Short-time measurement – the contribution of German electrical horology

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This article is an updated version of a lecture delivered at Greenwich in June 2010 to celebrate the fortieth anniversary of the AHS Electrical Horology Group, and is part of a series of papers illuminating the role of electrical timekeeping in various walks of life. It first discusses short-time recording devices used in sporting events and in the military. It then focusses on the Hipp chronoscope, used to measure very short-time intervals in physics, ballistics, psychology, chemistry and medicine.

Hours are familiar things and easily comprehended, and they regulate our daily lives in batches of twenty-four. We can be a quarter of an hour late, or take a break for half an hour, and find it hard to believe there is still an hour left at work. When we want to be a bit more precise, we use smaller units of time—minutes and seconds. Although these are one sixtieth of an hour, or 1/3600th of an hour, they still have a very familiar feel to them. But familiarity disappears if we start talking in terms of 1/3600,000th of an hour—the sort of measurement used in the world of short-time measurement. Almost any clock can easily show us minutes and seconds, but what about these very much smaller time periods? Theoretically, one could simply finely divide the dial of a clock, but very quickly we reach the limits of readability and resolution. Resourceful people might suggest, 'OK. Let's make the dial larger.' F.L. Löbner, a Berlin-based company, did just that, and in 1895 developed a huge stopclock (see Fig. 1).[1] This unorthodox timer had a dial 3 metres wide, and a hand about 2 metres in length. The movement was driven by a 400kg weight with a total drop of about 4 metres.

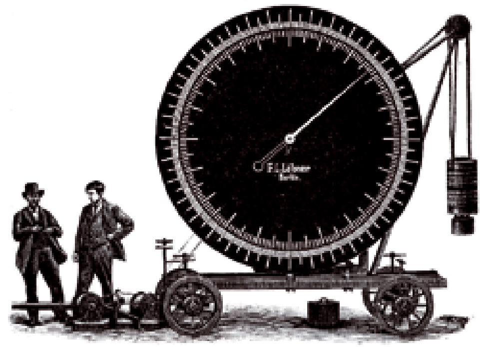

Fig. 1. Löbner's huge stopclock, developed in 1895. *DUZ*, no. 8 (1895), p. 89.

This clock could measure milliseconds (1/1000 sec) The hand moved very fast and made five revolutions per second. As it would be unsafe to stop the movement mechanically, owing to the huge inertia involved, time was determined photographically. These stop-clocks were used at racetracks, but how many were made by Löbner and whether any survive is not known. The Löbner device is an extraordinary solution, and perhaps not the most practical. Across the field of short-time measurement, we can observe a wide range of fascinating techniques for determining intervals and timings.

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1. *Deutsche Uhrmacher-Zeitung* (*DUZ*) No. 8 (1895), 89–90.

Fig. 2. The finish line. Three judges per runner, each with a calibrated stopwatch. See note 2 for source.

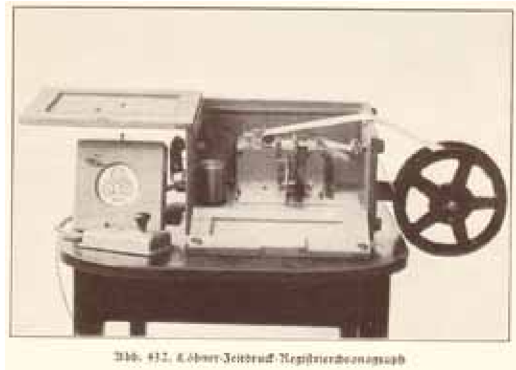


Fig. 3. The Löbner *zeitdrucker* with a *tertienuhr* as the time standard. See note 2 for source.

The 'zeitdrucker' and the 'tertienuhr'

In this survey of a variety of historic methods for the measurement of very short-time intervals, we start with techniques used at the less accurate end of the spectrum, in 1928, at the Amsterdam Olympic Games. Fig. 2 shows the critical element of a race, the finishing line. In this period, stopwatches accurate to $1/10$ second were used for races of up to 200 metres, while for longer distance an accuracy of $1/5$ second was stipulated. Electrical measurements were permitted, but at the outset there was little trust in electro-mechanical time measurement instruments. A book on athletics from 1930 describes in detail how timings were taken at sporting events.[2] In line with the finishing tape, the timing judges sat like birds on a perch, with calibrated stopwatches, trying to determine the running times of the different runners. The staggered arrangement of the judges at different heights allowed them to determine a finishing order, and their decisions were final. With more runners there would be three timing officials. However, any record of a runner's time was prejudiced by the 'personal equation' of the observer and therefore inclined to be inaccurate.

Löbner of Berlin specialized in the electronic timing of sports and was present in Amsterdam in 1928. For about three years the company had already been producing a recording apparatus, the so-called *zeitdrucker* or recording chronograph. The *zeitdrucker* (Figs 3 and 4) was protected by several Deutsche Reichs patents and consisted of several units.[3] The heart of the system was an accurate reference clock, in this case a specialized three-dial stop-watch, known as a *tertienuhr* (pronounced tertz-ee-en-oor), which provided electrical impulses (and which is explained in more detail later in this article). These impulses passed by way of a relay to the recording chronograph. A special motor ensured a continuous paper feed.

The recording unit could include various accessories, such as a push button for manual registration, and a switch for the manual starting of the paper transport system. In addition, a release mechanism could be supplied, which would automatically start the timer when the runners breasted a tape stretched across the start line. The system was complemented by a remote trigger which stopped the measurement when the finishing tape was broken. The runner who crossed the finish line first was registered electrically, and thereafter the other runners were recorded manually.

No complete Löbner recording chronograph has yet been located. However, the Museum of Science and Technology in Stockholm holds most of the parts of a

2. J. Fritz, 'Zeitmessung in der Leichtathletik', in Carl Krümmel, *Athletik. Ein Handbuch der lebenswichtigen Leibesübungen* (Lehmanns: Munich, 1930), pp. 565–72.

3. Johannes Fritz, German patents DE462687 (1925), DE450627 (1926) and DE473700 (1926).

Fig. 4. Recently discovered, extremely rare Löbner impulse clock, providing seconds input to the *zeitdrucker*, c.1936/37, as an alternative to a chronometer. Photo by the author.

system. In this case, the reference standard is a 1922 Ulysse Nardin chronometer, providing electric impulses each second.[4]

The *zeitdrucker* recording chronograph was innovative and its benefits are obvious:

- Measurement starts automatically with the breaking of the starting tape.
- The winner's time is automatically recorded when the finishing tape is broken.
- The remaining runners' times are registered by the pressing of a button.
- All the results are recorded on a single strip of paper.

There are many references to sports events where the Löbner recorder was used. On 19

4. Chris Hinchcliffe of the Technical Museum in Stockholm has published three (English) video clips on YouTube which demonstrate the system, including the Ulysse Nardin chronometer, and local and remote release. Search for 'Loebner timekeeper'.

Fig. 5. The Löbner recorder in use during the establishment of the new world speed record in 1929. BMW Group Archive, Werksfoto RF 2076/1.

Fig. 6. Electric starting pistol, used at the Olympic Games in 1936.

September 1929, Ernst Henne established a new world speed record, taking his BMW motorbike to 220 km/h.[5] The Löbner recorder was used to establish his speed, and BMW's archives include a remarkable picture, recording the event (Fig. 5).

The Löbner system was also used at the summer and winter Olympic Games of 1936. At the winter Games, it was used in the bobsledding, and at the summer Games for the marathon, 50km race-walk, the cross country element of the multi-discipline *Geländelauf des Offiziers-Fünfkampfes*, swimming, rowing and canoeing, cycling and equestrian events.[6] An Internet search will reveal four excellent images from the Dutch weekly *Het Leven*, showing the recorder in use at the summer Games.[7] Souvenir pictures of the Olympics included an image of John Fritz, the owner of Löbner, with the recorder, and another with the electric starting pistol (Fig. 6).[8]

Another old photograph shows how the system was further developed. A photocell and movie camera complemented the precision time standard and the *zeitdrucker*, creating the so-called 'photo-finish'. Although the Löbner system devised by Fritz

5. BMW Group Archive, *100 Jahre Ernst Jakob Henne, Der schnellste Mann der Welt*, pp. 26–32.

6. 'Die Kurzzeitmesser bei den Olympischen Wettkämpfen', *DUZ* (1 August 1936), 385.

7. Search 'images' for 'olympische spelen 1936 tijdmeting'.

8. Cigaretten Bilderdienst, *Die Olympischen Spiele 1936 in Berlin und Garmisch* (Altona: Hamburg, 1936), images 110 'Zeitmessung' and 109 'Startpistole'.

Figs 7–9. The *tertienuhr,* dial and movement. Photos by Frank Dunkel.

had some success, it did not last, probably resulting from a lack of development funds. Competition from Omega, among others, was intense. Löbner celebrated its 75th anniversary in 1937, but two years later filed for bankruptcy.[9] An old court record shows that, though Löbner had a global business, it could not meet its financial obligations.

Leaving the field of sports time measurement, there are other applications for precise short-term measurement. There is always a military application, owing to the perennial desire for improvement in weapons technology. Weapons manufacturers are interested in the comparative burn rates of different gunpowder compositions and also the velocity of projectiles fired from rifles and large guns. The ideal timing device in this forum was the *tertienuhr*, invented by Moritz Grossmann and Ignatz Marenzeller and later perfected by Franz-Ludwig Löbner.[10] The *tertienuhr* is a mechanical three-dial stopwatch, capable of measuring precisely to an accuracy of 1/100 sec. The name *tertienuhr* is derived from the Latin—*pars minuta tertia*, the next division down from the *pars minuta prima* and *secunda*.

The basic design of all *tertienuhren* is the same. The three dials (Fig. 7) show minutes (right), seconds (left) and 1/100 sec (top). On a full wind, the device can measure from hundredths of a second up to forty-five minutes. A *tertienuhr* will always have an 'up-and-down' indicator. Winding is via a knurled knob to the reverse. The movement is conventional, in the sense of circular plates, with three pillars, and fusee and chain arrangement. The escapement is of the frictional-rest type, with the pallets

9. 'Konkurs Löbner', *Die Uhrmacherkunst* (21 April 1939), 252.

10. H. Reichenbach-Hoffmann, 'Die Zeitmessung in der Heerestechnik', *AJU* (1930), 780–82. Detailed information on the *tertienuhr* can be found in Thomas Schraven, 'FL Löbner–Tertienuhren aus Berlin', *DGC Yearbook* 52 (2013), 161–94.

Modell 13: TERTIENUHR

mit mechanischem Auslösungsapparat

zum Messen der Brennzeiten von Zündern usw.

Abbildung: ½ natürl. Größe

Beginn und Ende der Brenndauer eines Zünders wird auf die **Tertienuhr** durch den **mechanischen Auslösungsapparat** wie folgt übertragen:

Beim Durchbrennen zweier straff gespannter Seidenfäden, die an zwei entgegengesetzt wirkenden Hebeln befestigt sind, wird jedesmal der Druckknopf der Uhr betätigt bzw. dieselbe erst ausgelöst, dann angehalten.

Fig. 10. *Tertienuhr* with mechanical release mechanism to measure the duration of burning of fuses etc. Undated catalogue 'Chronoskop und Tertienuhr', F.L. Löbner, c.1928.

Fig. 11. *Tertienuhr* signed F.L. Löbner, Berlin W. Photo by Konrad Knirim.

mounted directly on the balance staff, and since there is no separate lever between balance and escape wheel, the amplitude of the balance remains very small, at only a few degrees. The escape wheel itself has twenty-five teeth (Figs 8–9).

Tertienuhren are commonly found with one (as in Figs 10 and 11) or two push-buttons. Versions with one button can be used like a normal stopwatch—one push each for start, stop and zero—and versions with two buttons can be used in conjunction with an electric triggering device. An electric pulse energised a solenoid, which in turn will directly engage, by means of a lever, the push-button on the *tertienuhr*. In addition to electro-mechanical triggering there were also complete experimental setups for measuring the ignition times of detonators and for measuring the flight times of projectiles.

Tertienuhren were made by Johannes Hammer of Leipzig, F.L. Löbner of Berlin and Strasser & Rohde of Glasshütte between approximately 1880 and 1945.[11] Analysis suggests somewhere in the region of 1450 were manufactured in total by the three firms. The *tertienuhr* was a highly accurate timepiece, often bearing the inspection stamp of the PTR (Physikalisch Technische Reichsanstalt) in Berlin, and was a uniquely German product, not made elsewhere.

An interesting question was whether it was possible with early electro-mechanical technology to measure even smaller units of time? Remarkably, as long as 165 years ago, it was indeed possible, with the invention of the Hipp chronoscope, which allows for measurements to an accuracy of 1/1000 second. The history reveals some intriguing links between Germany and the United Kingdom.

The Hipp chronoscope

It is reported that the German Professor Wilhelm Eisenlohr (1799–1872) purchased a chronoscope from the well-known English physicist Charles Wheatstone. Eisenlohr taught mathematics and physics at Karlsruhe high school and at the same time taught physics at the Polytechnic School.[12] Eisenlohr made several journeys to England and it is probable that he returned with the chronoscope from one of these trips. Wheatstone developed his chronoscope to measure the velocity of projectiles.[13] Not much is known about his chronoscope but a short description appears in Eisenlohr's book:

> The main element of the Wheatstone chronoscope is a horizontal cylinder with a cord and a weight. The cylinder has a thread which moves a small wheel and the clockwork, which in turn moves the hand with a high velocity after the electric current is closed. An electromagnet stops the movement and the hand. This allows the exact measurement of 1/100th second.[14]

Eisenlohr attempted to prove Newton's Law of Universal Gravitation using the chronoscope, measuring the time it took for a metal ball to fall from a given height. A comparison of the measured time with the theoretical time supported the validity of the method, but Eisenlohr's measurements did not entirely agree with the formula. More on this experiment later.

The reason for the failure of the experiment is clear. The Wheatstone chronoscope has a weight-driven mechanical movement. When the electric contact is closed, the train starts to run, and therefore the recording dial. However, the mechanical movement has its own inertia and requires a given amount of time to reach a constant speed, with the result that the acceleration of the movement to running speed forms part of the time measurement. For accurate measurement a constant speed throughout the measuring period is vital.

We now move the focus to Reutlingen in Germany. After completing his apprenticeship, the clockmaker Matthäus Hipp (1813–1893) took up residence there and opened a clockmaking workshop in July 1840. Very quickly news of Hipp's ingenious inventions in both clockmaking and the application of electricity spread throughout the scientific world.[15] Hipp travelled to Karlsruhe to visit Professor Eisenlohr, and examined the Wheatstone chronoscope. Realizing the source of the problem, he soon developed his own chronoscope, based on Wheatstone's ideas. His new chronoscope was tested using the same experiment and the results were impressive. Wilhelm Oelschläger of Reutlingen (1816–1901)

11. Based on catalogues from the three firms: Hammer, *Neue Geräte zur Zeitmessung* (Leipzig, c.1940); Löbner, *Tertienuhr* (Berlin, 1928); Strasser & Rohde, *Prospekt Tertienuhr 1/100 sec* (Glashütte, nd).

12. E. Strobel, 'Wilhelm Eisenlohr', *Soweit der Turmberg grüßt* 11 (1950), 33–34.

13. C. Wheatstone, 'Über das elektromagnetische Chronoskop' in *J.C. Poggendorf, Annalen der Physik*, LXV (1845), 451; H. Schmidgen, 'Physics, ballistics and psychology, a history of the chronoscope in/as context 1845–1890', *History of Psychology* (February 2005), 46–78.

14. W. Eisenlohr, *Lehrbuch der Physik zum Gebrauche bei Vorlesungen und zum Selbstunterrichte* (Stuttgart: Krais & Hoffmann, 1852), pp. 623–625.

15. See H. Kahlert, 'Lorenz Bob und Matthäus Hipp', *Alte Uhren*, 4 (1987), 22–30; W. Keller and H.R. Schmid, 'Matthias Hipp' in *Schweizer Pioniere der Wissenschaft und Technik*, vol. 12 (Zürich, 1961), pp. 9–39.

Figs 12 and 13. Front and back of the oldest surviving Hipp chronoscope, signed 'M. Hipp in Reutlingen' (1849). Utrecht University Museum, Inventory No. ME-30. Photos by Jan Deiman.

reported that the difference between measured and calculated time was only a few hundredths of a second and Newton's law was verified by experiment.[16]

During the spring of 1849, one of these early chronoscopes was delivered to the Physical Institute of the University of Utrecht, where it remains, in the university museum—the oldest surviving Hipp chronoscope (Figs 12 and 13). With a running time of nearly one minute, it can measure to an accuracy of 1/500th of a second. It retains its handwritten instructions and a drop apparatus for its control and adjustment.[17]

Another example of an early Hipp chronoscope is at the Kustodie of Freiberg, which the university inventory book reveals was delivered in February 1851.[18] On Steinheil's recommendation, Hipp was appointed head of the Swiss telegraph works in Bern, and he took up his new civil service post on 23 March 1852, leaving Reutlingen behind. In the eight years he spent in Bern, he modified his chronoscope design several times but only six examples from this period are known to have survived.

In 1860, Hipp left the telegraph works in Bern and founded his own factory in Neuchâtel (Neuenburg), under the name Fabrique de Télégraphes et Appareils Éléctriques Neuchâtel. Here he produced electric clocks, electric telegraphs and scientific instruments, including chronoscopes. Fig 14 shows a factory produced chronoscope, listed in Hipp's catalogue as model 75.[19]

In 1861, Hirsch delivered a lecture,

16. W. Oelschläger, 'Das Wheatstonesche Chronoskop verbessert von Uhrmacher Hipp in Reutlingen', *Polytechnisches Journal*, CX (1848), 184–187.

17. Matthäus Hipp, *Anleitung zum Chronoskop an der Universität Utrecht* (Reutlingen, 5 March 1849).

18. See entry 105, 'Chronoskop von Hipp', in the *Katalog über den physikalischen Apparat Inventarbuch der Bergakademie Freiberg.*

19. M. Hipp, *Illustrierter Katalog der elektrischen Apparate der Neuenburger Telegraphenfabrik* (Neuenburg, 1869).

Fig. 14. Factory produced chronoscope, listed in Hipp's catalogue as model 75. Hipp No. 2889, c.1869. Photo Klaus Luginsland/Landesmuseum Mannheim.

including a detailed description of the chronoscope.[20] Like Wheatstone, Hipp used a mechanical clock movement driven by a weight and combined with an electromechanical unit, for starting the measurement. Wheatstone had failed to allow for the inertia of the mechanical movement. Hipp's solution was elegantly simple: he separated the clock movement from the dial. First the wheel train of the movement is started and when it has reached a constant speed, the dial can be engaged and measurement started.

Hipp's device has an ingenious escapement, shown in Fig I, top left in

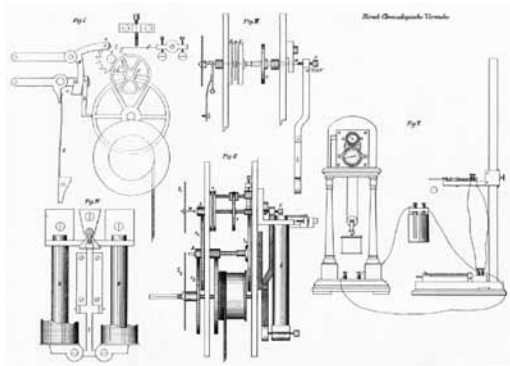


Fig. 15. The Hipp chronoscope as illustrated in Hirsch, 'Chronoskopische Versuche'.

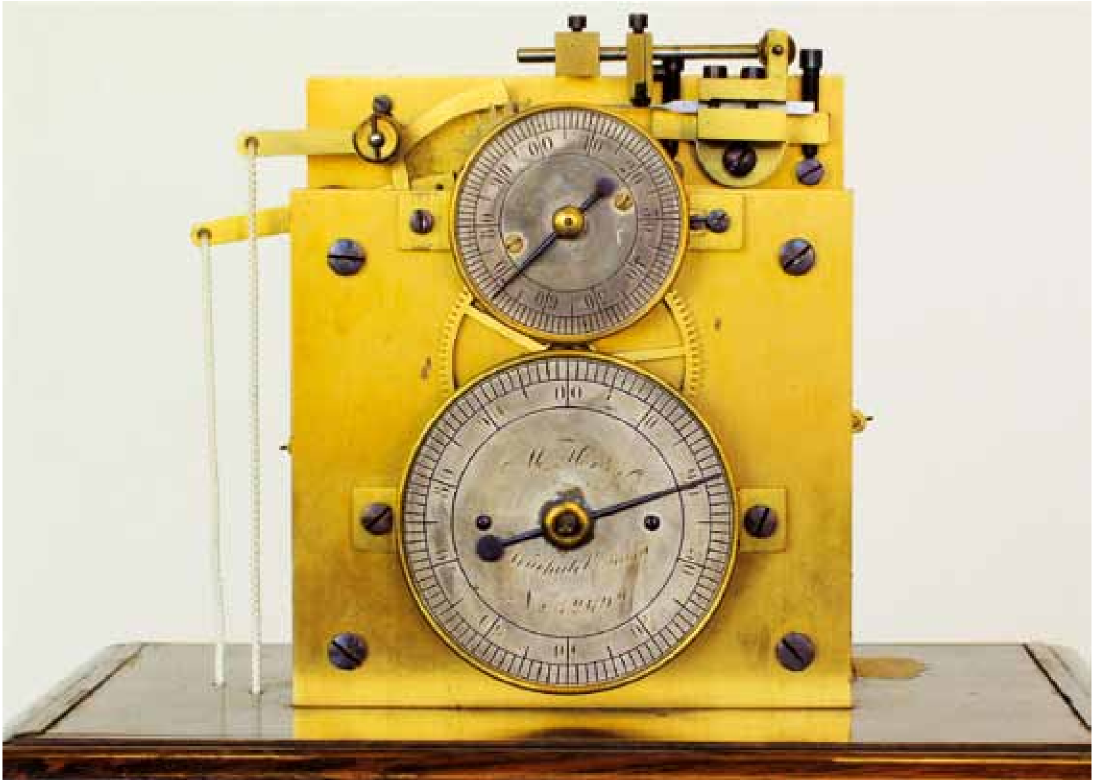
Hirsch's illustration (Fig.15). The main parts of this are a steel reed or lamella *f* fixed at one end (sometimes known as a Hipp lamella), and an escape wheel *s* with twenty teeth. The free end of the lamella rests against the tips of the teeth and is vibrated by them as the escape wheel turns at speed. Hipp used a lamella in his telegraphs as early as 1845.[21] If the lamella is set vibrating it makes 1000 vibrations per second, and thus the characteristic sound of a working chronoscope corresponds to 1000 Hertz. The escape wheel makes ninety-one turns per second.

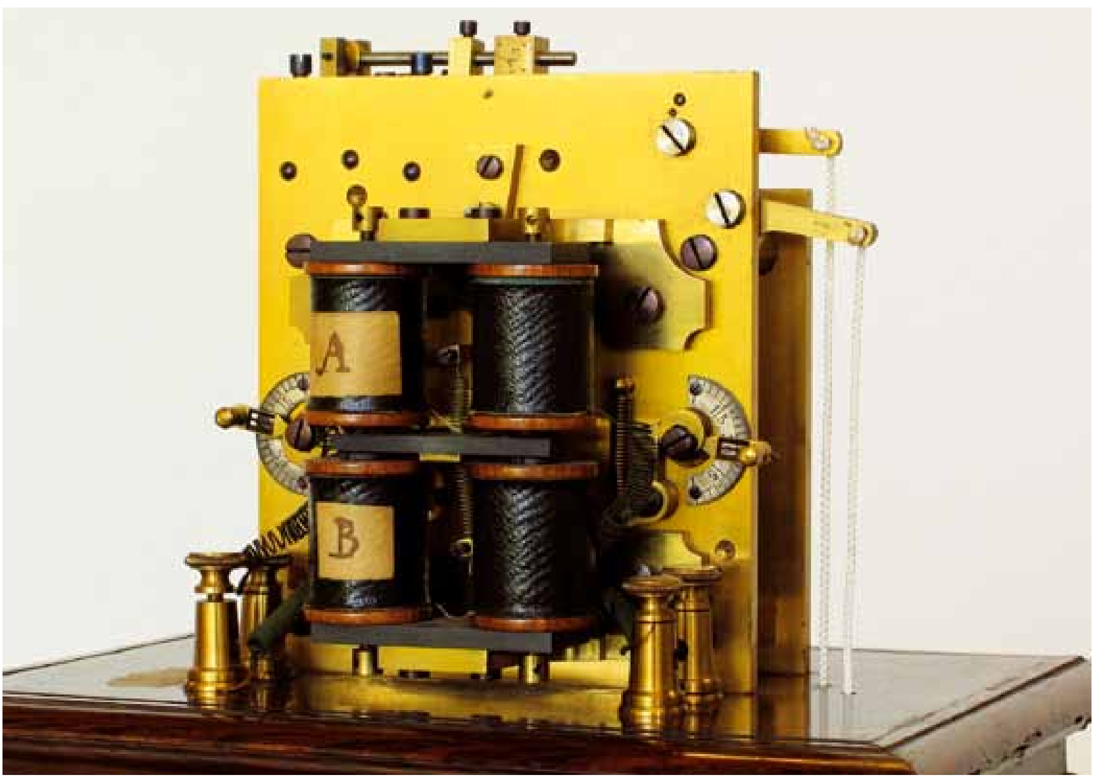
The movement is started and stopped by hand with the help of two cords fixed to the far left end of two levers, marked *a* and *b* in Fig. 15. The train for the hands is separated from the clockwork and has two dials, divided in 100 parts. The hand of the lower dial makes one turn per second and is marked to indicate hundredths of a second. The hand of the upper dial makes ten turns per second and is marked to indicate thousandths of a second.

This model of chronoscope, the type 75, was fabricated from 1860 to 1875 without any visible modification. In 1875, Heinrich Schneebeli of Neuchâtel published the first details of a new and improved chronoscope. Schneebeli's article reveals his ownership of a new chronoscope and that it carries his

20. A. Hirsch, 'Chronoskopische Versuche über die Geschwindigkeit der verschiedenen Sinneseindrücke und der Nervenleitung', delivered to the Scientific Society in Neuenburg (1861); published in *Moleschotts Untersuchungen zur Naturlehre des Menschen und der Tiere*, vol. IX (1865), pp. 183–99.

21. K. Bauder, 'Matthäus Hipp der große Erfinder auf dem Gebiet der Uhrmacherkunst in Verbindung mit der Elektrotechnik', *Dienstags Beilage zur Süddeutschen Zeitung* (21 October 1913).





Figs 16 and 17. Improved chronoscope model 88, c.1887, signed M. Hipp Neûchatel No. 12692. Lausanne University, Physics Dept. Photos by Jean-Francois Laude.

strong recommendation.[22] He writes that the chronoscope is well known and that nearly every physical laboratory has one. From the detailed description, we learn that Hipp had changed the escapement and the electric element of his chronoscope. Changes are visible to the rear, since older chronoscopes have a single arrangement of two coils, while the newer model has two separate pairs of coils, one pair above the other, with an armature arranged to pivot between the two. The rest position of the armature can be adjusted with two levers and springs.

The construction of the older chronoscope only allows measurement to occur up to the moment of an interruption of the circuit. The new arrangement of the electromagnets enables measurement between the making and breaking of a circuit (Figs 16 and 17).

On 15 February 1889, Hipp entrusted his two engineers von Peyer and Favarger with the management of his factory. His health was not good and he and his wife moved to Zürich a few days later. On 3 May 1893, Hipp died at the age of eighty. The new firm of Peyer, Favarger & Cie continued the fabrication of the Hipp chronoscope and a detailed description of the chronoscope is published in Albert Favarger's important 1894 work (revised 1924), *Die Elektrizität und ihre Verwerthung zur Zeitmessung*. In addition to the standard models, two new versions were now described.

In 1908, Peyer, Favarger & Cie was taken over by the limited partnership Favarger & Cie, which was later incorporated as a limited company in 1923. Clocks and instruments of this period are signed 'Favarger & Cie, successeurs de Hipp Neuchâtel Suisse', and carry a serial number. The chronoscope seems to have had significant use in science in this period. The 1913 trade catalogue shows eight additional models of the chronoscope.[23] Favarger modified the running time and design without significant changes to the main construction, and special chronoscopes were offered for a wide variety of specific fields of application.

In 1927, Favarger AG was renamed FAVAG – Fabrik elektrischer Apparate AG, and finally in 1932 FAVAG was acquired by Hasler. FAVAG chronoscopes of this period still utilised the basic design from the old electromechanical pattern introduced by Hipp eighty years earlier, but at additional cost one new development offered was a new arrangement for resetting the hands.[24] The earlier high quality wooden stand was replaced by a new stand of simple geometric form, in a cheaper wood. The signature changed to FAVAG SA, and the serial numbering system, which had run from 1860 to 1928, finally changed.

Shortly before the Second World War, FAVAG developed a new chronoscope. A mains synchronous motor replaced the entire assembly of lamella, mechanical movement and driving weight. However, following the old pattern, the main drive unit and the motion work are quite separate, and measurement is started electrically. The link between the two elements continues to be the two crown wheels which Hipp used in his first chronoscope. Accuracy to within a few milliseconds was maintained, and the known models include the M340, M400, M430 and M500 (Figs 18 and 19).

At the beginning of the 1950s, the M430 type was modified, forming the new M 500, characteristically featuring a plastic case (Fig 20).[25] In 1983/84, Hasler merged with Autophon to establish Ascom, and FAVAG was renamed Ascom FAVAG. In November 1989, the firm was sold to Bosshard (Moser-Baer) and manufacturing production ceased. In July 2002, Bosshard was renamed Mobatime.

The Hipp chronoscope was both invaluable in practical terms and a very

22. Heinrich Schneebeli, 'Über die Anziehungs- und Abreißungszeit der Elektromagneten', *Annalen der Physik und Chemie* 155 (1875), 156–164, 615–624.

23. Favarger & Cie, *Prix-Courant de la Fabrique de Télégraphes & Appareils électriques–catalogue B* (Neuchâtel, 1913).

24. FAVAG, *Precision time measuring apparatus* (Neuchâtel, 1928).

25. FAVAG, *Das Synchron-Chronoskop M430* (Neuchâtel, 1952).

Fig. 18. Motor-driven Chronoscope 591974, 1959, by Favag Neûchatel. Photo by the author.

Fig. 20. Motor-driven Chronoscope 702023, 1970, by Favag Neûchatel. Photo by the author.

expensive instrument—important in the history of science. It was easy to use, and its output was easily and immediately readable. Its production and sale was profitable. At first Hipp's Telegraph Works was the only supplier but from around 1890 other suppliers emerged, with other names appearing on the dials and in trade catalogues, such as Heinrich Diel and James Jaquet from Basel; Max Kohl from Chemnitz; Movado from La Chaux-de-Fonds; Michael Sendtner from München; Spindler & Hoyer from Göttingen; Constantin Fischer from Leipzig; Stoelting from Chicago; Leschhorn from Frankfurt M.; Löbner from Berlin; Joh. Hammer and Strasser & Rohde from Glashütte and E. Zimmermann from Leipzig. However, many of these are suppliers only—the only manufacturers were Hipp in Switzerland and the three German firms, Joh. Hammer, Strasser & Rohde and E. Zimmermann.

Fig. 19. Favag M430 catalogue (1952).

Fig. 21. Hipp chronoscope with a special contact sold by F.L. Löbner Berlin, c.1910. The maker was probably Strasser & Rohde from Glashütte. Photo by the author.

Figs 21–24 show three chronoscopes of German origin. The example in Fig. 21 is signed F.L. Löbner Berlin. This is an extraordinary instrument of the highest quality, mounted on a wooden board, with a longer running time. Despite the signature, the maker was probably Strasser & Rohde in Glashütte. Fig. 22 shows a chronoscope made by E. Zimmermann. The Zimmermann firm was founded in 1887, and manufactured and delivered psychological instruments to clients all over the world. The factory was in Leipzig, as were the headquarters, although these moved to Berlin in 1907. The name Zimmermann is connected closely with that of the Institute for Experimental Psychology in Leipzig and with Wilhelm Wundt. Zimmermann produced chronoscopes to his own design and held several patents.

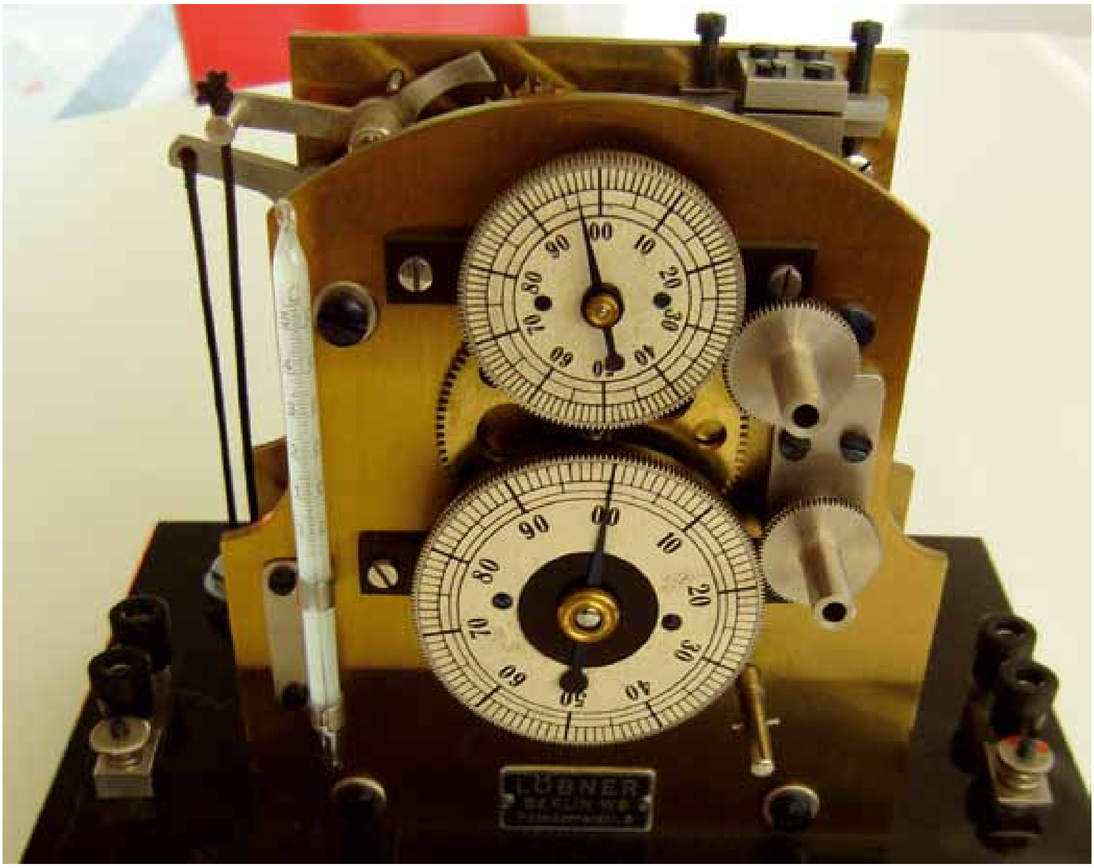
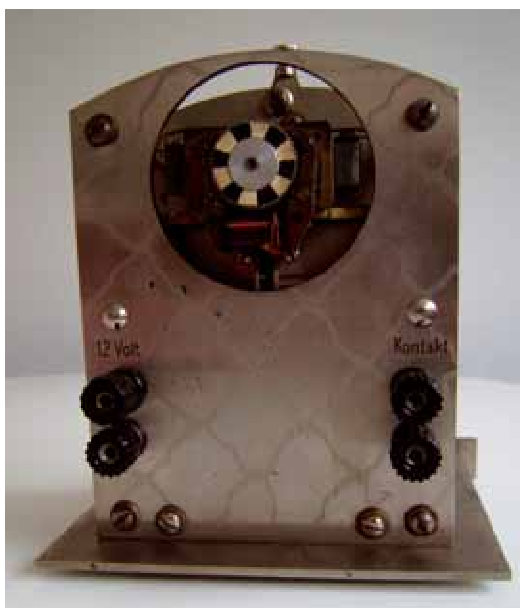


Fig. 22. Hipp chronoscope with reset of the hands, sold by F.L. Löbner Berlin, c.1936/37. The movement was made by E. Zimmermann in Leipzig. This instrument was used in an armament factory during the war. Photo by the author.



Figs 23 and 24. Special chronoscope with a time-switch driven by a synchronous motor. The maker was Joh. Hammer in Leipzig, c.1940. Most likely military use. Photos by the author.

Maker	Town of origin	Known survivors
Hipp	Reutlingen	3
Hipp	Bern	6
Hipp	Neuchâtel	32
Peyer, Favarger & Cie	Neuchâtel	29
Favarger & Cie	Neuchâtel	12
FAVAG	Neuchâtel	29
Strasser & Rohde	Glashütte	3
Joh. Hammer	Leipzig	4
E. Zimmermann	Leipzig	54
TOTAL		172

Table 1. Recorded surviving Hipp chronoscopes

Completing a tour of the manufacturers, Figs 23–24 show a chronoscope from Johannes Hammer's workshop in Leipzig. Hammer worked for Zimmermann, but left to establish his own factory in 1932, fabricating scientific instruments. He offered weight-driven Zimmermann chronoscopes, and motor driven versions of his own invention. The Hammer device is a time measurement instrument which can double as a timeswitch, capable of switching with an accuracy of one tenth of a second, the most logical explanation for which is something military.

Hipp chronoscopes were used across many different fields of science, but in the mid-1970s, after nearly 130 years of use, the era of the Hipp chronoscope finally came to an end, though over a long production period its construction changed very little. Even motor-driven chronoscopes exhibit elements visible in Hipp's first instruments. Now the Hipp chronoscope is a rare instrument. The majority of survivors exist in university collections, museums and psychological institutes. Only a handful are in private hands. At present, 172 examples have been recorded, broken down as follows by maker and place of manufacture (Table 1).

Application and use of the chronoscope

The Hipp chronoscope was an excellent short-time measurement instrument. Some typical uses across a variety of fields included:

- Physics   time of a falling body
- Ballistics   velocity of a projectile
- Chemistry   burning time of gun powder
- Psychology   reaction time, memory time
- Medicine   flavour and reaction time

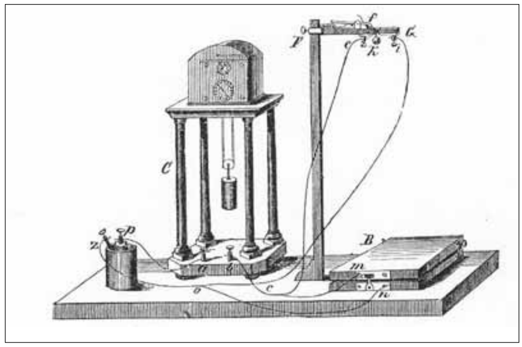


Fig. 25. Arrangement for the measurement of the falling time of a body. Taken from Eisenlohr (1852). See note 14.

Physics

An experiment to measure the time a falling body takes to drop invokes Newton's law which stipulates $s = \frac{1}{2} g t^2$, where s = distance dropped, g = acceleration owing to gravity and t = falling time. The apparatus is shown in Fig. 25. Lever *f* allows ball *K* to be released. This action also interrupts the electric circuit and the hands of chronoscope *C* begin to turn. When the metal ball *K* hits plate *B*, it causes the electric circuit to be closed and the hands stop. A comparison is then made between measured time and calculated time.

Table 2 (next page) shows the results of Oelschläger's 1848 measurements with a Hipp chronoscope. High measurement accuracy was achievable, at least for drops of more than a few centimetres.

Height in m	Calculated time in sec	Calculated time in 1/500 sec	Measured time in 1/500 sec	difference Δt in 1/500 sec
1.5	0.5530	276.5	278.7	-2.2 (0.8 per cent)
1.0	0.4515	225.8	230.0	-4.2 (1.8 per cent)
0.5	0.3193	159.6	160.2	-0.4 (0.3 per cent)
0.1	0.1428	71.4	69.7	1.7 (2.4 per cent)
0.02	0.0639	31.9	29.5	2.4 (8.1 per cent)

Table 2. Results of Oelschläger's 1848 measurements with a Hipp chronoscope

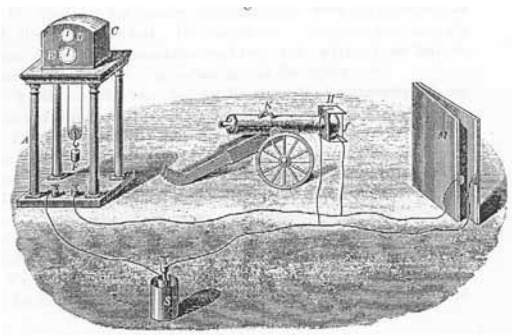


Fig. 26. Ballistic experiment to determine the velocity of a projectile. J. Dub, *Die Anwendung des Elektromagnetismus mit besonderer Berücksichtigung der Telegraphie* (Berlin, 1863).

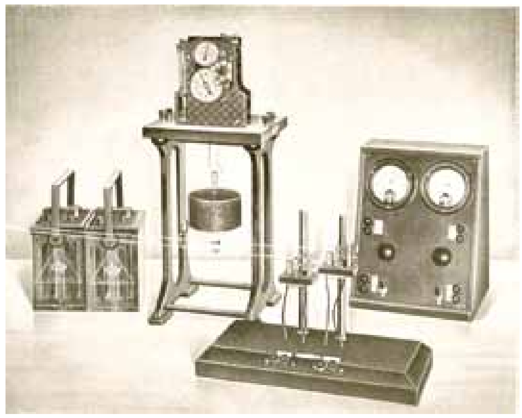


Fig. 27. Experiment to measure the burning time of gunpowder. Joh. Hammer catalogue (c.1940).

Hipp capitalized on the accuracy of these results and from the outset offered a drop test apparatus as an auxiliary instrument for the calibration of his chronoscopes.

Ballistics

The Hipp chronoscope was also evaluated positively in a military context. Fig. 26 shows an 1863 experiment to determine the velocity of a projectile. A wire *f* is stretched taut across the muzzle of a cannon, and is connected in parallel with the chronoscope, a battery *S* and the target *M*. When the experiment begins, the electric circuit is made, but the hands of the chronoscope do not move. When the projectile is fired, it cuts wire *f*, the circuit is broken and the hands begin to move. When the projectile reaches target *M*, which operates as a switch, the circuit is remade and the hands stop. A combination of known distance and measured time provides velocity. Hipp's friend Oelschläger made similar experiments in 1849, determining that a rifle bullet travelled at 323 metres per second.[26]

Chemistry

The Hipp chronoscope can be used like a *tertienuhr* but offers higher accuracy, suitable for tests to measure the time taken

26. W. Oelschläger, 'Das Hippsche Chronoskop zur Messung der Fallzeit eines Körpers und zu Versuchen über die Geschwindigkeit der Flintenkugeln', *Dingler's Polytechnisches Journal* CXIV (1849), 255–259.

Fig. 28. Very accurate electric measurement of the burning time of gunpowder with a chronoscope. Joh. Hammer catalogue (c.1940).

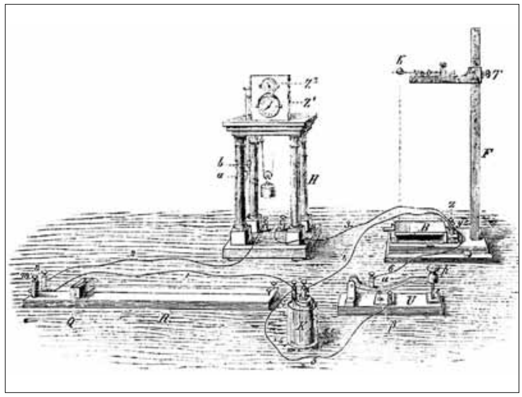


Fig. 29. Reaction time measurement. W. Wundt, *Grundzüge der physiologischen Psychologie* (Leipzig: Engelmann, 1874), p. 770.

for gunpowder to burn. The test combined a Hipp chronoscope with a 'thread-burning device'. Electrical impulses are transmitted to start and stop the chronoscope. Fig. 27 illustrates the electrical arrangement for this trial, where the two threads are stretched taut, and as they are successively burned through, so the connections to two electrical switches start and stop the measurement. Fig. 28 shows a device where threads are unnecessary.

Psychology

In the middle of the nineteenth century, several scientists attempted to examine the nerves and sensory systems of animals (including humans) in order to understand and explain various mental processes. In 1848/49 Emil du Bois-Reymond showed that neural activity is an electrical phenomenon.[27] In 1850, the physiologist Hermann von Helmholtz from Königsberg demonstrated by experiment that a neural stimulus requires some time to produce a response from the brain.[28] In the latter part of the century, the physician, psychologist and philosopher Wilhelm Wundt introduced scientific and experimental working methods into psychology. He studied mental processes and was particularly interested in reaction time in humans.[29] In most cases, Wundt used a Hipp chronoscope in his tests.

Wundt's scientific work met with great approval and became known as 'experimental psychology'. In 1875, Wundt secured a position at the University of Leipzig where he collected apparatus for studying mental processes, founding the first experimental psychology laboratory in 1879. Leipzig alumni spread Wundt's science of experimental psychology worldwide, and soon new institutes for the discipline were founded: Göttingen (1881), Johns Hopkins in Baltimore (1883), Copenhagen (1886), and so on. In 1889, the year Hipp retired, fourteen new institutes were founded and ten years later there were fifty such institutes and laboratories. The work of Wundt and his followers led to a significant demand for chronoscopes, and thus a manufacturing capacity evolved to meet that demand.

It was not yet possible to measure the 'velocity' of thought directly, but it was possible to measure the time from an

27. Emil du Bois-Reymond, *Untersuchungen über thierische Elektrizität* (Reimer: Berlin, 1848).

28. H. Helmholtz, 'Über die Methoden kleinste Zeitteile zu messen und ihre Anwendung für physiologische Zwecke', *Königsberger naturwissenschaftliche Unterhaltungen*, vol. II (1854), pp. 169–189.

29. Förderverein Wundt Stiftung, *Von Neckarau bis Großbothen* (Deutscher Psychologen Verlag: Bonn, 1994), p. 33; H. Gundlach, 'Wilhelm Wundt', *Deutsche Biographische Enzyklopädie* (München, 1999), pp. 598–599.

Subject	Reaction time (seconds)	No. of tests
A. Hirsch	0.1490	81
Mayer	0.1584	32
G. Guillaume	0.2015	22
Desor	0.2432	23
M. Hipp	0.2433	11

Table 3. Results of reaction times tests with a Hipp chronoscope.

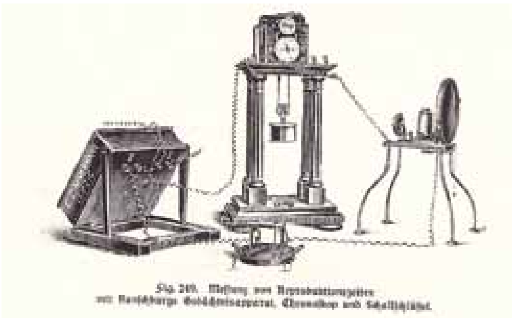


Fig. 30. Psychological experiment with Hipp chronoscope, memory apparatus and acoustic apparatus. See note 31 for source.

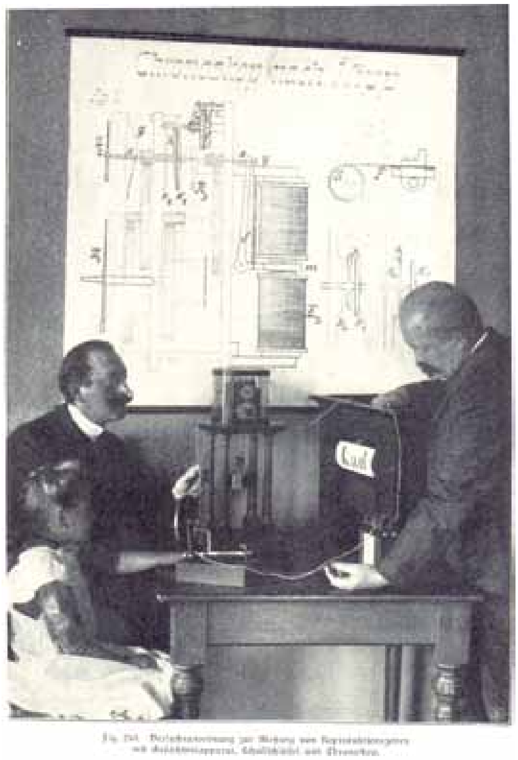


Fig. 31. Experiment with Hipp chronoscope and memory apparatus. See note 31 for source.

external stimulus to the reaction it produced. Long before Wundt started experimenting, Adolphe Hirsch (1830–1901) modified Hipp's calibration test to form a reaction time experiment. The clamp of the drop apparatus retains a metal ball as in other experiments. When the clamp releases, the ball falls and engages a wooden catch, producing an audible 'click' of wood on metal, but it also interrupts the electric circuit and starts the chronoscope. The experimental arrangement is shown in Fig. 29. The subject has to react to the 'click' by depressing a key immediately. The key closes the electric circuit and the chronoscope is stopped. The measured interval is the reaction time of the observer and a highly personal characteristic. These experiments were reported on by Hirsch in an 1861 lecture, published in 1865.[30]

Being an astronomer and the head of the Neuchâtel observatory, Hirsch was familiar with the problem of the personal equation and he tried both to explain it and to find ways to correct for it. For his experiments, Hirsch borrowed two chronoscopes from Hipp. Hirsch measured reaction times in relation to the different senses, i.e. sight, touch and hearing. He found reaction time varied for each sense and also for different parts of the body, owing to varying nerve lengths. Hirsch used a number of noted characters in these experiments, including Hipp, Guillaume and Garnier. Having pioneered the field, Hirsch urged other psychologists to expand on his experiments, using chronoscopes. The results of some of his tests appear in Table 3.

30. A. Hirsch, 'Chronoskopische Versuche'.

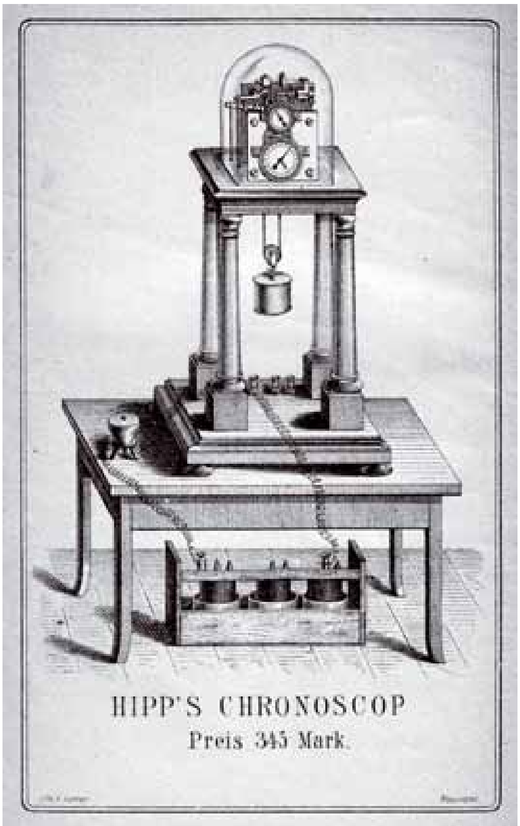


Fig. 32. Advertisement in G. Jaeger, *Lehrbuch der allgemeinen Zoologie* (Leipzig, 1885), vol. 2.

Hirsch had the shortest time, while Hipp appears to have been slowest, but it is noticeable that the times broadly correlate to numbers of tests, and it may be that Hirsch had 'learned' to react more quickly over so many trials.

Early in the twentieth century, Rudolf Schulze gave a detailed account of the prevailing tests and instruments used in experimental psychology.[31] A typical experiment was designed to test perception, association and memory, with a Ranschburg apparatus. The set-up is shown in Fig. 30. The 'Ranschburg Memory Device' (a mnemometer) presents a series of visual stimuli successively, at a specified rate, to be memorized. Symbols, letters or numbers are marked on a white disk, and temporarily revealed through an exposure slot. The disk is driven in steps by an internal motor. The duration of each step is controlled by a metronome and a switch. Optionally, the steps may be prolonged by pressing a key, and the metronome is then used to determine duration. Another variant would be the use of a chronoscope in the circuit, determining the duration of each step to a much higher degree of accuracy (Fig. 31).

Medicine

Professor Gustav Jaeger (1832–1917) is best known for his strong endorsement of 'Die Normalkleidung als Gesundheitsschutz' (the rational clothing system to protect health), after which the Jaeger woollen brand is named. Less well known is that the circle of contemporaries around him urged him to debunk homeopathy and to prove scientifically that homeopaths were charlatans with their dilutions. Jaeger succeeded in convincing himself otherwise, and part of his rationale came from numerous tests which tended to suggest humans were indeed susceptible to extremely small influences, an example being a change in reaction time in the presence of an odour. Using a Hipp chronoscope for what he termed *neuralanalyse*, Jaeger established the effect of odours on performance.

Jaeger developed his own method of chronoscopic measurement. The observer had to react to the hand of the smaller dial starting to move, by pressing a key, which in turn stopped the hand. The elapsed time indicated by the dial reflected the subject's reaction time which Jaeger named *nervenzeit*, or neural time. Since the hand of the small dial on a standard Hipp chronoscope (measuring thousandths of a second) moves very fast, it is difficult to observe, and was unsuitable for Jaeger's purposes. Jaeger therefore recommended ordering from Hipp's Neuchâtel works a specially modified version which ran at half-speed (Fig. 32). In 1883, Jaeger examined the effect on reaction time of different odours. He used three different flavours: pears, butanoic acid and marsh water. He found that for pears, reaction

31. R. Schulze, *Aus der Werkstatt der experimentellen Psychologie mit besonderer Berücksichtigung der Methoden und Apparate* (Leipzig: Voigtländer, 1909), pp. 136–8, 212–4.

time was relatively short. For butanoic acid reaction time was longer. The surpirse was marsh water, which smells muddy and feculent, which Jaeger suggested causes disgust. This led to the longest reaction time.

Summary

The field of short-time measurement includes a wide variety of ingenious devices designed to capture measurements which cannot be made with conventional clocks or timers. Whether attempting to map the speed of thought, or just to recognize the split second divisions between athletes, a fascinating and diverse range of solutions were devised by different inventors. The German contribution to this field is marked, and among the pioneers, Hipp stands out as the most influential, with his chronoscope establishing a standard for the resolution of fine measurements which remained unchallenged over decades. I hope that this survey of the various German makers' efforts will provoke further work on the history of short-time measurement devices elsewhere in the world.

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- 'The Hipp Chronoscope', based on a talk given at a meeting of the Electrical Horology Group of the AHS at the Science Museum, London, on 23 November 2003 – 56 pp. Available as pdf at http://vlp.mpiwg-berlin.mpg.de/documents/schraven_art13.pdf
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- 'Johannes Hammer – Leipzig, Geräte zur Kurzzeitmessung', *Chronométrophilia* 76 (2014), 93–103
- 'Löbner – Tertienuhren aus Berlin', *DGC Jahresschrift* 52 (2013), pp. 161–194
- 'Zur Herstellung des Hippschen Chronoskops in Deutschland', in preparation for 2016.