Trochotron Beam-Switch Counters and Numeric indicators

The trochotron is a true miracle of ingenuity, a divide-by-ten high-speed counter in a single vacuum tube, fully exploiting the combined influences of magnetic and electric fields on electrons moving in a complex electrode structure. For some aspects it resembles the multi-cavity magnetron, but here the electron flow is fully controlled and at any time precisely addressed to the selected electrode system, in a fantastic equilibrium play. Nonetheless it never gained popularity, its use being confined to few high-end applications. Military mainly appreciated its intrinsic reliability, a single tube replacing dozens of components and parts, when they still looked with suspicion at the solid state solutions. Soon it disappeared, early victim of the migration to solid state, as other expensive devices and average people never heard of it. Just its fascinating name survives today and even the simple documentation of many types is no longer available. The collection includes samples of several trochotron types and even a couple of complete equipment based upon these counters.

History and basic structure

Trochotron was the trademark for a little-known hot-cathode counter tube, in which electrons move along trochoid-like trajectories, under the effects of combined electric and magnetic fields, in a special electrode structure. Probably it was a by-product of investigations in progress since the early ‘40s on electronic switches, capable of replacing mechanical or capacitive types as fast multiplexers for analog signals. Ericsson is credited by someone of a leading role in investigating these devices, but we can find remarkable interest by other firms. In Electronics, August 1944, we find an article referring to a radial beam device designed at Bell to operate as 30-line multiplexer/demultiplexer. The full description had been already published in the Bell System Technical Journal, April 1944. Here we find a detailed study on electron beams controlled by magnetic fields in a cylindrical system of electrodes. The author, A. M. Skellett, used the most advanced techniques to give a full characterization of the electrons trajectories and of the tube behavior and a 30-channel complete signaling system had been successfully operated over short distances in New York City. In Electronics, August 1951, an article describes a very complex electronic 25-line multiplexer, devised by B.R. Shepard at General Electric. Electrons in the beam-switch tube were focused and directed by an external magnetic field, perpendicular to cathode, to flow through one out 25 grid systems, before reaching a common plate. Actually, since the magnetic focusing generated a double ended beam, the number of grid systems was doubled, two opposite grid pairs being driven by each input-channel amplifier. In 1956, five years later, National Union registered its 25-line multiplexer, the 6324, very similar to the GE prototype, if not the same.

Fig. 1 – The National Union 6324 intended as 25-line multiplexer.

The next step was the design of a beam switch tube with intrinsic stable states, capable of switching on clock pulses, more or less as the stepping relays used in the telephone exchanges. As far as we know, none of early hot-cathode Ericcsson counters led to commercial productions. 'Pulse and Digital Circuits' by Millman and Taub describes a sleeve-anode two-electrode device, similar to the one devised by Backmark at Ericsson. It was a crude structure, yet it was characterized by stable states, usable as divide-by-ten counter. Since no grid was available, negative switching pulses were applied to the common anode.

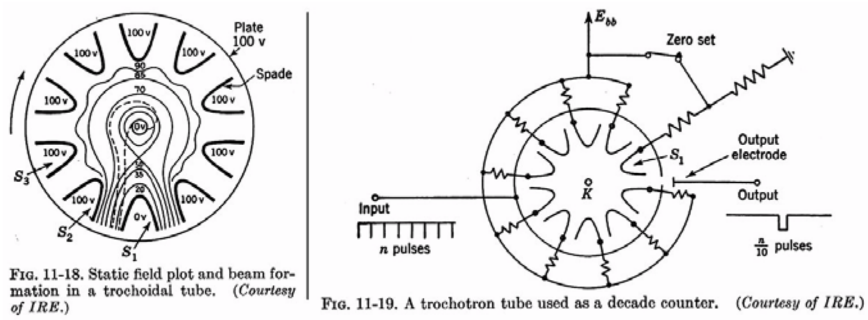

Fig. 2 – Left: field distribution in the above two-electrode beam-switch counter. Right: circuit to use the same tube as counter.

The first commercial beam-switch tube, specifically designed for use as counter, was advertised in May 1955 by Haydu Brothers in Electronics magazine. George and Zoltan Haydu in Plainfield, NJ were in business since 1936, advertising special parts for vacuum tube industry: electrodes, spacers, electron guns, up to anode blocks for magnetrons and glass-blowing machinery. They also contracted small runs of special tubes for larger manufacturers. Being a smart and flexible manufacturing plant, probably they were involved in prototyping trochotron samples for the Burroughs Research Center based in Paoli. Around 1955 Burroughs decided to build its own tubes and bought the entire Haydu plant, leaving for a while the direction to the same founders: details of the merging are not known. The very early device, a 'Beam Switching Tube' still no name, was advertised in May 1955 by Haydu Brothers of New Jersey, subsidiary of Burroughs Corporation, with its own mark. A couple of months later, in July, the tube was referred to as 'Magnetron Beam Switching' or MBS tube, claimed to replace 152 components, including 22 vacuum tubes. This tube, whose internal code was MO-10, design no. 100, had been registered to Haydu in June as 6700. In December a new MBS appeared in the pages of Electronics, the H-B 101, registered under RMA-EIA as 6701. In the same page the H-B 101 was associated for the first time to H-B 106 Nixie numeric indicator, the very early nixie, later registered as 6844, in a complete 'Varicount' counting module. In the above devices the prefix H-B stays for Haydu Brothers. One year later the Haydu brand would definitely disappear, replaced by 'Burroughs, Electronic Tube Division, Plainfield, New Jersey'.

Fig 3 – The three Haydu ads in 'Electronics' magazine during 1955. (Click to enlarge)

For each count position the 6700 MBS used the three-electrode structure devised by Fan and Saul Kuchinsky at the Research Center of Burroughs in Paoli, PA. To understand its operating principle we refer to the figure below, illustrating the internal structure and the connections of a typical trochotron.

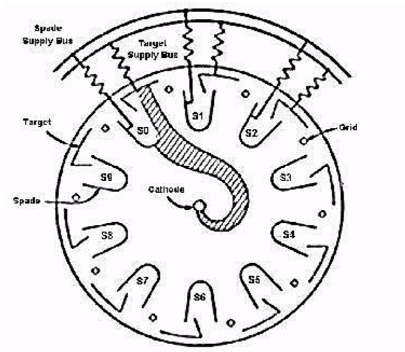

Fig. 3 – Electrodes of a divide-by-ten trochotron, with part of supply buses. Targets are 'L' shaped, with fin penetrating in the back the spades, to prevent electrons from escaping toward the glass envelope.

An inner ring of ten V-shaped spade electrodes S0 to S9, one for each counting position, surrounds the cathode. Ten electrodes, called targets, are all around, each target partially shadowed by the corresponding spade. A grid rod is between each target and the successive spade. All odd grids are connected together to a base pin and all even grids go to another pin. Typical supply voltage from 26 to about 200 volts is required, depending upon the magnetic field. Targets are fed through load resistors of relatively low value, while the value of load resistors to spades is much higher, typically 100 kohms or more. The glass envelope containing the described electrode structure is immersed into a cylindrical magnet, flux lines being parallel to the cathode itself.

Depending upon operating conditions, this tube has several operating modes, even oscillating ones. Here we try to give an intuitive description of its operation as counter, according to the notes of the same Kuchinsky. At power-on, under the combined influence of the external magnetic field and of the electric field generated by the 10 spades, the tube is in a cut-off state. Electrons are forced by the magnetic field to follow quasi-circular equipotential orbits in a dynamic equilibrium, in the region between spades and cathode. Due to their curved trajectories and to the shape of spades, influence from the targets in the background is almost entirely masked off.

The initial zero condition is set by pulsing the S0 spade low for a short while. Electrons spiraling in its vicinity, now feel the influence of the electric field from the target T0 behind, their trajectories being modified due to the target attraction. Subsequently their flow deviate to T0. Due to the curved trajectory, about 15% of total electrons impinge the spade S0, holding its potential low even after the reset pulse. The resulting current distribution to the target T0 and the spade S0 is roughly illustrated by the dashed path starting from the cathode in the fig.3 above. This is a stable state and the current through the selected target is approximately constant, in the order of some milliamperes.

In typical counting applications the switching grids are driven by a bi-phase sequencer, which supplies negative pulses alternately to the even and to the odd grid buses. A negative pulse of suitable amplitude, applied to the grid close to the holding spade, counteracts the attraction of the selected target, releasing the beam from the target itself. Repelled electrons, due to the rotating trajectories imposed by the magnetic field, move then to the leading spade. The current increase through the spade cause a remarkable drop of its potential and the beam is then attracted by the corresponding leading target in the background. A new stable condition is then reached at each counting pulse.

Trochotrons found some niche applications in high speed, top priced counting equipment. These devices were bulky and expensive when compared to gas counters, as the dekatron, but were capable of operation at frequencies as high as 10 MHz. A drawback in the use of Trochotrons was the need for a quite expensive Nixie tube, when visual indication was required.

Overview of known types

The early trochotron line, with external magnet, includes:

- **HB-100 / MO-10 / 6700**, the basic type capable of operation up to 2MHz.
- **HB-101 / 6701**, low-voltage variant operating up to 1MHz at 26 volts.
- **6703 / BD-301**, similar to 6700 with addition of magnetic shield.
- **MO-10R**, with built-in spade resistors , capable of operation up to 10MHz.
- BD-309, the shielded variant of the MO-10R.

Fig. 4 - From left: three samples of 6700, the first one badged Haydu, two samples of 6701 and a 6703.

Note the multiple coding for the 6700 and 6701. On the tecnical sheet stored at RMA for the 6700 we find the proprietary code H-B 100, indicating a design no. 100, and the code MO-10, where M probably stays for ‘Magnetron’. In the case of the documentation for RMA 6701, we only find the alternate Haydu internal code with the design number H-B 101. Starting from the 6703, we can find internal codes starting with ‘BD’, probably for ‘Burroughs Design’, followed by a number.

In order to reduce the size of its counters Burroughs introduced a redesigned family, derived from 6700 and 6703, with scaled down electrode spacing and glass bulb stepped-down a few millimeters over the base. Known types using the new design are:

- BD-203, the unshielded variant of 6700.
- **BD-316**, the shielded version.

Fig. 5 – Photo of a shielded BD-316

In 1960 Burroughs renewed the family adding the compact Beam-X types. Moving the magnet inside the electrode structure, the diameter of Beam-X trochotrons was scaled down to about the size of a 9-pin miniature tube. 10 slim magnetic rods were placed behind the 10 spades, originating the required magnetic field and even operating as targets. Both unshielded and shielded versions were available. Cross-section of a Beam-X counter is given below.

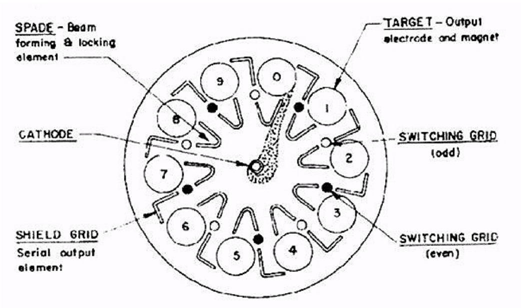

Fig. 6 – Cross-section of a Beam-X counter. Here the required magnetic field is generated by slim magnetic rods, the circles numbered 0 to 9, even used as targets. Ten L-shaped shield grids in the background capture electrons escaped from the electrode interaction space.

Only some of the surviving Beam-X types are documented. The proprietary code starts with the prefix ‘BX’, followed by four digits. Looking at the known types, the first digit should indicate the presence of magnetic shielding and the operating voltage, according to the table below:

- BX 1… - Unshielded type, standard voltage
- BX 2… - Magnetic shield, standard voltage
- BX 3… - Unshielded type, low anode voltage
- BX 4… - Shielded type, low anode voltage

Some of the known types are:

- **BX1000 / 6710**, the basic unshielded type, capable of operation up to about 3MHz.
- **BX2000 / 6711**, the basic shielded type, same electric specs as BX1000
- **BX2003**, **BX2004**, **BX2005**, all not documented.
- **BX3000**, low-voltage, 26 volts, unshielded type

Fig. 7 – The unshielded BX1000 and of some shielded Beam-X types.

Trochotron tubes were too expensive to be widely diffused. Yet we find productions by European manufacturers. The Mullard/Philips ET51, also approved as CV5277, was equivalent to the 6700. Other equivalents were the Ericsson (ETL) VS10G, its shielded variant VS10G/M, the high-current VS10H and the low-voltage version VS10GK.

Fig. 8 – The Mullard ET51 and the VS10G compared with the Burroughs 6700.

- Numeric indicators, Inditron™, Nixie™ and Pixie™

Trochotron counters do not give visual indication of actual counting position. Due to the DC drop of the active target, their state can be easily detected using neon bulbs connected to each target. The early indicator was the Inditron™ by National Union. Saul Kuchinsky, the responsible for trochotron development at Burroughs had worked before at National Union. The H-B 106 Nixie™ indicator was first announced by Haydu-Burroughs in December 1954. In January 1957, when the Haydu brothers had definitively left the direction of the company, the H-B 106 was registered to Burroughs as **6844**. In the same month the **6844 (HB-106)** was advertised in Electronics as made by Burroughs Corporation, Electronic Tube Division, Plainfield, NJ. Actually it is a device which combines in the same bulb ten neon lamps with common anode and separate cathodes shaped as numerals, from 0 to 9. When cathodes were directly connected to the target pins of each trochotron, only the one connected to the active target lighted up. A low-cost replacement for Nixie™, the Pixie™ indicator was also proposed. Here the anode was a disc, punched with the ten numerals, and the cathodes were simply short extensions of the pins below. Its indication resembled that of a gaseous decatron counter.

Fig. 9 – Samples of GI-21 Inditron™, 6844 Nixie™ and of Z550M Pixie™ numeric indicators.

Nixie™ indicators survived trochotrons and other tubes, being still in use well in the semiconductor age, until replaced by LED, LCD and VFD displays. Here an **HP 5245L** solid state counter.

Typical applications

Luckily I recently found a couple of counters, both built around trochotrons. The first one is the U.S. military **FR-114U**, part of AN/TSM-16 frequency meter, manufactured around 1960 by Van Norman Industries. It accepts input signals from 20Hz to 1MHz. The set is now fully operating and complete with its operator and service technical manuals. It proved to be an incomparable help to understand how these tubes were actually used, well beyond the typical applications found in the scarce existing documentation.

Fig. 10 – Pictures of the FR-114U frequency meter.

Count or frequency is displayed by six 6844 Nixie displays, each driven by a counter module based upon a selected 6703 trochotron. Five modules are rated for operation up to 100KHz, while the first one, corresponding to the least significant digit, is rated for 1MHz. Each counter module interfaces through a couple of connectors, the top one to the corresponding display and the bottom one to signal and supply buses.

Fig. 11 – Photo of a 100Kc decade counting module with a BD301/6703 trochotron.

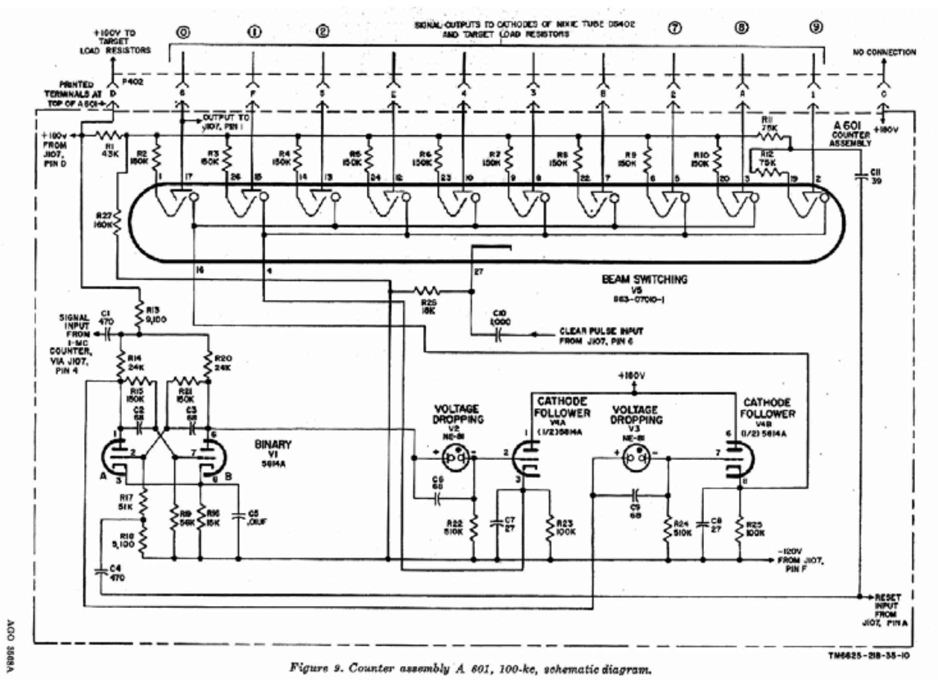

Fig. 12 – Diagram of the 100 Kc counter module

From the diagram above we can see the interface signals of each module to mainframe and to other modules. Just four signals are required, all through the bottom connector:

- Pin 1: Output signal, from target T(0) to the following stage
- Pin 4: Input signal, from the previous stage
- Pin 6: Clear input pulse
- Pin A: Reset input pulse

Operation is controlled by a sequencer generating timings for reset, count and display states. To initialize trochotrons, before each count, two steps are required: clear and reset. The positive clear pulse, applied to cathode of trochotrons, unlocks electrons from any target previously engaged. Trochotrons return in cut-off state and can now be initialized to their ‘zero’ count. This is accomplished by a negative reset pulse to the ninth spade S(9). The same pulse also sets the input signal flip-flop to its ‘even position’, so that odd grids in the trochotron are negative and even grids are positive. Due to the polarity of grids, the beam skips T(9) and locks to the next target T(0), ready to start a new count. Modules operate with +180 and –120 volts supply voltages. Total voltage, 300VDC, feeds counters through about 36 kohms target loads and 18 kohms cathode resistors. The spade resistors, 150 kohms each, are tied to a voltage divider at about 100V, referred to cathode.

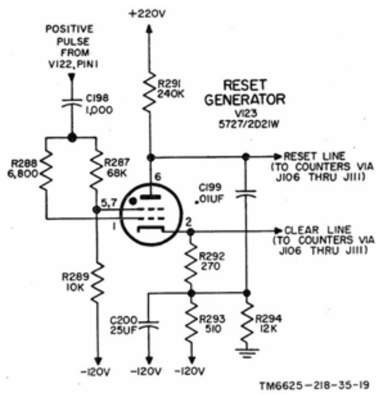

Figure 21. Reset generator V123, schematic diagram.

Fig. 13 - Schematic diagram of the reset sequence generator. A single 2D21W thyratron generates both the clear and the delayed reset pulses.

The input signal is fed to the bi-phase counting flip-flop and then, through cathode follower buffers, alternately drives even and odd grids of the associated trochotron. The output signal to the next module is derived directly from the T(0) target.

The second set, using 6700 trochotrons, is a six digit counter/timer shown in the photos below. I hope to light it, even if the job can be difficult, since no documentation can be found and the same power supply connector is missing.

Fig. 14 – Pictures of the 6-digit trochotron counter, probably from rangekeeper set.

References:

Millman and Taub, Pulse and Digital Circuits
Burroughs datasheets and application notes
TM 11-6625-218-35 Field And Depot Maintenance Frequency Meter AN/TSM-16
Manufacturer’s data

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