A concise yet complete description of Schwilgué's series calculator

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The accidental (but not independent) rediscovery of Schwilgué's large adding machine by a Swiss computer scientist in Strasbourg in December 2014 has led to a number of rushed publications, containing many incorrect, misleading and ill-informed statements.

As a consequence of these premature publications, the machine will be exhibited at the Bonn Arithmeum, but since we have completely analyzed it in 2009, we have decided to give a complete and concise summary of its functions before it leaves Strasbourg for Bonn on April 16, 2015. (A more complete description has been deposited earlier at the French Academy of sciences and in other places, and also in encrypted form on `http://locomat.loria.fr`.)

Before giving the details of the machine, let us list several features that have recently been highlighted:[1]

- this machine was supposedly built in the 1830s;
- this machine was supposedly built for the Strasbourg astronomical clock;
- this machine is supposedly the first "Prozessrechner" in history, that is some kind of calculating machine commanding another tool or machine;

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[1]This short note intentionally does not give any sources, nor references. It is only meant to assert the priority of the first complete study and understanding of the machine.

- this machine is supposedly not in working condition;
- according to the curator of the Arithmeum, the machine stores the numbers using a *Schaltklinke*, anticipating what Dietzschold did around 1880.

Each of the above statements is incorrect. Unfortunately, some of these statements have been widely publicized in an article published in the German *c't* magazine by A. Stiller in January 2015. Quality research takes time and it is unfortunate that some researchers prefer to publish early, incomplete and sometimes incorrect information for the sole purpose of adding a new trophy to their collection.

We now give a complete description of the machine. Our purpose is to be as concise as possible. In particular, there will be no picture and no drawing, as these are not necessary at this stage. Use your imagination!

The first thing to understand is the purpose of the machine. It is a specialized calculating machine and not an attempt at creating a general calculating machine. It is pretty pointless to compare this machine to Thomas's arithmometer, for instance. The same could be said of Babbage's difference engines. Schwilgué's machine has limitations and these are irrelevant. For instance, it is not made for subtracting numbers, nor for multiplying numbers. The machine has only one purpose, that of calculating multiples of some value using additions, and on 12 digits, and it is with respect to its purpose that the machine must be judged, not with respect to goals that are totally foreign to it. Schwilgué's machine is useful for positioning tools whose position is given by angles at regular intervals, such as a gearcutting machine. Schwilgué has built several gearcutting machines, and one machine built in 1842 could position a wheel with a theoretical accuracy of 10^{-7} turns. The actual accuracy was not that large, but in order to have the angles with a large accuracy, Schwilgué wanted to compute the fractions $1/p$, $2/p$, ..., p/p on 12 places. For instance, with $p = 13$, Schwilgué wanted to have $1/13 = 0.076923076923\ldots$, $2/13 = 0.153846153846\ldots$, etc., merely by adding a truncated value of $1/13$ again and again. The values so obtained were copied on paper and could be used as an input for the gear-cutting machine. This gearcutting machine, contrary to what has been written, was not revolutionary, and it has also already been described several times in the past. One should by the way be cautious with the hagiographic writings of Schwilgué's successors which tend to exaggerate Schwilgué's merits.

It should be observed that there was no automatic drive of the gear-cutting machine, and it is therefore *ridiculous* and *naïve* to view this calculating machine as a *Prozessrechner*.

Moreover, this adding machine was very certainly invented in late 1843 or early 1844, that is *after* the completion of the astronomical clock (1838–1843). It was therefore not made for the clock! The machine seems to have slightly evolved and the current machine follows plans dated 1852.

The machine is in working condition, but it is rusty and a bit dirty. Even in these conditions, with care, it can be made to operate.

The machine is made of 12 almost identical blocks (one for each place), a command arbor, and a command block. The machine is *weight-driven*, but the weight and its string have disappeared. (A small part of the string is still extant and should be kept.) A crank is used 1) for rewinding the machine, and 2) to clear carries. The crank is normally not used to operate the machine (unlike machines such as Odhner's), but it can be used for that purpose.

Once it is rewound, a detent is shifted and the machine does one addition, and stops. This operation is repeated until the machine is rewound. After each computation, the values are copied on paper. The advantage of a weight-driven machine is *automation*. One does not want to turn a crank hundreds of time. Schwilgué wanted to automate that, in the same way as Babbage wanted to power his difference engines with steam.

The command block is similar to a striking work with two 54 teeth wheels, a pinion of 9 leaves, a second wheel of 47 teeth, and a double threaded worm. The weight is attached to a string which is wound around a drum driving one of the 54 teeth wheels, and this wheel meshes with the second 54 teeth wheel, as well as with the pinion. The second 54 teeth wheel drives the command arbor. The pinion drives the second wheel and the worm which leads to a brake and an arm stopped by the detent. (The detent is actually made of two parts, but we don't enter into these details here.) When the detent is released, the arm is freed and the work turns, until the detent again meets a notch on the 54 teeth wheel of the command arbor. There is also a notch in the other 54 teeth wheel, and the two work together as in common striking works.

When the command block is triggered, the 54 teeth wheels perform one turn and so does the command arbor. This arbor is tangent to the 12 blocks and carries 24 arms, organized helicoidally, two per block. The helicoidal arrangement is not new and has been used several times before. It is a natural consequence of the relative position of the blocks, of the arbor, and of the need to sequentialize the additions at each place: first the units, then the tens, etc. The same is done on other machines, such as the common Odhner-type machines. Sequential additions are also performed in the drum-like calculating machines, including the Curta, but in that case, there is no need for an helix. The arrangement of the computing blocks dictates the structure of the command arbor.

Each block displays three digits and the three sets of 12 digits represent three 12-digits numbers. One is a mere counter, and it will show 000000000000, 000000000001, 000000000002, etc. The other is a constant and will never change during an operation. It will for instance store a value such as 076923076923 for $1/13$. The third one will merely show the multiples of the constant. There are therefore two independent, but synchronous, functions: the counter, and the multiple. These functions are synchronous, so that one value (the counter) could serve as an entry to the second (the multiple). In the case of the counter, the machine has to add one to the units, and to propagate the carries. In the case of the constant, the constant must be added to the stored sum, and carries have to be propagated. Each of these two functions is obtained by two arms of the command arbor. One arm is for incrementing the counter, the other is for adding one digit of the constant to one digit of the sum.

Let us consider the counter first. At the beginning, only the units have to be incremented, but afterwards, carries may be transferred from one block to the next. This is done as follows. The rotating arm can meet a wedge which is part of a lever, but that lever has two positions: in the lower position, the rotating arm does not meet it, and in the upper position it does. The lever is in the upper position whenever the previous block has produced a carry, or in the case of the first block (the lever is artificially maintained in the upper position). A carry is prepared when the counter digit wheel (carrying a pin) reaches 0. When the rotating arm meets the wedge, it pushes the lever up, and the end of the lever carries a pawl acting on a ratchet wheel attached to the next block's counter wheel. Therefore, carries are transmitted from one block to the next. Moreover, thanks to a small counterweight, the carries are cleared whenever they are used. This is not done for the very first carry (from the first block to the second), merely because the constant addition of one unit makes it unnecessary. When starting a computation, one has to make sure that all carries are cleared. This can be done by going one by one through all carries, but one might also use the crank on another arbor, which is specially made for clearing carries. Turning the crank in one direction will raise all the levers carrying the wedges. Since this will also advance the figures, the best way to clear the carries is to set all the counter figure wheels (except the first two which are set to 0) to 9, and to clear the carries with the crank.

Adding the constant is done as follows. First, the constant is stored by the position of a wheel (which incidentally has 11 and not 10 sides). This wheel carries a 11-leaves pinion meshing with a 17 teeth sector. The sector ends with a pin on which a special arm rests. The position of this arm is therefore related to the value of the constant digit. This arm carries a pawl which acts permanently on a 100-teeth ratchet wheel. (Since the contact is *permanent*, the analogy with Dietzschold's *intermittent* pawls is incorrect.) The second arm of the command arbor can meet this arm, and push it, but how long it pushes it depends on the initial position of the arm. When the arm is in the lowest position, the command arm doesn't meet it. This corresponds to the value 0. In the next position, it takes it along for 9 units, then for 8, and so on. The 100-teeth ratchet wheel is attached to a 100-teeth spur wheel which meshes with a 10-leaves pinion, attached to the sum figure wheel. And this is how the constant figure wheel is added to the sum figure wheel. The fact that the constant figure wheel has 11 sides, one of which is blank, is merely a reminder not to turn this wheel beyond a certain point. It would also have worked with 10 sides. But with 11, Schwilgué took some pain making the wheel larger, and did intentionally not align the arbors, so that the digits would appear in the same plane on the top. This wheel can be turned in both directions.

Carries for the constant are taken care as follows. Whenever the figure wheel of the sum goes from 9 to 0 (or beyond), a pin raises a lever in the next block, and that lever is normally retaining a three-armed lever. When that lever is released, one of its arms comes in the way of the command arm. When the latter reaches it, it raises it, and the third arm of the three-armed lever carries a pawl which moves the 100-teeth wheel by one tooth, thus advancing the figure wheel by one unit. This at the same time puts the three-armed lever back in its normal position. One should notice that contrary to what happens with the counter, the lever for the carry transfer cannot remain in an upper position, but the three-armed lever may be unretained, causing false carries. Therefore, at the start of a computation, the carries should be cleared by making sure that all three-armed levers (of which there are naturally only 11) are in a retained position. This can be done by hand, or using the crank which, in the same position as for clearing the counter carries, can clear the sum carries, by pushing a small counterweight attached to the pawl of the three-armed lever.

Besides clearing the carries, the machine can easily be set to an initial value, but since clearing carries can increment values, a specific order has to be observed.

The machine was advertised for 300 to 400 Francs in 1846, but it seems unlikely that any was sold, as it was too specialized. Pictures of the machine were exhibited in 1920 and it was briefly described in several places throughout the years. It was probably exhibited in the Strasbourg museums before WWII, but put in storage afterwards, until its rediscovery in 2009.

Advice for the Arithmeum restorer

We trust that the restoration will follow the highest possible standards, and will be fully documented. We also hope that each screw will remain attached to its particular place and that there will be no swaps whatsoever. The remaining part of the string should not be discarded, but returned to the Strasbourg museum at the end of the exhibition. The Arithmeum should also provide a replacement weight.