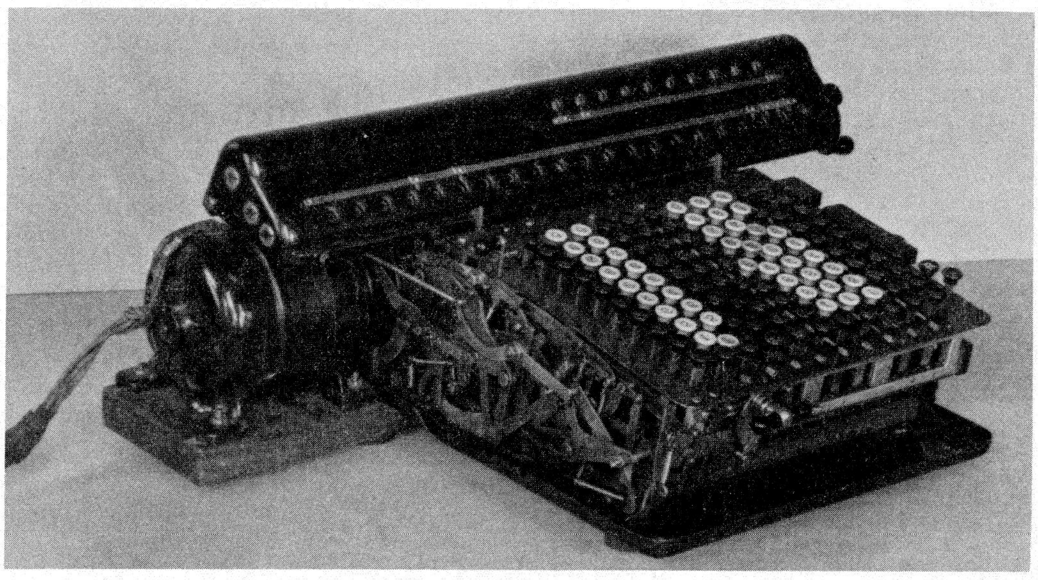


31 Torres y Quevedo Machine
A fundamentally different type of division control was developed by Torres y Quevedo of Madrid. He built an electromechanical machine and exhibited it at the Paris Centennial of 1920. This machine is typewriter controlled.



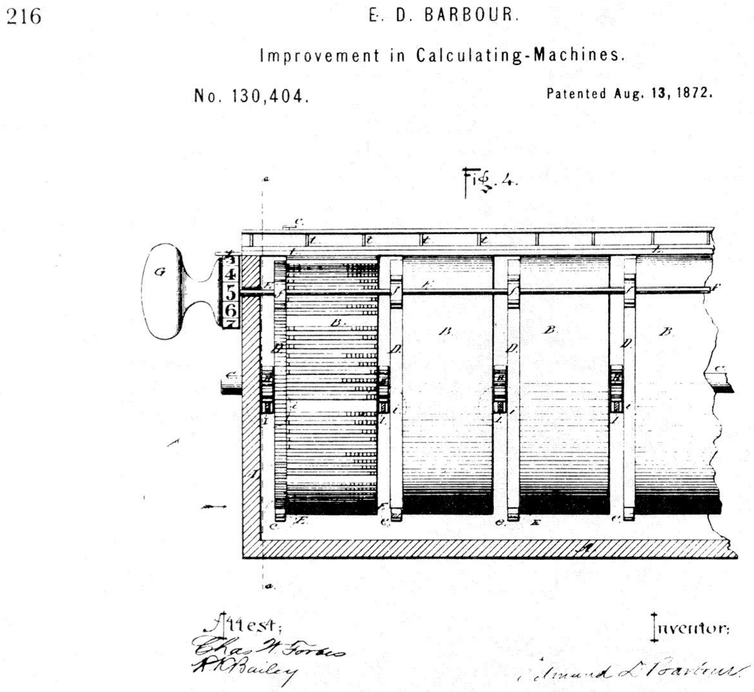
32 Torres Diagram

The Torres principle provides for the control of the program of operation in division by means of a device known as a "comparison" mechanism. The dividend is "compared" with the divisor during each subtractive cycle, the registration of each quotient digit terminating with that cycle in which the dividend becomes less than the divisor. The diagram shown here is copied from the *Bulletin de la Société d'Encouragement pour L'Industrie Nationale*, published in Paris, September–October issue, 1920. (The *Bulletin* explains an error in this diagram.) It illustrates the stepped-commutator electric circuit arrangement that makes the "comparison" and controls the operation of the machine. "Comparison" mechanisms have also been developed that are wholly mechanical; one form is used in the Marchant machine as a partial control of the program of operation in division.



33 First Full Automatic Monroe

The problem of the control of the program of operation in division in a reversible actuator machine is fundamentally different from the control of division in a unidirectional actuator machine. This picture shows what I believe to be the first reversible actuator machine built with full automatic control of the program of operation in division. It was planned in 1920 and completed in 1922, exactly one hundred years from the time Thomas de Colmar planned and built his first model. This machine also embodies full automatic multiplication and the first commercially successful plus and minus bar controls. After the features of this machine were commercialized, the Franklin Institute awarded the Monroe Company the John Price Wetherill Medal in recognition of the attainment of full automation in the four rules of arithemetic, which had been the objective of the industry during the hundred years following the first commercialization of a calculating machine by Thomas de Colmar.

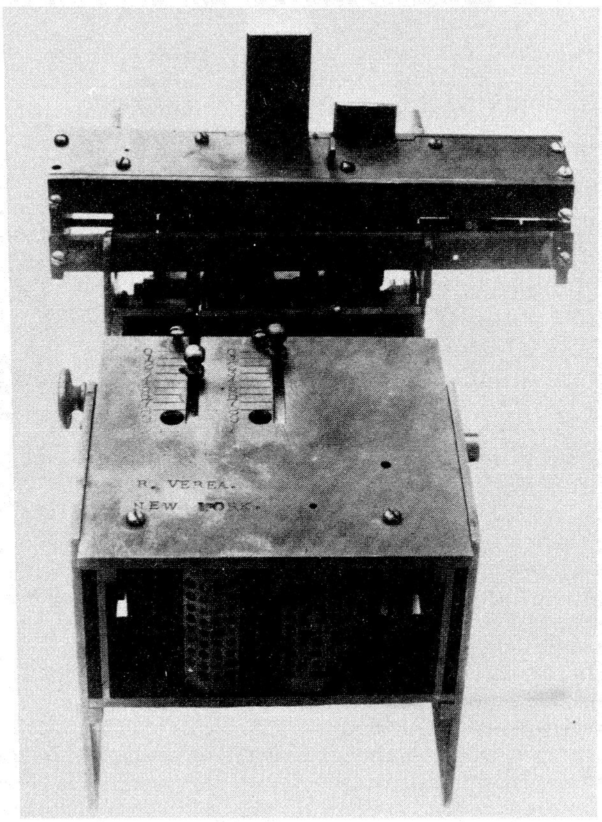


34 Barbour Patent

I shall now direct your attention to the development of "direct" or "partial-product" multiplying machines.

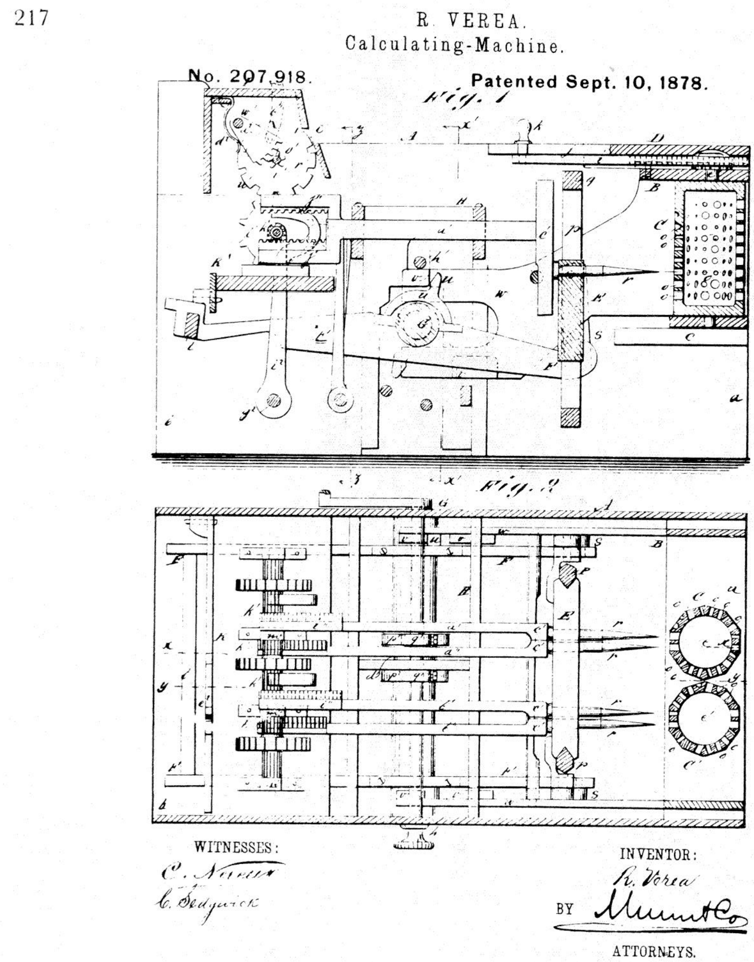
The first attempt I know of to totalize partial products directly on numeral wheels was made by Edmund D. Barbour of Boston.

This picture shows Figure 4 of his United States Patent 130,404 which was issued in 1872. So far as I know, the constructional principle of Barbour has never been commercialized.

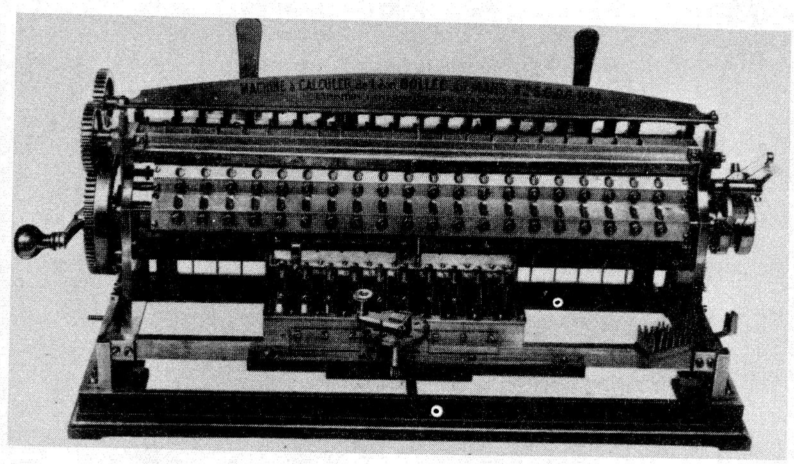


35 Verea Machine

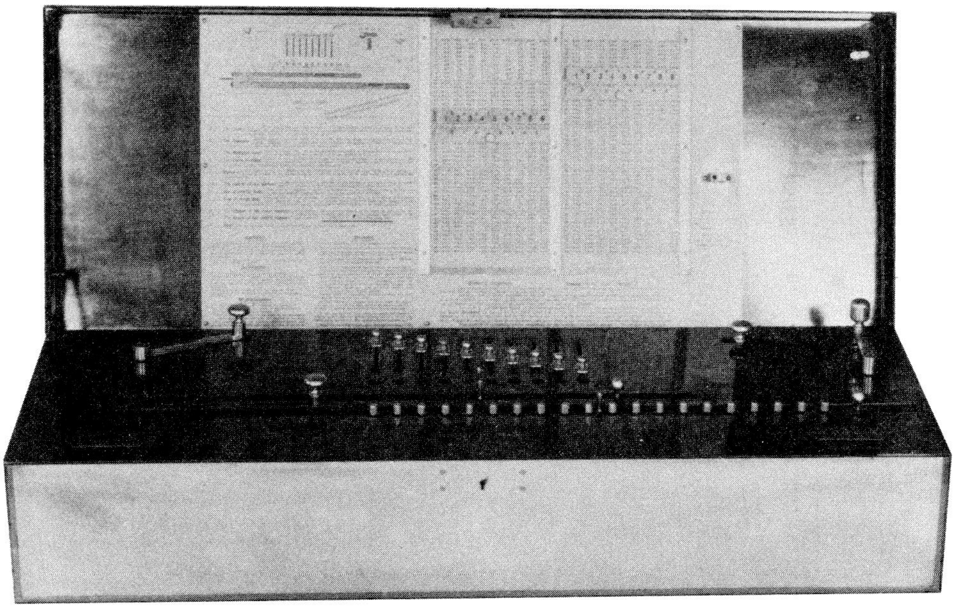
I believe the credit for having developed the partial-product multiplying mechanism in the form in which it has been widely used goes to Ramón Verea, a Spanish resident of New York City. When he filed his application for a patent, he submitted this small model to the United States Patent Office, where it remained for many years.



36 Verea Patent
This is a copy of Figures 1 and 2 of United States patent 207,918, issued to Verea in 1878. At the right are the partial-product cylinders having holes of graded size to limit the movements of the conical plungers that enter those holes, in accordance with partial-product values. One such cylinder was provided for each order of the multiplicand. Verea made and patented this invention with no commercial ambitions; it was apparently his hobby.



37 Bollée Machine
Léon Bollée, the famous French builder of racing automobiles, made a partial-product multiplying machine in 1889, at the age of 18. During the next few years he made and sold several machines like the one shown here. He found that making automobiles was more profitable, and he abandoned the manufacture of calculating machines.



38 Millionaire Machine

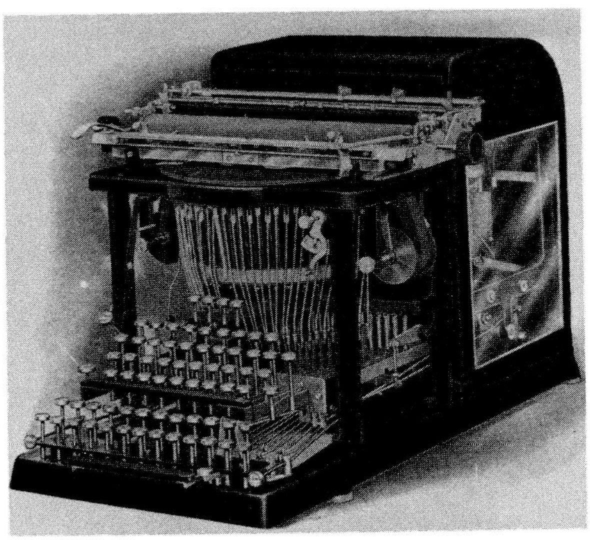
The Millionaire calculating machine, which embodies a partial-product multiplying mechanism, came on the market a few years before the turn of the century. It was invented by Otto Steiger of Munich in the early nineties, and was manufactured in Zurich. The Millionaire was widely sold throughout Europe and America during the first quarter of this century.

Although I have spoken of these partial-product machines as "multiplying machines," they were also usable for addition, subtraction, and division.

Associated with my brother, I sold Millionaire machines in New England in 1905 and 1906. Our most interesting sale was to Percival Lowell, who told us that his observations of the orbit of Uranus disclosed the presence of a more distant unknown planet, and that he bought a Millionaire machine to make computations which he hoped would lead to its discovery. He told us it would take more than three years to make those computations with paper and pencil.

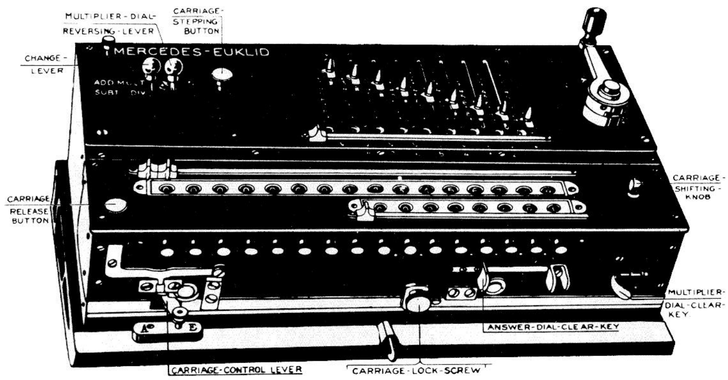
In 1916, I read of his death at the Lowell Observatory at Flagstaff, where I understand he had been searching for the undiscovered plant.

In 1930, Pluto was discovered by Dr. C. W. Tombaugh at the observatory. Of that discovery the *Encyclopaedia Britannica* says: "It is believed among those most conversant with this field of astronomy, however, that the finding of Pluto was a happy accident of the search." If the existence of something has been detected and established by mathematical deduction, and searched for a score of years, who shall say its finding "was a happy accident"?



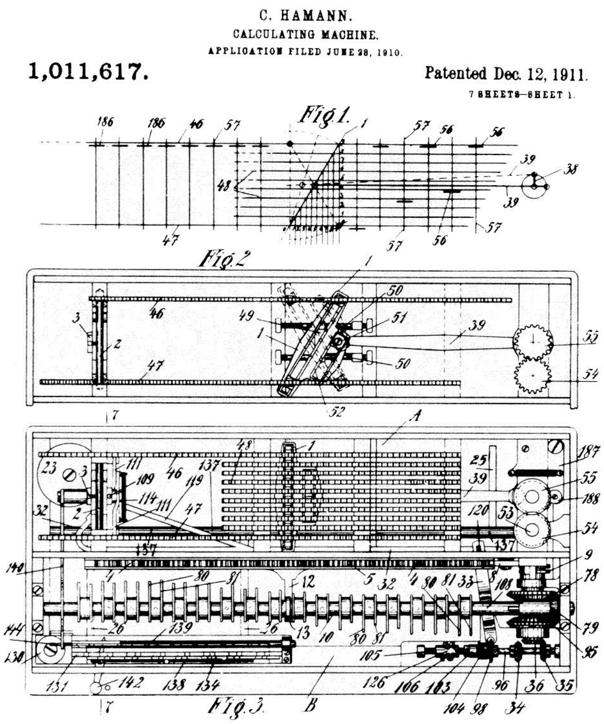
39 Moon-Hopkins Machine

The Burroughs Moon-Hopkins billing and bookkeeping machine is the best-known partial-product multiplying machine now on the market. It was invented by Hubert Hopkins of St. Louis during the first decade of the present century.

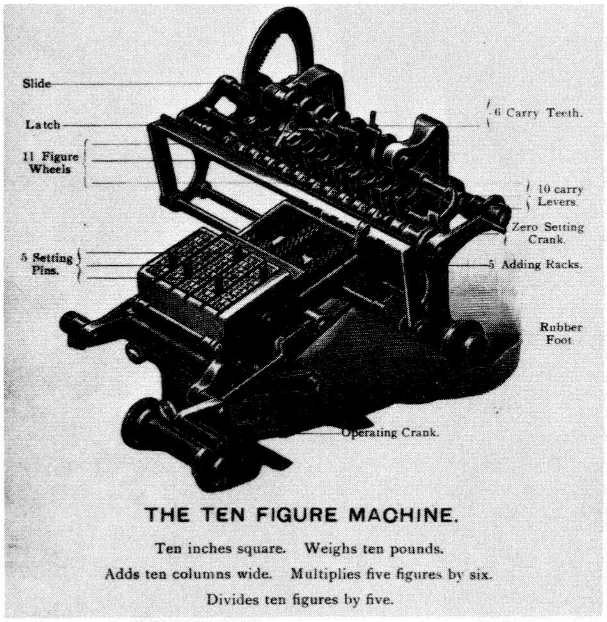


40 Mercedes Machine
One variation of the polyphase, nonreversible-cycle type of machine should not be overlooked: the Mercedes. The numeral wheels of this machine always rotate in an additive direction; subtraction and division are done by automatically adding the complement of the subtrehend or the divisor. Although operated by a rotary drive, this machine has reciprocating digital-value actuators.

41 Christel Hamann
The Mercedes machine was patented by Christel Hamann in 1911 and was brought on the market at about that time.

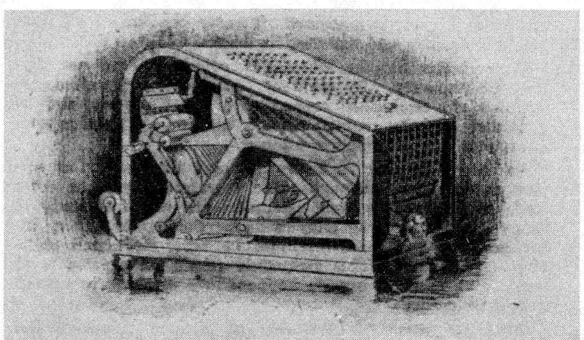


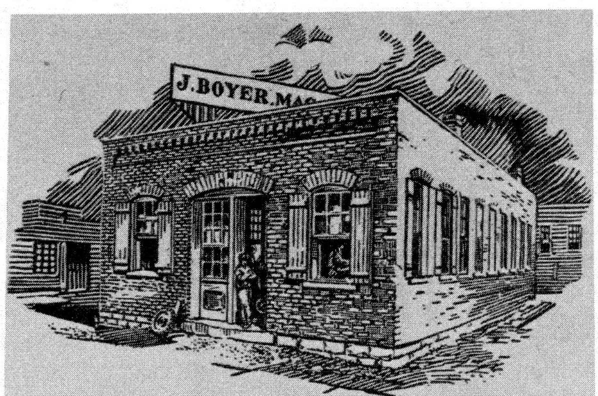
42 Hamann Patent
The means for adding the complement to effect subtractive registration may be seen in the drawings of Hamann's United States patent 1,011,617. The numeral wheels are driven by ten racks numbered 48. These racks are driven to and fro by a lever 1, which swings about a pivot at its rearward end for addition and about a pivot at its forward end for subtraction. From rear to front, these ten racks move respectively 0 to 9 steps for addition, and 9 to 0 steps for subtraction. Special means are provided to rotate the numeral wheel of lowest order one additional step, or figure, during subtraction, thereby adding the complement of the subtrehend or divisor in the numeral wheels to effect subtractive registration.



43 Grant Machine
The "ciphering hand-organ" was invented by George B. Grant of Lexington, Massachusetts, and was manufactured by the Grant Gear Works of Boston. It deserves mention because of the substantial number made and sold during the final 15 or 20 years of the last century, particularly in and near Boston. During the years 1905 and 1906, I saw many of these machines in use in that vicinity. It was a crank-operated, reciprocating-actuator machine of the polyphase, nonreversible-cycle type, used for solving problems in the four rules of arithmetic.

44 William Seward Burroughs
This brings us to the consideration of reciprocating-actuator listing machines. The pioneer inventor of this type was William Seward Burroughs. The machines that grew out of his series of inventions, which began in the 1880s, are so well known that there is no need for comment by me.

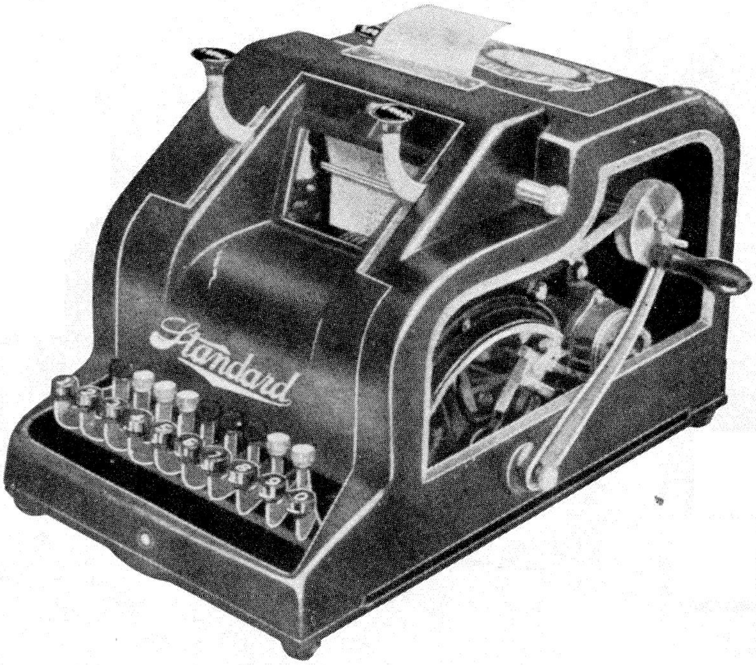

The First Model of an Adding Machine Made by Mr. Burroughs



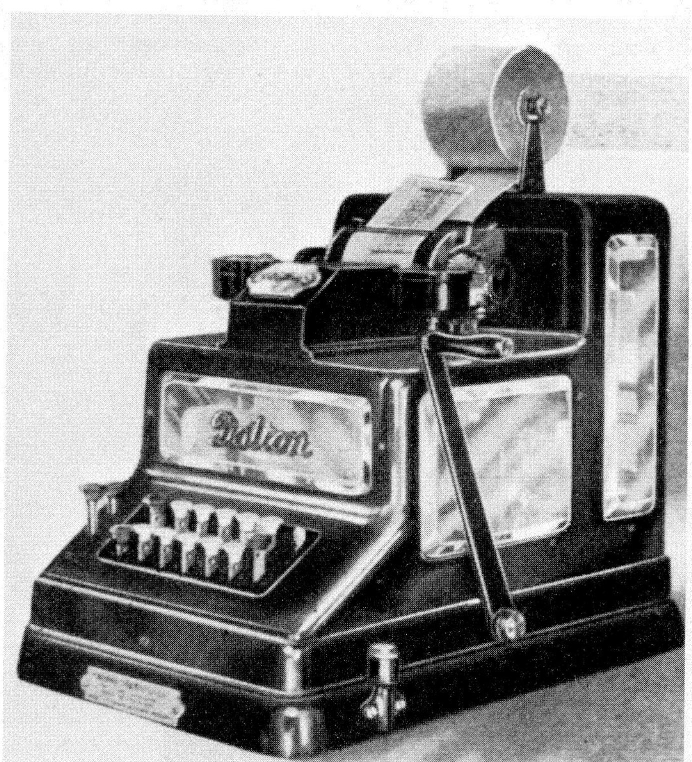
The Boyer Machine Shop, St. Louis, Where One of the First Successful Adding and Listing Machines was Born
Courtesy of the Burroughs Adding Machine Company.

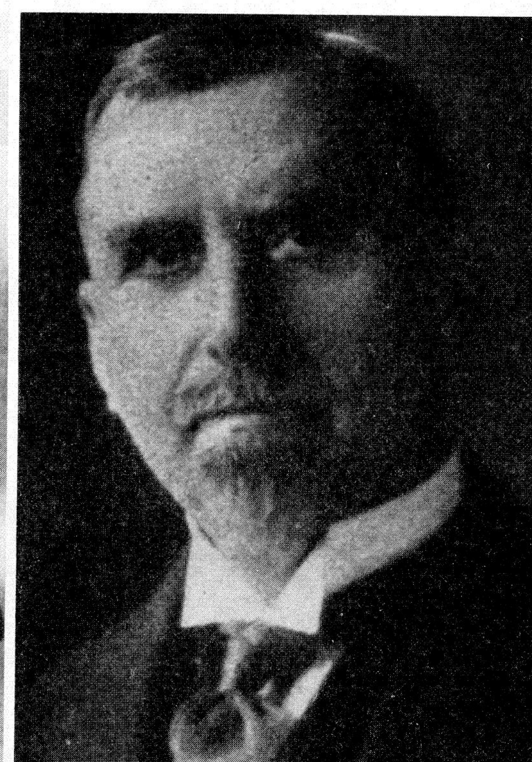
45 First Burroughs Machine and Factory
Here are often-published pictures of the first Burroughs machine and factory. It is interesting to note that throughout the history of the art, many of the outstanding inventors had close personal contacts with one another. Burroughs and Baldwin were intimately acquainted.

In his memoirs, speaking of his first model completed in 1873, Baldwin wrote: "It was on this model that I had William Seward Burroughs do some work for me. Mr. Burroughs, with his father, had a small general machine shop in St. Louis. Not until about 1880, did Mr. Burroughs start work on his own adding machine with a keyboard set-up."

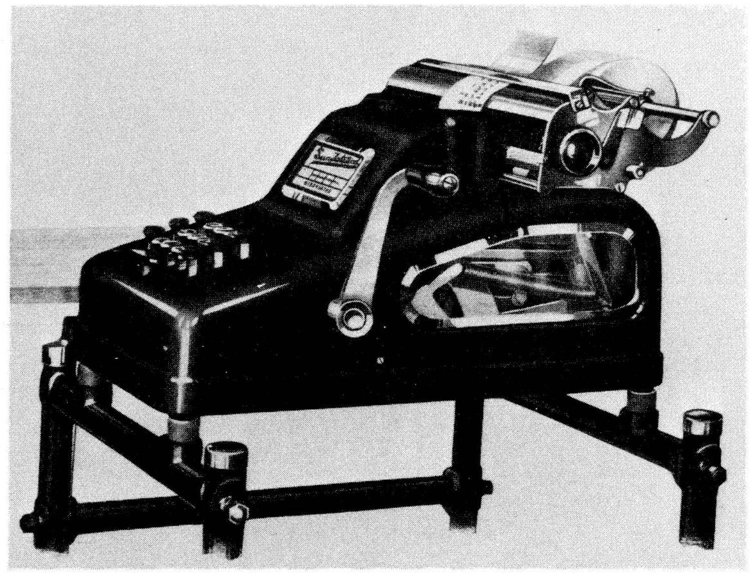


46 Standard Adding Machine
The Standard adding machine came on the market about 1901 and was widely sold for several years. It was invented by William W. Hopkins of St. Louis (I assume he was the brother of Hubert Hopkins of Moon-Hopkins fame). The Standard was the forerunner of a long line of ten-key machines. Aside from the ten digital keys, the Standard had a row of red and white column-finding keys.

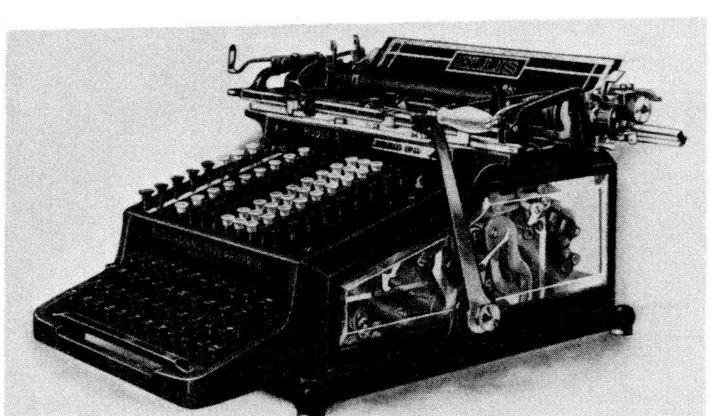




47 Dalton and His Machine
The next ten-key listing machine to gain prominence was the Dalton, another creation of Hubert Hopkins. James L. Dalton, known as "Jim," was admired and respected by all of us who knew him—particularly by all who worked with him.



48 Sundstrand and His Machine
Oscar Sundstrand was another boy inventor who, at the age of 19, built a machine destined to take a prominent place in the history of the art. Oscar and his brother David established the manufacture of the Sundstrand machines at Rockford, Illinois, about 40 years ago. The arrangement of the ten-value entry keys of the Sundstrand machine gained such popularity as to have been copied by a score or more of ten-key listing machines that followed it on the market in Europe and America. Modernized machines based on the Sundstrand invention are being manufactured in Hartford; they are known as Underwood-Sundstrand.

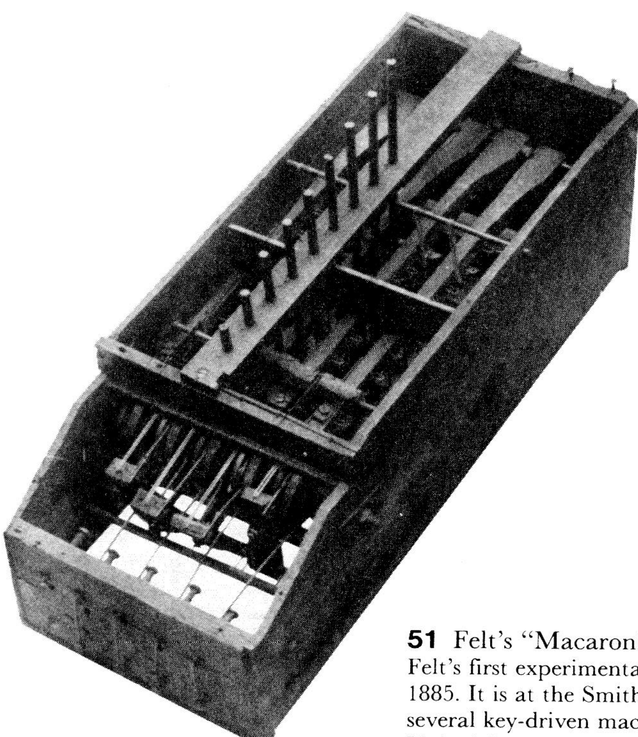


49 Ellis Adding Typewriter
Another product of a St. Louis inventor was the Ellis adding typewriter, developed by Halcolm Ellis about 40 years ago. The Ellis machines were manufactured in Newark, New Jersey, for many years, and finally consolidated with the National Cash Register Company.

223 It seems that many of the machines developed in the United States had their beginnings in or near St. Louis, which is surprising, since no adding or calculating machines are manufactured in that city at the present time. Each of the following machines was originated or had an early history in or near St. Louis:

- Baldwin-Monroe
- Burroughs
- Standard
- Dalton
- Universal (acquired by Burroughs)
- Moon-Hopkins (acquired by Burroughs)
- United Multiplier (acquired by Powers-Samas of London and incorporated in the Powers punched-card controlled machines to add and multiply in British money)
- Teetor, a listing machine manufactured in St. Louis about 1919
- Pike (acquired by Burroughs)
- Ellis Adding Typewriter (acquired by National Cash Register)
- Brennan (acquired by Remington Rand)

50 Dorr E. Felt
Dorr E. Felt commercialized the reciprocating type of digital actuator in another form, the key-driven computing machine known as the Comptometer. Like many others, Felt was a mere lad when he built his first computing machine.

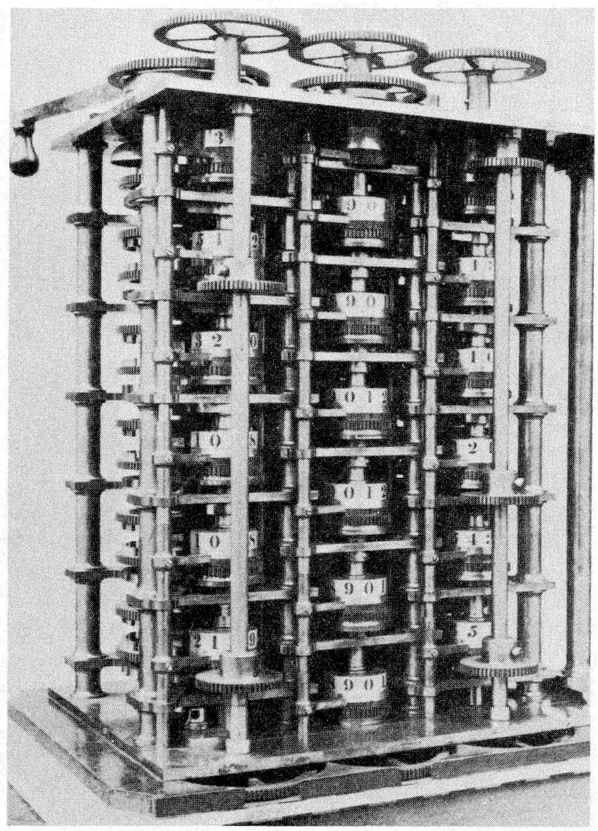


51 Felt's "Macaroni Box"
Felt's first experimental model, known as the "macaroni box," was constructed in 1885. It is at the Smithsonian Institution in Washington. At the present time several key-driven machines embodying reciprocating actuators are made in the United States and Europe.

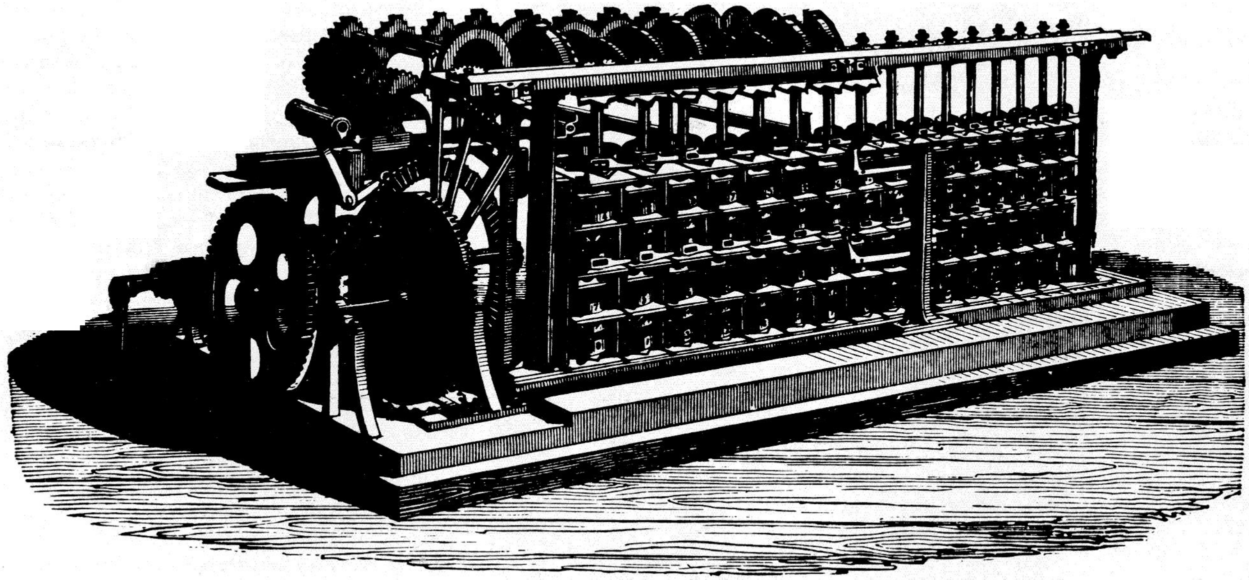
52 Charles Babbage
One more subject merits our attention: automatic sequence control. There is little early history of sequence control as it is known today, and that early history appears to be restricted to the so-called difference engines and to machines controlled by punched cards.

It appears that a Hessian military engineer, J. H. Müller, had a conception of the principles of a difference engine as early as 1786. Müller's conception is described in an article published during that year in Frankfurt am Main by E. Klipstein, entitled, "Description of a Newly Invented Calculating Machine."

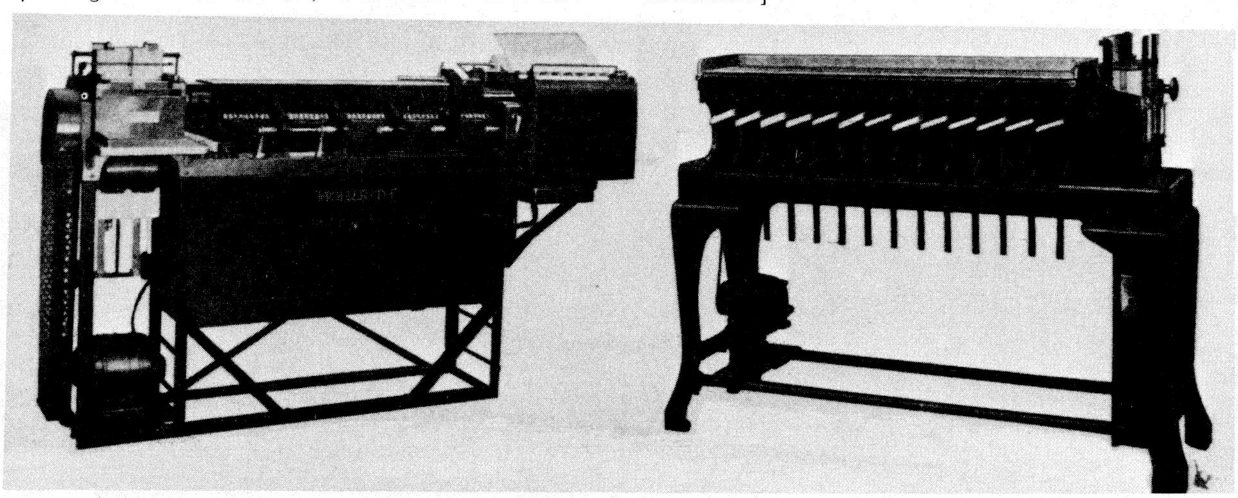
Beginning in 1812 and devoting most of his life to the subject, Charles Babbage invented and constructed several difference engine mechanisms, which, although not a complete success, contributed generously toward the advance of the art.



53 Babbage's Difference Engine
This is a picture of the best known of the Babbage machines, which is now preserved in the Science Museum at South Kensington, England. The objective of difference engines was the computation and printing of mathematical tables by the automatic sequential addition of multiple orders of differences. [Many scholars today would stress Babbage's plans for the Analytical Engine, which embodied so many features of present computers.]



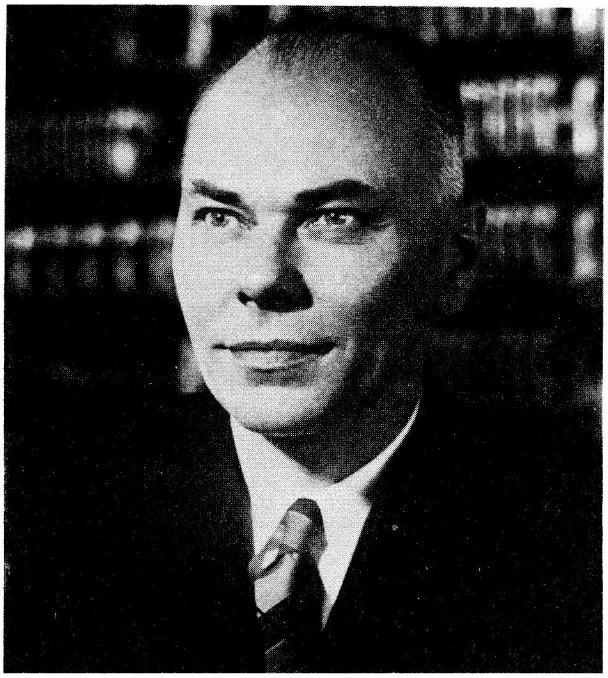
54 Scheutz Machine
The first dependable and useful difference engine was built by Georg Scheutz and his son Edvard, of Stockholm. The first Scheutz machine was completed in 1853. One of the Scheutz machines was presented to the Dudley Observatory at Albany, New York, by an American, J. H. Rathbone, where it was used to compute and print mathematical tables. Difference engines have also been constructed by Martin Wiberg of Sweden and by George B. Grant of Boston, the manufacturer of the Grant calculating machine, previously described. The Grant difference engine was exhibited at the Centennial Exposition at Philadelphia in 1876. [The Scheutz machine is now in the National Museum of History and Technology, Smithsonian Institution. During the years between World War I and World War II, the art and practice of computation based on difference methods were highly developed in England by L. J. Comrie, who used available (but modified) commercially made calculators.]



55 Hollerith Machines
The work of Herman Hollerith of New York City led to the commercial development of punched-card controlled computing machines shortly before the year 1890. This picture illustrates one of his early models.

At the time the Franklin Institute made the award of the John Price Wetherill Medal in recognition of the attainment of full automation in the four rules of arithmetic, one hundred years after the production of commercial machines was started by Thomas de Colmar, some of us at Monroe realized that the first era of development of four-rules calculators had been completed.

We sensed that the next logical advance would be automatic sequence control, but we did not realize its potentialities and did nothing about it.

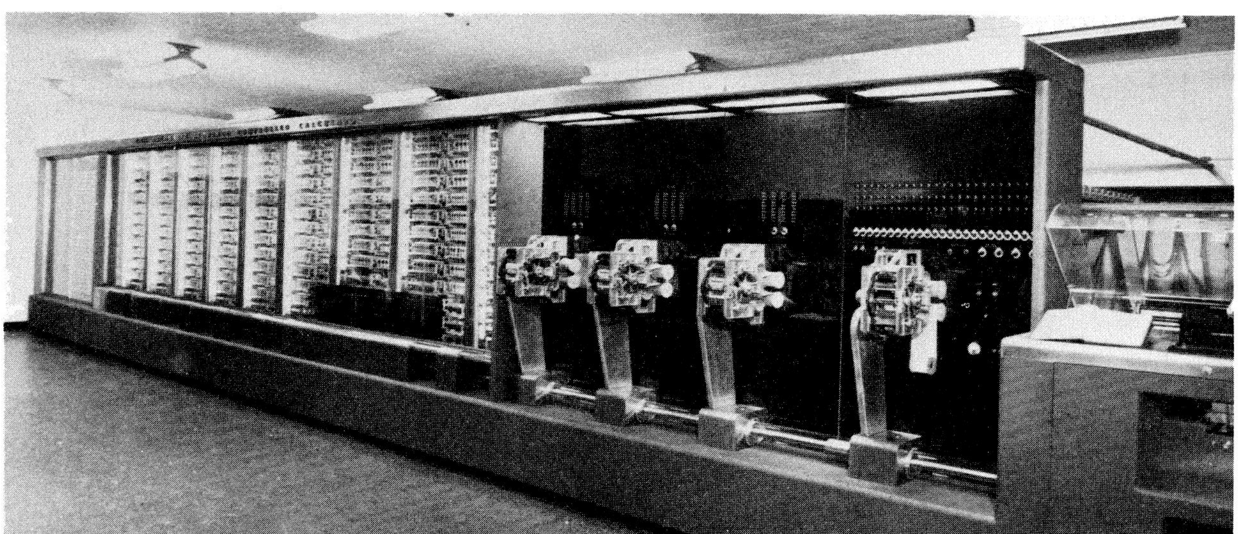


56 Howard H. Aiken
It remained for Howard H. Aiken to inaugurate the second era of development of computing machinery, the large-scale digital computer with automatic sequence control.

On April 22, 1937, Aiken outlined to me his conception of this advanced type of equipment and explained what it could accomplish in the field of mathematics, science, and sociology. He told me certain branches of science had reached a barrier that could not be passed until means could be found to solve mathematical problems too large to be undertaken with the then-known computing equipment.

He outlined to me the components of a machine that would solve those problems. His plans provided automatic computation in: the four rules of arithmetic; preestablished sequence control; storage and memory of installed or computed values; sequence control that could automatically respond to computed results or symbols, together with a printed record of all that transpires within the machine; and a recording of all the computed results. I recognized a feasible construction in the outline of the mechanism he proposed to build.

What he had in mind at that time was the construction of an electromechanical machine, but the plan he outlined was not restricted to any specific type of mechanism; it embraced a broad coordination of components that could be resolved by várious constructive mediums. I knew then that the second era of development of computing machinery had started.



57 Aiken's Mark I
When I later saw Aiken's Mark I at the Computation Laboratories of Harvard University, I knew that era was well under way.