Arithmeum's Analytical Engine Trial Model Replica

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Introduction

In the Science Museum (ScM) in London exists an Artefact named *Babbage's Analytical Engine, 1834-1871. (Trial model)*, of which pictures are online, see [ScMTrialModel]. According to the online texts, this is *a portion of the mill with a printing mechanism*, and *Only part of the machine was completed before his death in 1871*.

A very similar machine is shown in the Arithmeum in Bonn, Germany. The IBM archives [IBM] also have a small photo of such a machine; both evidently replicas. No written information is available on these; it may be that the machine at IBM is a replica made from the original of the Science Museum, and the machine in the Arithmeum a replica made from the replica by Dr. Roberto Guatelli. IBM had hired Guatelli for many replicas made between 1951 and 1961 [Tomako1997]. Prof. Herbert Bruderer has recently posted information on Guatelli's replicas on [Bruderer], but included no information on an AE trial model replica.

It is rather strikingly that there is no substantial information on a machine that is apparently the first ever built (trial model of a) processing unit for a programmable automatic computer.

As the original in the Science Museum is apparently not in working order (as opposed to the desktop-calculator like machine made later by H. P. Babbage), the replicas share the same fate. At least for the replica in Bonn, obviously no effort has been made to align gears and other machine elements. This might have been to keep the replica as close as possible to the original, but might be distracting visitors that try to understand the machine.

All available full view pictures of the machines, original and replica, show a view with cam drives in front and the grid of toothed bars in the centre. This might today be the visually more impressing side, but it does hide the relevant parts of the machine.

The other side, for which as today no (good) photo seems to exist, has the substantial part of the machine, i.e. the calculating mechanism. Therefore, it is considered the front, and the side usually shown the back side.

Tim Robinson provided valuable additions and corrections.

Portrayal

Taking into account the details from the next section, a summary of the machine is given, that in general does describe it as factual where assumptions were made, presenting a model as a target of verification and further investigation.

The machine is a proof-of-concept model for the calculation part of an automatic computer. It neither has a store for variables nor automatic control, i.e. no programming device. While a store may be connected to the digit racks at the back side, there is no place where the operation of the machine as defined by the cams and levers could be intercepted or modified.

Seen from the front — which is the side not presented to visitors — there is central column of stacked pairs of discs, and two slightly smaller number axes to the left and right of it, which are piles of single gearwheels with a multiple of 10 teeth.

Between a number axis and the central column is a pair two pinion axes of small gearwheels with 10 normal teeth and an extra single long tooth. The single tooth has the thickness of a disk of the central column, while the inner teeth are axially extended. One of the pinion axes can be elevated while the other one is lowered for the thickness of the central column discs. If thus the number gearwheel is rotated while the pinion gear is coupled, the single long tooth acts on the lower or upper disk of the central column. The lower plate is be the 10's warning plate and it should be moved by the pinion when the figure wheel passes from 9 to 0 (in addition). The upper plate is the 9's warning plate, and it should be set when the central column is moved sideways for any disk where the figure wheel stands at 9. At the right of image 611 one of the three “ladders” can be seen which pass up inside the column to lift these plates.

On the back are twenty-six toothed digit rods, extending from left to right. There is no indication of a sign; using complements for negative numbers cannot be excluded. Each number column has a coupling axis that can be move laterally to connect the number column to the digit rods. Each coupling axis is located on the outer side of the number columns. The coupling is done inversely by a single lever, i.e. at most one of the number axes is connected to the digit rods.

There are two toothed bars on top and below the number rods that can also be moved horizontally from left to right, with matching segmented gearwheels. These are the main drives that provide all circular motions of the columns; they were referred to as *great racks* by Babbage.

While the number axes have bearings at the top to keep them vertical, this is not the case for the central column. There is a mechanism at the back that protrudes through the number rods; it might move the central column laterally.

The printing mechanism is also used to enter numbers into the machine for testing the mechanism. No mechanism can be identified to reset the machine to a sensible initial state.

Several knife-like bars align the teeth of rods and gearwheels; they were called *locks* by Babbage and are the same as in the DE2.

The interaction of the one central axis, the two number axes, the four pinion axes, and the two transfer axes is still to be determined. It its also not clear if the two number axes are used to accumulate numbers, or if this is done in the pinion axes. It is thus not even evident how a single addition is performed.

Description

Note 1: The parts are named as felt appropriate; the names may be misleading and are not checked against other sources, in particular the Babbage Papers [BAB].

Note 2: The assembly did evidently not try to align machine elements properly, so the situation is treated as if alignment was proper, and misalignment normally not mentioned.

The machine has a ca. 2 cm thick base plate, 100 cm wide and 70 cm deep. In the corners are four rods of 57 cm length, that support two long top bars running from side to side. Below the base plate, the rods are extended down for nearly 20 cm, whereon the machine rests (pic. 523).

Three links connect the top bars directly at the ends, and two others in the middle are elevated (pic. 523, 566).

One central column is in the middle of the machine, with two number axes to the left and the right (pic. 541). The latter two are supported on top by the elevated latches; the central axis is not laterally fixed on top (pic. 620).

Besides holding the number axes, the elevated latches have each a U-shaped bracket (pic. 566), with holes on a common horizontal axis. It looks like a device for attaching something to the back of the machine, although a corresponding hook at the base plate is not evident. They are probably intended for forked levers that would operate in the groove at the top of the axes to provide lifting as in DE2.

Behind the axes — on the side of the cams — are twenty-six digit rods of nearly full machine length, several millimetres thick and about 3cm wide, with teeth on both long sides (pic. 524). They are supported left and right to the axes by digit rod supports (pic. 564), so that they can be shifted horizontally parallel to the longer side of the base plate.

Two additional, slightly thicker, toothed rods are at the top and the bottom (pic. 566, 626). A thick polished shaft is driven from below the base plate and moves the toothed rods horizontally (pic. 566, 624). Both are connected by a light vertical bar for uniform up or down movement; the latter is, however, not allowed by the guides for the rods (pic. 624). There is an elbow on top (pic. 624) that keeps the bar horizontally fixed.

A forked driving mechanism from the vertical shaft to the toothed rods would allow either raising the rods, or the shaft (pic. 624). However, the rods cannot be moved vertically, and there is no indication that the vertical shaft is raised (pic. 597).

The toothed rods match segmented gears on top and bottom of the number axes (pic. 573, 567), if the segmented gears are elevated. Whether the segmented gears turn the disc wheels or rotate something else is unclear, but note the bolt downwards (pic. 570). This bolt appears to be a lock to prevent rotation of the axis in the lowered position. If the axis is raised to put the sectors in line with the racks the bolt would be lifted free of the framing allowing the shaft to rotate.

The central column has a pair of discs per digit (pic. 583); it is not clear whether these are connected. The upper disc has long extruding parts with a small tooth that fits into the teeth of the nearby gear (pic. 572).

The number axes have one gearwheel (pic. 583, 584, 585) per digit. These gearwheels have a large number of teeth; it would be surprising if it is not a multiple of 10. Also, there are lugs protruding axially (pic. 582, 611), presumably every 10th tooth. Corresponding lugs are on a vertical bar (pic. 582, 611), which is not movable radially, but might be forced to move when the gearwheel's lug matches a lug on the vertical bar. This may be the “reducing bar”. It passes through a curved slot (image 611). It should be able to rotate about the axis and as it does so it can “reduce the wheels to zero”. It probably also has vertical motion because it would need to be lifted free of the lugs on the wheels to allow addition. Another possibility is that the segmented gears move the vertical bars and thus force the gearwheels to a common state.

Between the central column and each of the number axes is a pair of pinion axes (pic. 582, 583) with small gearwheels having 10 small teeth that can be driven by the digit axes, and one larger lever that may operate on the central column discs (Pic. 611).

For each pair of pinion axes, one can be raised while the other is lowered (pic. 611). The amount of elevation is small; about the thickness of one of the gear disks of the central column. The column near to the number rods is lowered if the connection column (see below) connects the number axis to the number rods, and vice versa (pic. 602). It looks like the pinion wheels are always in contact with the number gearwheels, but a support for holding them there has not been identified.

On the outer side of each of the digit axes is a transfer axis with medium sized gearwheels which, when activated, couples the number axis to the digit rods (pic. 563, 587). The transfer axes are moved to the connected and unconnected state by a long lever with a central bearing (pic. 558) in such a way that at most one transfer axis is connected. This is an interesting and late development by Babbage. Instead of the profiled teeth as in DE2 to allow gears to engage directly by lifting columns he introduced these extra pinions which can be swung into place after the column is raised into line with the racks. This allow the regular profile of the teeth to ensure smooth engagement and lets the wheels be thinner and so the columns shorter. He wanted them short enough that they only needed support top and bottom.

In the back of the machine are some gears and five cam drives on a primary shaft (pic. 524). The inscription on the cams divides the rotation into 32 units (pic. 595).

A secondary shaft supports seven levers, with four levers driven by the cams and also having vertical parts, of which one is actually connected to inner parts of the machine (pic. 558). The others have more or less evident connection points inside the machine; just the connecting links seem to be missing.

The middle cam driven lever has no vertical part, but a screw to fix it to the secondary shaft (pic. 558). Two of the levers on the secondary shaft have no cam drive, but are connected to the inner part by latches.

Note that the two outmost levers on the secondary shaft are practically unmovable by slotted latches that could easily be removed (pic. 558).

More cams and control levers are below the base plate (pic. 600).

A mechanism at the back has a pair of scissor-like hinges that extend through the digit bars and can be moved left-to-right and right-to-left uniformly (Pic. 524, 616, 623). The device is driven by a rod through a hole in the base plate, that turns a horizontal pivot, to which two vertical levers are fastened, that in turn drive the hinges (pic. 524). Screws in fixing the vertical levers allow to adjust the distance (modern Allen / INBUS screws are used) The action effected is unclear; it could move the central column laterally, which fits to the lack of fixation of the latter on top. It remains the question if this is a reliable construction.

The digit axes are not fully the same; the one on the left side has an additional vertical round shaft (pic. 613).

There are several bars to lock (and thus align) teeth (pic. 587, 574).

On the left, there is a printing mechanism (pic. 576, 577) for 25 digits in groups of 3, 8 and 14, which can be set by the digit racks. The horizontal movement of the digit rods is translated by gears to a vertical movement of densely packed vertical digit select racks. No decoupling mechanism for the printer has been identified; it seems that the printer always reflects the state of the digit rods. As the upmost digit rod has a corresponding gear, the lowest digit rod may be the one not connected. Note that on each second of the digit rods there are 12 missing teeth on the side of the coupling gear. It is unclear whether these gears can slide along the rods, as many of them are not actually in connection with the racks, or if this is just the missing alignment of machine elements. The tooth profile looks incorrect for a right angle drive.

In [BAB], S/2/2, page 348, it is mentioned that the printer mechanism can also be used to enter numbers (hint from Tim Robinson).

References

Some references are not yet verified, and the list just collects entries:

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