BERNHARD HUBER

The Engineer of Precision Time: Pendulum Clocks by Sigmund Riefler

In 2012, Sigmund Riefler was designated by American horologists as the most important clockmaker of all time[1]. This is a good reason to take stock of Sigmund Riefler and his achievements in the following essay.

The Early Years.

Sigmund Riefler (1847-1912) was born in a small village in the Allgäu region. His auspicious family background was the basis for his later success. His father, Clemens Riefler, completed a four-year clockmaking apprenticeship and made a longcase clock himself. As early as 1841, he founded the firm of Clemens Riefler together with three workmen and began at once to make technical drawing material. He profited from the growing demand for measuring and drawing instruments accompanying rising industrialization in the nineteenth century. Clemens Riefler invented the "Zirkelkopfgriff", a knob at the top of the drafting compass with which it could be easily held, and it was universally copied, making the firm of Riefler respected world-wide. After his father's death, Sigmund Riefler devised another system of drawing instruments patented in 1877 which also gained world-wide renown and was produced unchanged for a hundred years. The superior construction and remarkable accuracy of the drawing instruments, for which Riefler received many awards, were the basis for

Frontispiece: Patent document 50739 for a double wheel escapement for chronometers from 1889 (Photo: Dieter Riefler)

Fig. 1: Clemens Riefler's awards ca. 1885 (DGC archive)

the firm's economic success and international reputation.

Sigmund Riefler attended the trade school in Kaufbeuren in the Allgäu and, in 1865 near the end of his apprenticeship as a mechanic in his father's firm, he crafted a framed wall clock with recoil escapement. Subsequently, at the age of 18, he attended the polytechnic institute in Munich to study mathematics, geodesy, physics, electrical engineering and astronomy. From 1870 until 1876 he worked as a land surveyor in Schleswig-Holstein and developed new measuring equipment at the same time. After the death of his father, the three brothers took over the family firm. In order to get into closer contact with the institutes of science, and above all the observatory, Sigmund Riefler moved to Munich in 1878. His two brothers Adolf and Theodor stayed in the Allgäu and managed the prospering firm making technical drawing instruments.

The thriving finances of the enterprise enabled Sigmund Riefler to purchase a high-class residence in Munich's Lehnbach Square No. 1. This became his home, research center and laboratory.

Sigmund Riefler's Inventions and Publications

The Escapements made by Sigmund Riefler.
In his laboratory, Riefler devoted himself mainly to accurate timekeeping. The head of the university observatory in Munich-Bogenhausen, Hugo von Seeliger who had expressed a wish for a precision clock, had a great influence. In the engineer's rigorous way of thinking and as an excellent mathematician, Sigmund Riefler engrossed himself in the problem.

Riefler was not a trained clockmaker, but he had become engaged at an early age with the subject of timekeeping. Initially he focused upon a movement with a balance and balance spring. After completing his apprenticeship as a mechanic in 1865, he had the idea of an escapement in which "the energy from the wheel train is transferred to the balance through the balance spring". At the age of 22 in 1869, he constructed a first model while home in the family business. But neither this model "nor quite a number of other constructions which I completed throughout the years" proved satisfactory.

Not before "the beginning of the year (1889) did I manage to construct this escapement described below, which in theory is perfect and at the same time is astoundingly simple. Apart from that it can be also applied to pendulum clocks with an entirely free swinging pendulum"[2]. Sigmund Riefler was granted patent DRP 50739 (see fig. frontispiece). In the German clockmakers journal (Deutsche Uhrmacher-Zeitung) of March, 1890, he described his new invention, the free-spring impulse escapement as "an escapement for chronometers and other portable time-keepers with an entirely free vibrating balance and for longcase/wall clocks with an entirely free swinging pendulum".[3]

Fig. 2: The company ca. 1900 with Adolf (left), Sigmund (center) and Theodor Riefler (right) (DGC archive)

Clemens Riefler
FABRIK mathematischer JNSTRUMENTE
Nesselwang
& München.
A.D. 1900.
fec. L. Heydecker jr. Arch. Kempten.

Reading this publication is worthwhile as it impressively demonstrates Riefler's analytical way of thinking. His revolutionary idea was to exclude as imperfect the principle of direct power transmission to the balance, a principle used for centuries in every escapement. Instead, Riefler moved the balance spring stud to and fro with the vibrations of the balance so that the balance itself could oscillate entirely freely. In order to achieve this, he introduced a special double-wheeled escapement, an entirely new concept without precedent. A model of this is shown in fig. 3.

In his patent specifications, Sigmund Riefler wrote that his entirely free escapement could also be applied to pendulum clocks. The relevant design is shown in fig. 4. In the same way as the balance spring is used to impart an impulse to the balance, the suspension spring is used to impart energy to the pendulum on a knife-edge suspension. In time with the pendulum oscillations, the suspension spring is impulsed and thus provides the necessary force to to sustain the oscillations.

After the patent application in July, 1889, numerous incremental improvements were made until 1894, and in 1907 a final version emerged. Along with Eduard Saluz4, Jürgen Ermert has authored a multi-volume standard work—*Precision Pendulum Clocks in Germany 1730-1940*5—and he has done intensive research on this which soon will be published[6].

Fig. 3: Model for new escapement with a completely freely oscillating balance and driven via the balance spring stud (Photo: Dieter Riefler)

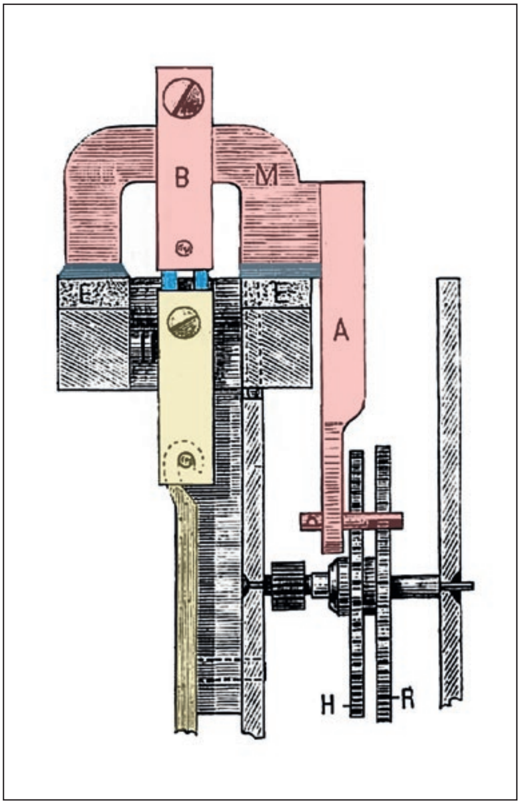


Fig. 4: Free spring escapement for pendulum clocks, schematic diagram. In red: pendulum block with pallets and knife-edge suspension (gray), suspension spring (blue), pendulum (yellow)

In operation, the free spring escapement proved to be susceptible to shocks and land tremors which could seriously disturb the clock's rate. Therefore, Riefler designed another escapement which is simpler and superior[7]. He named it "a free gravity escapement with the pendulum oscillating on a knife edge". In June, 1913, it was granted German patent DRP 272119. The impulse to the pendulum was imparted by two small gravity arms attached to the pendulum block and activated by a double escape wheel like the free spring escapement's.

It was not Riefler's intention to further perfect his new gravity escapement in place of his free spring escapement. His intention was to create a reasonably priced precision pendulum clock which would be easy to set up. He downplayed optimum performance but the clocks with a gravity escapement actually performed even better than those with a free spring escapement.[8]

The New Pendulums made by Sigmund Riefler.

Riefler was well aware that he also needed a first-class pendulum along with a new escapement for his precision pendulum clocks. In the introduction to his comprehensive paper of 1894 he wrote: "The uniformity of the rate of a pendulum clock depends mainly on 2 factors: firstly the thermal compensation of the pendulum, secondly the superiority of the escapement".[9] It is interesting that he referred to the pendulum as first in importance.

Consequently. after Siegmund Riefler developed his free spring impulse escapement, he immediately concentrated on improving the pendulum. There were four requirements he set for a pendulum in order to achieve optimal thermal compensation[10]. Riefler concluded in his analysis: "For the production of compensation pendulums the best material is without doubt mercury".[11] Since the invention by Graham in 1721, the mercury compensation pendulum, with an iron rod and a container filled with mercury at the lower end, had proven deficient. Rapid temperature changes are quickly absorbed by the thin pendulum rod, but it takes a long time for the large compact mass of mercury to reach the new temperature. Apart from that, the mercury was all at the lower end of the pendulum and could only compensate at that position whereas the thermal reaction occurred along the entire pendulum length. Moreover, the shape of the conventional mercury pendulum was unfavorable because of air drag. Sigmund Riefler overcame these disadvantages

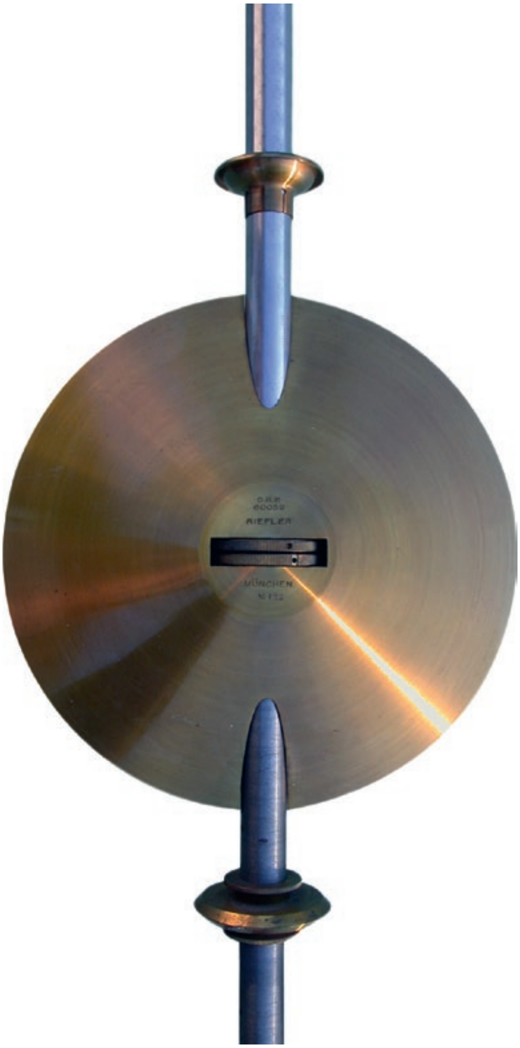


Fig. 5: Mercury compensation pendulum by Riefler (Photo: Jürgen Ermert)

by using a steel tube filled two-thirds with mercury. He added a slim steel bob weighing several kilograms. For this he received in March, 1891, German patent DRP 60059. As the extent of thermal compensation was critically dependent upon the individual coefficient of expansion of the steel tubes, Riefler had each of them tested in the Physikalische Reichsanstalt (Imperial Institute of Physics) in Berlin.

The first use of this pendulum was in Riefler clock No. 1 (fig. 6), with a free spring impulse escapement, at the observatory in Munich in 1891, and it represented a quantum leap forward. The remarkable performance achieved by this clock is registered in the records of the Munich observatory (fig. 7)[12], as well in a contemporary examination of the rate of Riefler No. 1 during changes in temperature. Compared to the timekeeping results of pendulum clocks offered by other manufacturers, Riefler's was superior to all competitors as fig. 8 shows[13]. Ludwig Strasser, the director of the School for Horology in Glashütte (Deutsche Uhrmacherschule), visited Riefler's laboratory in 1891and was convinced by the high quality of the unprecedented mercury compensated pendulum.

Within just two years, Sigmund Riefler had dramatically improved the accuracy of precision pendulum clocks with his free spring impulse escapement and the new mercury compensation pendulum. By 1900, approximately 230 of these mercury compensation pendulums had been sold[14], mostly to other makers of precision clocks.

Fig. 6: Riefler clock no. 01, engraved on the dial: S. Riefler, Munich 1890. This clock was created in close collaboration with Hugo von Seeliger, then director of the Munich Observatory, and was used there from 1891 (Photo: Jürgen Ermert—Deutsches Museum München)

Fig. 7: The rating certificate of the astronomical clock no. 1 by Sigmund Riefler, issued by the Munich Observatory in 1891

Auszug aus der Gangtabelle der astronomischen Uhr Riefler Nr. I.

Datum der Zeitbestimmung	beobachteter tägl. Gang Secunden	mittl. täglich. Gang der Beobacht-Serie Secunden	Temperatur C°	mittl. Barometerstand zwischen 2 Beobachtgn. mm	mittl. Barometerstand der ganzen Serie mm	auf 715,83mm Barom. red. tägl. Gang Secunden
1891 Sept. 1			+ 19,4			
„	− 0,06			715,5		
„ 2			+ 20,6			
„	− 0,07			717,5		
„ 3			+ 21,3			
„	+ 0,06			717,8		
„ 7			+ 18,6			
„	+ 0,08	+ 0,030		719,75	719,03	− 0,002
„ 9			+ 18,6			
„	+ 0,02			722,8		
„ 10			+ 18,1			
„	+ 0,09			722,1		
„ 11			+ 18,6			
„	− 0,05			720,7		
„ 12			+ 18,6			
1891. Dec. 5			+ 5,6			
„	+ 0,04			718,52		
„ 10			+ 5,0			
„	+ 0,02			712,50		
„ 12			+ 5,0			
„	+ 0,11			719,16		
„ 21			− 1,9			
„	+ 0,06	+ 0,023		721,94	717,45	+ 0,007
„ 23			− 2,8			
„	+ 0,07		− 5,7	729,15		
„ 28			− 1,0			
„	− 0,02			715,80		
„ 31			+ 4,0			
„	− 0,08			710,12		
1892. Jan. 10			+ 0,0			
1892. Aug. 16			+ 22,3			
„	− 0,02			720,6		
„ 18			+ 23,8			
„	− 0,01			715,3		
„ 19			+ 25,3			
„	− 0,05			711,9		
„ 20			+ 24,4			
„	+ 0,05	+ 0,010		718,05	716,33	+ 0,005
„ 22			+ 24,4			
„	+ 0,03			715,02		
„ 27			+ 21,3			
„	− 0,01			715,52		
Septemb. 1			+ 20,6			
„	+ 0,06			720,40		
„ 2			+ 20,6			

Zusammenstellung

der Compensationsconstanten einiger der besten astronomischen Uhren.

Lfde Nr.	Name der Uhr und Ort ihrer Aufstellung	tägl. Gangänderung für + 1° C. Secd.	grösste Temperaturdifferenz, C°	Quellenangabe
1	Hohwü Nr. 17 ..... Sternwarte zu Leiden	− 0,0151	17,6°	Kaiser, Astr. N. Bd. 63, Nr. 1502
2	Tiede Nr. 400 ...... Sternwarte Berlin	+ 0,0222	15,4°	Zwink, Inaug.-Dissert. 1888.
3	Knoblich Nr. 1952 .... Observ. Potsdam	− 0,0360	16,8°	Becker, Astr. N. Bd. 96, Nr. 2290
4	Dent .... Observ. Hongkong	− 0,0350	—	Doberck, „ „ Bd. 120, Nr. 2868
5	Hohwü Nr. 34 ..... Sternw. Upsala	− 0,0350 − 0,0265	15°	Schultz „ „ Bd. 103, Nr. 2452
6	Knoblich Nr. 1847	− 0,0025	19°	Schumacher „ Bd. 91, Nr. 2166
7	Dencker Nr. 12 ..... Sternw. Leipzig	− 0,0160	22°	R. Schumann, Ber. d. k. S. Gesellsch. d. Wiss. 1888
8	Hipp Sternw. Neuchâtel (von 1885—1887)	+ 0,0610	—	Hirsch, rapport général sur l'observatoire de Neuchâtel
	Desgl. .... (von 1888—1890)	− 0,0049	16,5°	
9	Knoblich Nr. 1770 .... Sternw. Bothkamp	− 0,0442	19,8°	Tetens, Inaug.-Dissert. 1892
10	Riefler Nr. 1 ...... Sternw. München	+ 0,0008	31°	Anding, Sternw. München.

Fig. 8: The temperature behaviour of precision clocks by leading manufacturers at the end of the 19th century in comparison to the Riefler clock no. 1

In 1896, Charles Édouard Guillaume discovered a special alloy of nickel and steel (known as Invar from 1907 onwards) which barely distorted with temperature changes. Riefler soon realized that a material with such properties would be ideal for making precision clock pendulums. With a low coefficient of expansion in a pendulum rod, the compensation system would be simplified. As seen in fig. 9, there were only two small tubes of brass or steel on the pendulum rod above the regulating nut and that held the bob. He was granted his German Patent DRP 100870 for this renowned pendulum as early as October 1897[15]. Extensive experimentation soon proved, however, that after the rods had been acquired (initially from Impy in France and then also from Krupp in Germany), they showed considerable thermal after-effects caused by molecular distortion. Expansion did not occur at a steady rate but in uncontrollable jerks[16], ruling out their use in precision pendulum clocks. Sigmund Riefer eagerly went to work on the problem and solved it by carefully heat-treating the rods for 20 days in a specially made tempering oven in Nesselwang. This complicated process was decisive in the long-term durability and superior quality of Riefler's pendulums. Another advantage was that the individual coefficient of expansion for each pendulum rod was measured by the Imperial Institute for Physics and Technology in Berlin (Physikalisch Technische Reichsanstalt) or by Guillaume in Sèvres[17] Above all, it relied upon the strict methodical way in which Sigmund Riefler, with his knowledge of physics, calculated the compensation elements. Details can be found in Giebel[18].

Because of Ludwig Strasser's pragmatism, he acquired from his main competitor 82 Riefler pen-

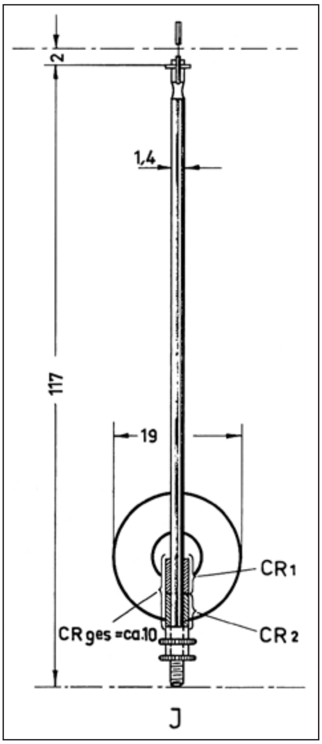


Fig. 9: Structure of the nickel-steel compensation pendulum by Riefler (Photo: Dieter Riefler)

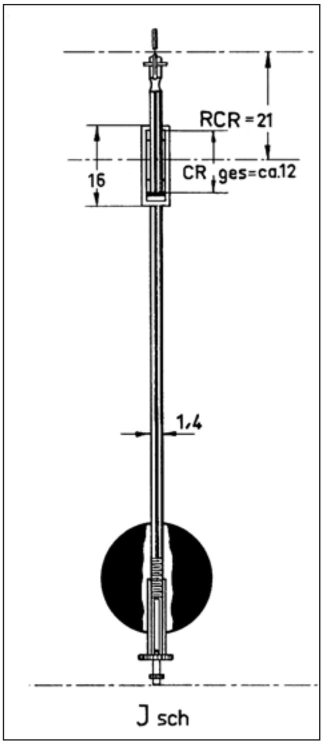


Fig. 10: Structure of the "Schichtungs-kompensations-pendel" (compensation pendulum for layered air) by Riefler (Photo: Dieter Riefler)

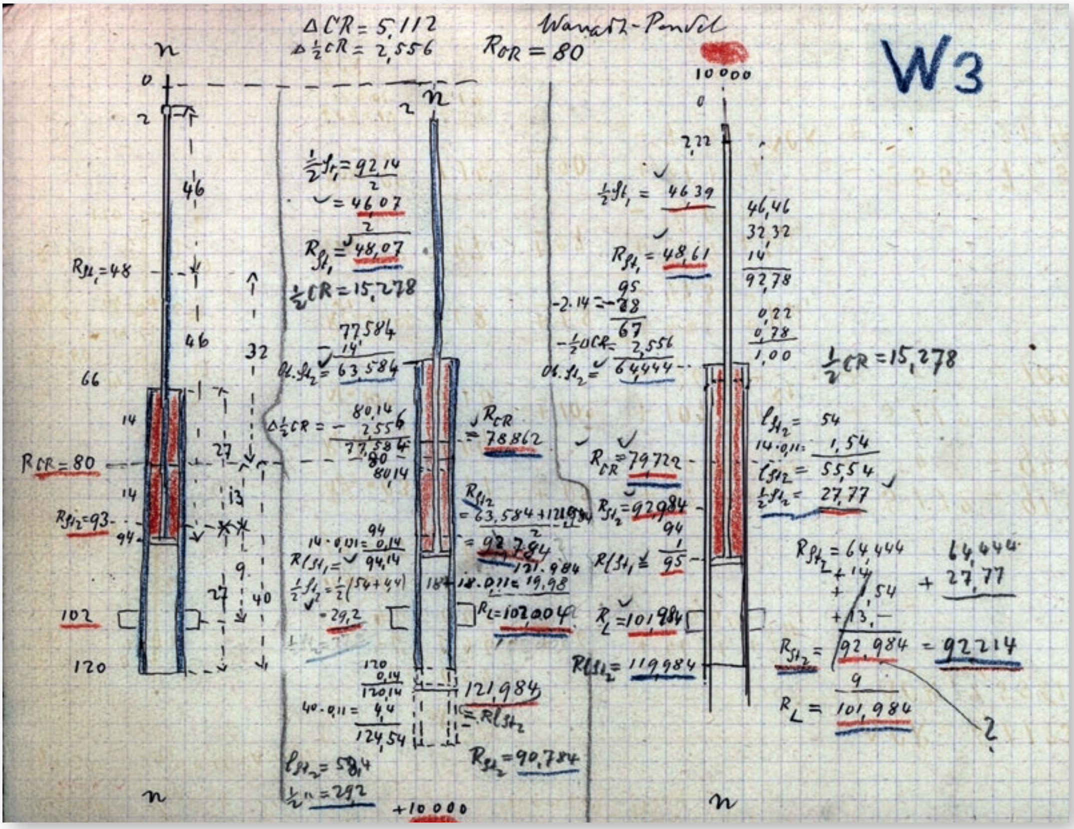


Fig. 11: Design considerations for the "Schichtungskompensationspendel" (DGC archive)

dulums, used in his own firm's best observatory clocks. In price lists from 1908 and 1913, Strasser even offered nickel-steel pendulums from Riefler as an alternative to his own pendulums[19].

The compensation pendulum made of Invar was a masterstroke of engineering by Riefler and quickly replaced the mercury compensation pendulum. However, problems occasionally cropped up with varying clock room temperatures and heights (especially when heated by electricity). The top of the pendulum could be subject to a temperature different from the lower part where the compensation components were located. The problem was first recognized by Bernhard Wanach at the Institute for Geodesy in Potsdam. He encouraged Riefler to develop a suitable pendulum to solve this problem. Beginning in 1908, Riefler worked on this problem and attached the compensation element to the top of the pendulum (fig. 10), thus creating the so-called "Schichtungspendel"—a compensation pendulum for layered temperature. The mathematical calculations to determine these elements proved very difficult. Riefler could not find a perfect solution to the problem and for six months employed two mathematicians who made more than 8000 repeated calculations. Figure 11 shows an extract from these.

Fig. 12: Time-keeping system in the Deutsches Museum with master clock no. 98 in the glass tank and two slave clocks (Photo: Jürgen Ermert.-Deutsches Museum)

An extensive analysis can be found in Pavel.[20] Patenting this concept was thwarted by the patent officer who, despite numerous attempts, was unable to understand the calculations, and Riefler withdrew the application.[21] It remains certain that pendulums with compensation for layered temperature fulfilled the most stringent requirements. The question remains as to what proportion of the overall accuracy achieved by Riefler clocks resulted from compensation for layered temperature.

From 1911, 123 of 127 Riefler clocks were equipped with pendulums compensated for layered temperature. Altogether 135 of these pendulums were produced.[22] In comparison, this was a small percentage of the 4104 Invar pendulums made by Riefler. As his firm built only 635 clocks itself, the majority of the pendulums were acquired by other firms because of their excellent properties. This is evident from the Riefler firm's correspondence in the archives of the German Horological Society (Deutsche Gesellschaft für Chronometrie) in Nuremberg. Apart from their principle customer Siemens, the following firms acquired Riefler pendulums: Bohmeyer, E. Bosell (Milan), Bürk & Sons, Fratelli Solar (Udine), Furtwängler, Hörz, Junghans, Lenzkirch, Neher, Strasser & Rhode, Telefonbau & Normalzeit as well as Theodor Wagner.

The Use of Electricity.
From about 1840, electricity began to be used in timekeeping. Alexander Bain was granted a patent for electric clocks as early as 1841.[23] The Berlin astronomer Wilhelm Foerster gave an account in 1867 of Christian Friedrich Tiede's pendulum clock in a glass tank with an electromagnetic escapement.[24] At the First International Exhibition of Electricity in 1881 in Paris, H. Schweitzer of Solothurn displayed a new system of electrical winding. Along the same lines, the "Elektrische Normaluhr" (electrical master clock) patented in 1882 by Alois Winbauer of Baden near Vienna used an electrically impulsed gravity arm to drive the clock[25]. Until 1900, Sigmund Riefler used in his precision pendulum clocks the conventional form of eight-day weight drive with manual winding and maintaining power. Riefler was well aware that a sensitive clock with a free spring impulse escapement should be protected from any disturbing external influences when winding the clock by hand. Apparently he was interested in Winbauer's invention because a total of seven Riefler clocks have Winbauer's winding mechanism.[26] It can be assumed that this inspired Riefler's own electrical winding system. In the case of Winbauer's mechanism, the winding acts on the minute wheel every seven to eight minutes. Riefler believed that more frequent winding would result in better timekeeping, and the elimination of all slowly-revolving driving wheels would be advantageous.[27] His winding arm acts on the wheel which engages with the escape wheel pinion (fig. 13), resulting in a winding frequency of only 40 seconds. He was granted a patent for it as early as May,1903, Deutsches Reichs-Patent No. 151710.

Riefler's electric winding has extra advantages over conventional weight-driven trains because it avoids the loss of energy from the transmission of power through all of the usual gear wheels. In Riefler's case, the transmission ratio of the power from its source (the gravity arm) is seven and a half fold as compared to 900-fold in a weight-driven movement. And instead of a driving weight of 1.5 kilograms in normal clocks, a winding arm of about ten grams is sufficient for the electric winding system.[28]

Electricity not only made electro-magnetic winding possible, but it also was important for time-service systems. As early as 1839, Carl August Steinheil of Munich had shown in principle that time signals could be transmitted to slave clocks.[29] In 1846, Alexander Bain set up a telegraph line from Edinburgh to Glasgow where a master clock could synchronize dials. The era of

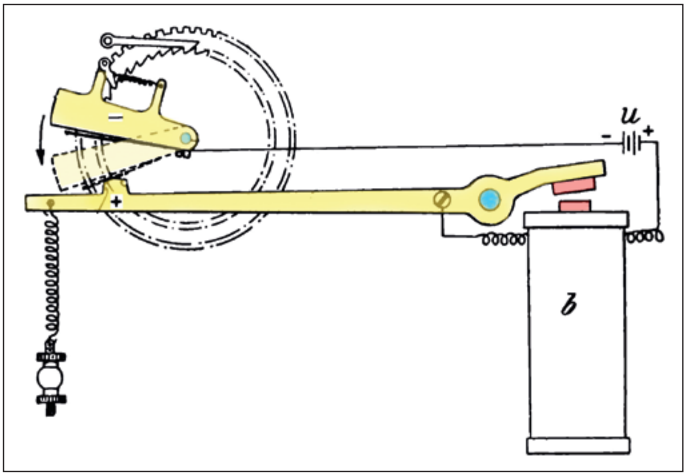


Fig. 13: Electric winding by Riefler, schematic diagram

time-service systems had begun.[30] In his paper published in 1927 *Precision Pendulum Clocks and Time-Service Systems for Observatories*[31], Sigmund Riefler provided for astronomers in observatories an instruction manual for setting up and maintaining such systems and to this end offered numerous additional features such as electric seconds contacts and polarity-alternating devices.

The Production of Riefler Clocks.
Sigmund Riefler was not a clockmaker, but was an engineer with exceptional talents. He worked on his most important inventions, the free spring impulse pendulum and the mercurial pendulum, in his laboratory in Lenbach Square from 1889 to 1891. The precision mechanics in Nesselwang were exclusively producing high-quality drawing instruments at this time, raising the question of who initially manufactured the clocks for Sigmund Riefler. Jürgen Ermert has considered this question intensively.[32] He shows that in Nesselwang they were a long way from mass-production of clocks and pendulums. Seemingly the firm of J. Neher and Sons played a significant role here. The firm had been making clocks since 1862. In the firm's letterhead of 1899, it boasted that Neher had "been preferentially entrusted with the construction of precision clocks (Dr. Riefler system) by the inventor himself and has alone the exclusive right to construct the compensating pendulum D. R. P 60059".[33] The movement for clock No. 1 (for the Munich observatory) definitely was made by Strasser & Rhode

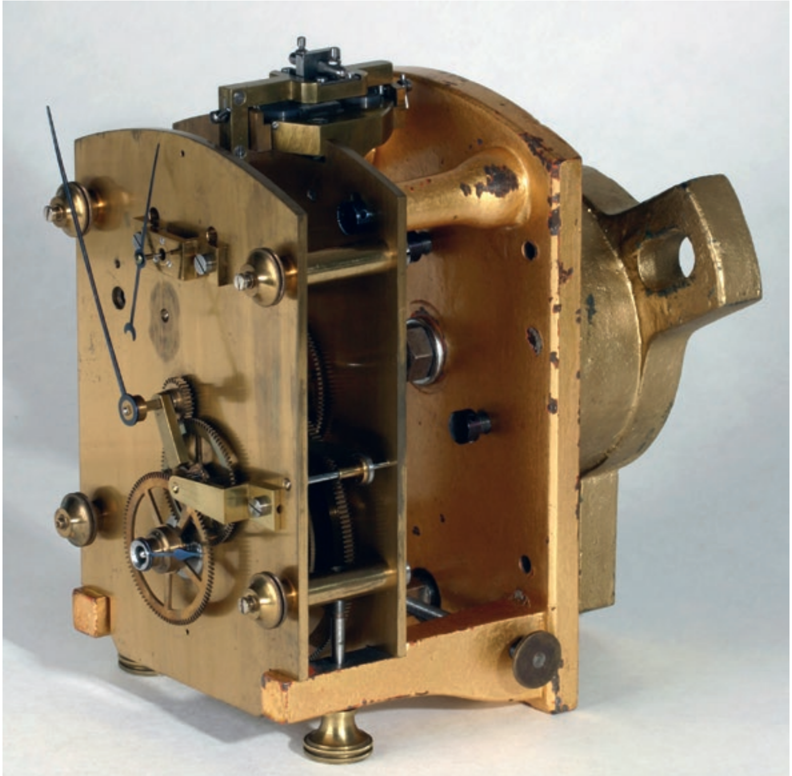


Fig. 14: Early experimental clock by Riefler from 1890 with free spring escapement in the German Clock Museum Furtwangen (Photo: Deutsches Uhrenmuseum Furtwangen)

in Glashütte, and afterwards Riefler added his new escapement.[34] The movements for Riefler No. 3 and No. 8 also came from Glashütte.

A thorough examination of the very early Riefler movement of 1889 (fig. 14) showed that it did not come from Glashütte, but presumably from J. Neher and Sons in Munich[35].

The level of development achieved by Sigmund Riefler, after numerous step-by-step improvements in 1907, then formed the basis for clock production in Nesselwang until 1965.[36] From about 1905, Riefler also made dead-beat escapement clocks which he liked to use as synchronized slave clocks in time-service systems. These achieved good timekeeping results as well, although he had rejected this escapement for theoretical reasons in his 1894 paper.[37]

The Accuracy of the Riefler Clocks.
Sigmund Riefler strived in every respect for perfection and accuracy for his clocks. As early as 1895, he had housed the best of his clocks in air-tight low-pressure cases with glass domes in order to eliminate any barometric effects. For his best tank clocks with pendulums compensated for layered temperature (type D), he guaranteed an accuracy rate of +/– 0,01 to – 0,03 seconds per day. With the help of the comprehensive tables[38] he drew up, the clock pendulum was adjusted according to its intended location before it was delivered. Even the carbon dioxide content and humidity of the air would be taken into account. In order to correct rate gains or losses, a slight change of air pressure in the tank, with the help of the accompanying tables, would suffice.

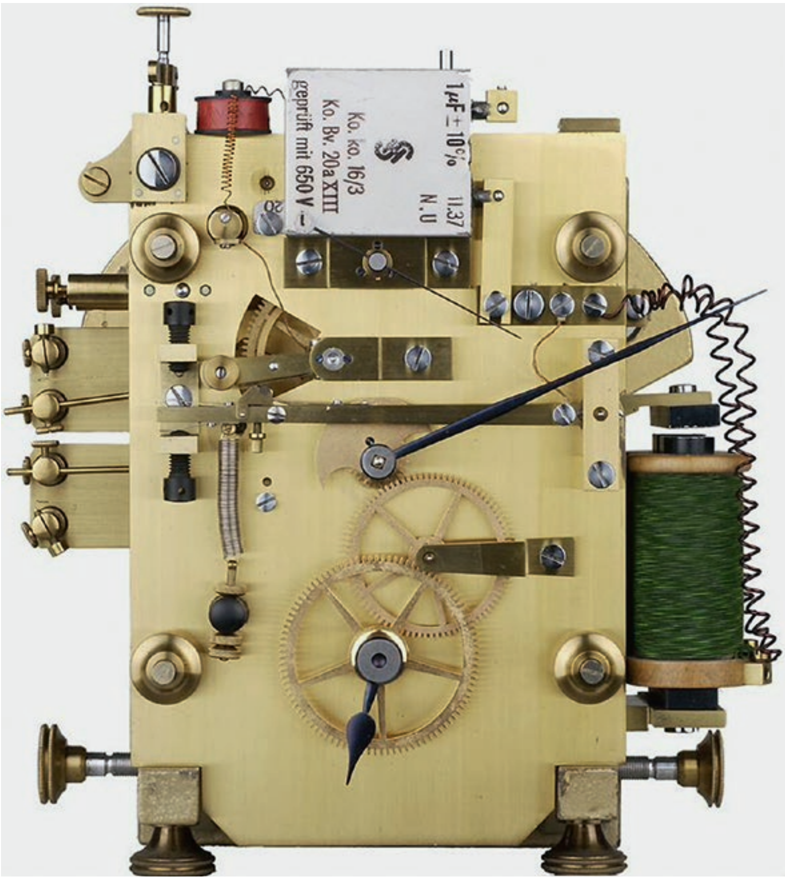


Fig. 15: The movement of the later clock No. 763 with gravity escapement (Photo: Bernd Liebscher)

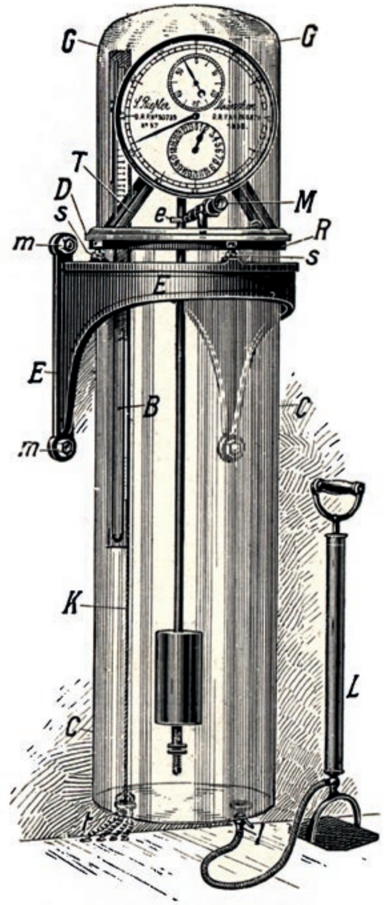
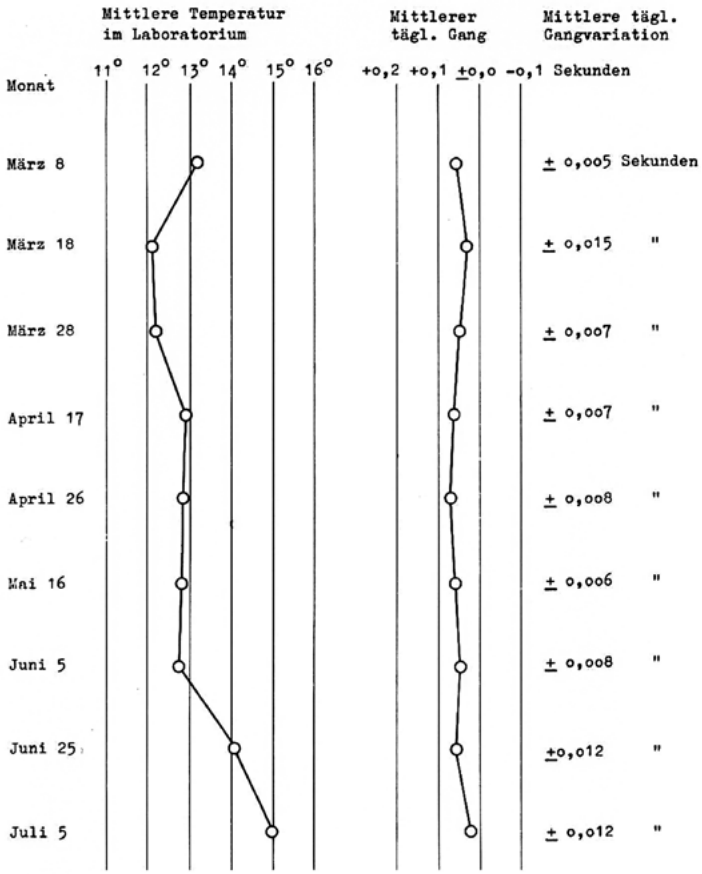


Fig. 16: Tank gauge in a hermetically sealed case with air pump for regulating the clock via change in the air pressure (DGC archive)

As such, Sigmund Riefler essentially had reached the physical limits for a mechanical clock. This is clear from the following figures: lengthening the pendulum by 0.002 mm causes a losing rate of 0.1 seconds per day. If the mass of 1 liter of air changes by only one thousandth, it means a daily change of 0.01 seconds. Earth tremors and vibrations also had a significant effect, which meant that the clock had to be set up free from all vibrations. Figure 17 shows how flawless the rate of such a clock was.

Before it was delivered, each clock would be tested for months in the Nesselwang laboratory, and its daily rate would be recorded as well as the consistency of that rate. Figure 18 shows an extract from such a test certificate. Results were achieved that were not surpassed for several decades.

Fig. 17: Average daily rate of Riefleruhr No. 561 with "Schichtungspendel" 3122 in the event of temperature fluctuations (Photo: Dieter Riefler)



154 Grafische Darstellung des mittleren täglichen Ganges der Uhr Type D Nr. 561 mit Schwerkrafthemmung und Pendel Type J^1_{sch} Nr. 3122 unter Einfluß von Temperaturschwankungen

Sadly, Sigmund Riefler died in 1912, and his successors could not significantly improve upon his clocks. However, horological progress did not halt, and in 1921 the English engineer William H. Shortt developed a new system that achieved accuracies exceeding 0.01 second per day. This was made possible by a freely oscillating pendulum that received a brief mechanical impulse from a "slave clock" every 30 seconds. Fearful of falling behind, the firm of Riefler took up the ideas of the Göttingen physicist Max Schuler who in 1924 proposed a completely new type of pendulum clock. As a further development of the Shortt concept, the pendulum did in fact swing freely as Schuler powered it electromagnetically. In addition, Schuler used a special compound pendulum which he had designed to minimize the effects of external influences on oscillations.

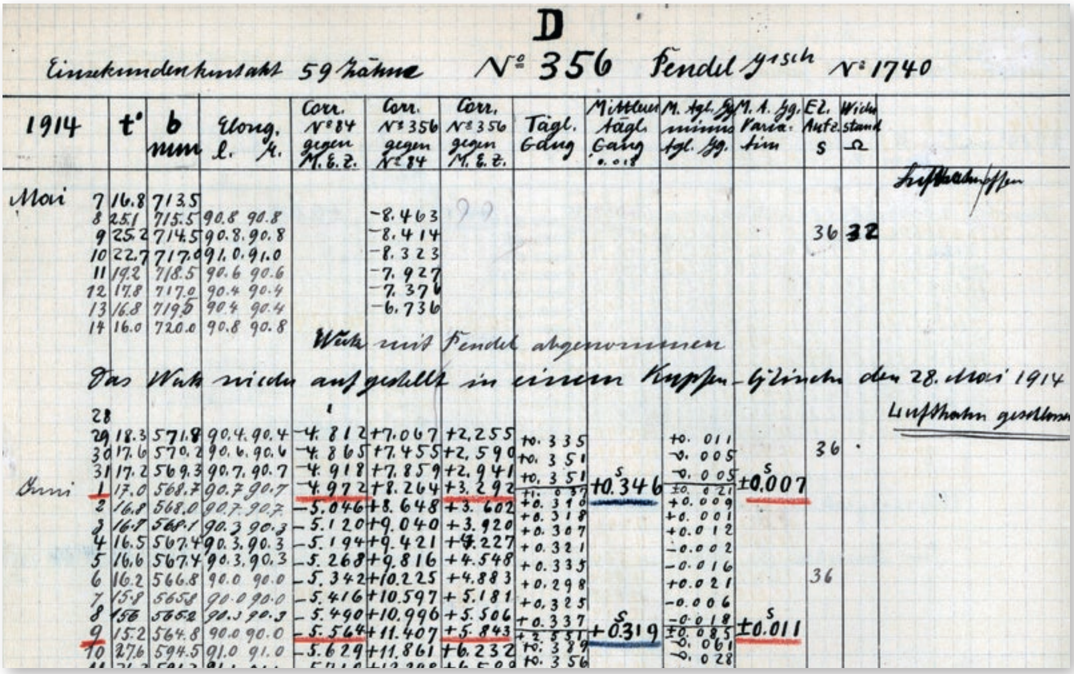


Fig. 18: Extract from the test records for the accuracy of the clock No. 356 of 1914 (DGC archive)

Moreover, the pendulum oscillations were recorded opto-electronically by a photoelectric sensor. The long history, for the period 1924 to 1964, of four clocks built according to Schuler's design can be found in the Riefler archive at the DGC Library. A detailed essay by Saluz[39] showed that the project failed not because of the concept, but because of the unreliability of the electronic components which at the time did not have the necessary long-term reliability.

In the 1930's, Udo Adelsberger and Adolf Scheibe at the Physikalisch Technischen Reichsanstalt in Berlin developed the first quartz clocks in Germany with an accuracy unattainable by mechanical precision pendulum clocks.[40] The long-term stability of these clocks was so good that in 1935 they detected irregularities in the rotational speed of the earth (Figure 19). Quartz clocks and later atomic clocks made all mechanical precision pendulum clocks redundant, and 70 years of Riefler clockmaking finally ended in 1965.

The Riefler Archive in the DGC Library.

It was a stroke of luck when Stefan Muser, owner of the esteemed auction house Dr. Crott, happened upon a large number of files and other interesting documents from the firm of Clemens Riefler. Among these are 157 files of original correspondence from 1911 until 1970. The records of timing trials, which were conducted often for months, were a veritable treasure trove. For 493 of all 635 clocks made by Riefler, original documents are available, starting with clock number 20 (Figure 18). A copy of the complete sales accounts for all 635 clocks also is available. Stefan

Muser immediately recognized the importance of the documents and, after lengthy negotiations, arranged in 2012 for the entire collection to be donated to the library of the Deutsche Gesellschaft für Chronometrie. It now is permanently accessible to the public for scientific and historical research. Thanks to Peter Dormann, the entire content of the collection, more than 40,000 pages, is digitally researchable. Numerous other original documents, including personal letters from and to Sigmund Riefler as well as many workshop drawings, make the archive a goldmine for every researcher.

Why was Siegmund Riefler successful?

Sigmund Riefler's success is due not only to his talent as an engineer and inventor, which enabled him to create ingenious improvements for the construction of precision pendulum clocks. Certainly in his youth he was also inspired by his father Clemens' world of precision mechanics and drawing instruments.

Because of his solid financial position as co-owner of the Clemens Riefler company, Sigmund Riefler had his own Munich research laboratory, allowing him to conduct extensive experiments. This went far beyond what a normal clockmaker could ever have afforded and was partly responsible for the great results achieved in a relatively short time. Another reason for his success certainly was the brand name "Riefler" which was already known worldwide from its drawing instruments. Customers associated this name with "first-class quality" and "universally superior",

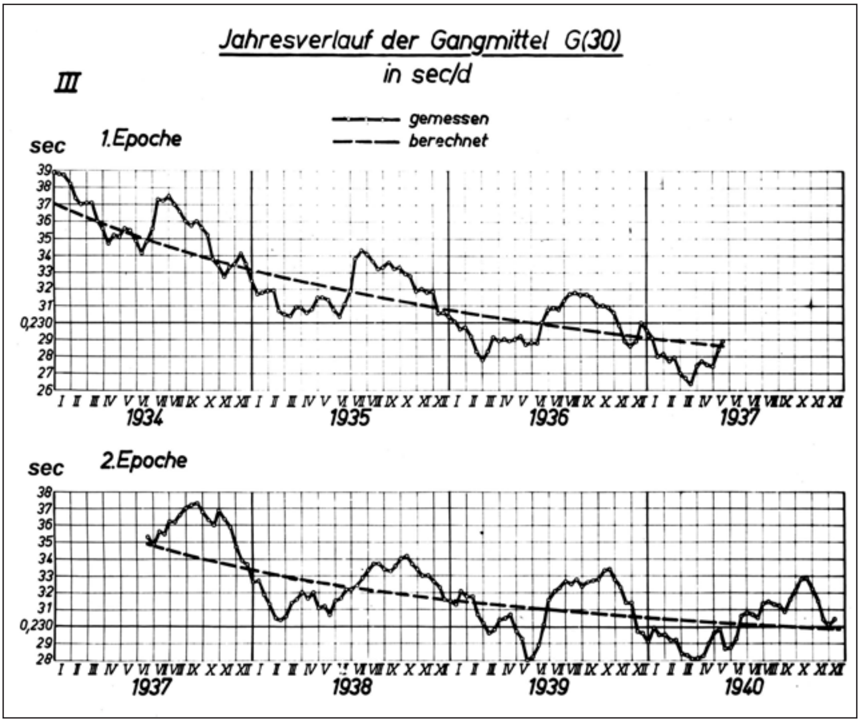


Fig. 19: Annual rate records from 1934—1940 for the quartz clock III of the Physikalisch-Technische Reichsanstalt (DGC archive)

Fig. 21: Worldwide locations of Riefler clocks (DGC archive)


RIEFLER" - Uhren Clocks Horloges
Riga
Warschau
Krakau
Cernauti
Bukarest
Sofia
Kopenhagen
Helgoland
Hamburg
Berlin
Stuttgart
München
Genf
Neuchâtel
Wien
Budapest
Agram
Lussinpiccolo
Pola
Stockholm
Leningrad
Moskau
Kasan
Kiew
Charkow
Rostow
Nikolajew
Odessa
Krim
Istambul
Turin
Bologna
Florenz
Rom
Neapel
Palermo
Messina
Kairo
Jakutsk
Tomsk
Jrkutsk
Newschwang
Taschkent
Sendai
Tokyo
Yokohama
Kyoto
Kalkutta
Bangkok
Bombay
Manila
Cavite
Sumatra
Bandoeng
Semarang
Johannisburg
Cap d. guten Hoffnung
Adelaide

making it much easier for Sigmund Riefler to enter the world market. At international industrial fairs, he could present his clocks alongside the drawing instruments with no further introductions needed.

Significant for Sigmund Riefler were his adept English and French language skills. The company of Clemens Riefler took part in the 1893 World Fair in Chicago with their technical drawing instruments. Sigmund Riefler accompanied them to exhibit his clock No. 6. For this timepiece he received first prize in the competition for inventions in the horology sector. With his adept salesmanship, he was able to convince the Washington Observatory to acquire this clock. Adolf Leman of the Physikalisch-Technische Reichsanstalt in Berlin contributed to the successful marketing by traveling with them to Chicago in 1893 and delivering a lecture on the success of Riefler's pendulum and free spring escapement at the International Congress of Astronomy.[41] The lecture was subsequently incorporated into the official report of the American government. That's the way to advertise successfully! Clock No. 36 was installed at the Washington Observatory in 1900 and, together with three other Riefler clocks, provided the USA time standard[42] for several decades. That spurred the success of Riefler clocks. Several prizes were garnered every year. In 1900, he received his initial First Prize at the World Fair in Paris. In order to promote his clocks, he reported extensively on his inventions in numerous national and international magazines. These papers also were read at observatories which were important potential customers.

The World Exhibition of 1905 in Liège was also a great success for Riefler. He was awarded two First Prizes and was able to show to the world his recently completed large clock system for the Belgian observatory in Uccle. A total of 19 precision pendulum clocks had been integrated into this system and still survive, including eleven Riefler clocks, with four highest-quality Riefler tank clocks used as master clocks. Sigmund Riefler's success may also have hinged upon the worldwide advent of standard time at the end of the 19th century. The introduction of the associated time zone system inevitably led to the responsibility of each individual nation for its own time standards. Accordingly, the demand for high-precision clocks increased. With the help of telegraphy, transnational time comparisons had been carried out since the middle of the 19th century, for such reasons as determining the positions of observatories. No country wanted the embarrassment of not keeping up with its neighboring countries' accurate time standards. This provided a great sales tool for a company that presented itself to the world as a leading manufacturer of the finest precision pendulum clocks. Sigmund Riefler's clocks came exactly at the right moment. Within a brief time, many countries around the world purchased Riefler clocks for establishing their national time standards, as shown in fig. 21.

In Germany, Central European time was introduced by law on April 1, 1893. As early as 1895, Sigmund Riefler offered a telephone service from his laboratory in Munich to clockmakers and other interested parties.[43] The time signals were transmitted to the caller's handset or strip chronograph so that the signal could be monitored accurately to about 0.1 second. This onset of telephone or telegraphic transmissions of seconds signals is also likely to have influenced the sale of precision pendulum clocks. From March 1910, the radio station in Norddeich sent wireless time signals, and at the same time the Berlin Observatory also provided 300 subscribers with seconds signals by telephone via the firm Normalzeit.[44] From 1919, the Hamburg Seewarte in Germany was responsible for the radio service and sent time signals worldwide, enabling ocean-going ships to receive the exact time daily.[45] For this task, two Riefler tank clocks were required.

Were Riefler clocks an overall economic success? Unfortunately, there are no facts or figures to answer this intriguing question. It is certain that developments in his clock business could be generously financed with the profits from selling technical drawing instruments. Sigmund Riefler sought utmost precision. His target groups initially were observatories and scientific institutes. These acquired most of the mere 635 clocks produced over the course of 70 years. These clocks were very expensive. According to the 1906 price list, they cost between 1500 Marks (type A) and 3800 Marks (highest quality), the cost of a family home. A seconds pendulum clock with a "mere" dead beat escapement, however, was offered for "only" 600 Marks.[46] The sale of Invar pendulums went well, of which a total of 4104 were produced. Of these, 3500 were purchased by other precision clock manufacturers because of the pendulums' excellent properties.[47]

Conclusion.

Sigmund Riefler was a brilliant engineer with immense knowledge and strong analytical skills. He studied the weak points of timepieces, found new approaches to eliminate those weaknesses. and put his steadily improving concepts into practice.

Juergen Ermert puts it in a nutshell: "Sigmund Riefler is much more than 'one of the most important clockmakers of all time'. He was a highly creative and extremely gifted clock designer with a high degree of horological know-how who massively stimulated precision timekeeping and time-service systems, which were needed in industry, science and economy worldwide."[48]

Literature

Adelsberger, Udo/Scheibe, Adolf: Die Gangleistungen und technischen Einrichtungen der Quarzuhren der Physikalischen Technischen Reichsanstalt in den Jahren 1932-1944. Band 1: Die Quarzuhren der PTR und der Nachweis der Schwankung der astronomischen Tageslänge, Typoskript Berlin, Heidelberg and Braunschweig 1950.

Bain, Alexander: Improvements in the Application of Moving Power to Clocks and Timepieces. Patent GB 8783 vom 11. January 11th 1841.

Bain, Alexander: A Short History of the Electric Clocks, London 1852.

Die neue Strassersche astronomische Pendeluhr "DUB", in: Deutsche Uhrmacher-Zeitung 32, 1908, no. 14, pp. 219 f.

Ermert, Jürgen: Präzisionspendeluhren in Deutschland von 1730 bis 1940; so far 5 volumes published, Overath 2013.

Foerster, Wilhelm: Über die gegenwärtige Entwicklungsstufe der Zeitmessung und Zeitregelung, in: Deutsche Uhrmacher-Zeitung 34, 1910, Nr. 17, pp. 280 f.

Saluz, Eduard: Die genaueste Pendeluhr der Welt—aber wozu? in: Deutsche Gesellschaft für Chronometrie. Jahresschrift 52, 2013, pp. 125 – 138.

Kummer, Hans-Jochen: Ludwig Strasser—Ein Uhrenfachmann aus Glashütte, München 1994.

Pavel, Heinrich: Die Schichtungskompensationspendel von Sigmund Riefler, in: Deutsche Gesellschaft für Chronometrie. Jahresschrift 54, 2014, pp. 157 – 172.

Riefler, Dieter: Riefler Präzisions-Pendeluhren von 1890 – 1965, 2. edition, München 1991

Riefler, Dieter: 155 Jahre Clemens Riefler, Nesselwang, 2016.

Riefler, Sigmund: Doppelradhemmung für Chronometer mit vollkommen freier Unruhe und für Pendeluhren mit freiem Pendel, in: Bayerisches Industrie- und Gewerbeblatt 22, 1890, no. 10, pp. 113 – 119.

Riefler, Sigmund: Hemmung für Chronometer und andere tragbare Uhren mit vollkommen freischwingender Unruh und für Standuhren mit gänzlich freischwingendem Pendel, in: Deutsche Uhrmacher-Zeitung 14, 1890, no. 5, pp. 34 – 36.

Riefler, Sigmund: Die Präcisions-Uhren mit vollkommen freiem Echappement und neuem Quecksilber-Compensationspendel, München 1894.

Riefler, Sigmund: Das Nickelstahl-Compensationspendel D. R. P. 100870, München 1902.

Riefler, Sigmund: Präzisions-Pendeluhren und Zeitdienstanlagen für Sternwarten, München 1907.

Giebel, Karl: Das Pendel, 2. edition, Halle 1951.

Riefler, Sigmund: Tabellen der Luftgewichte, der Druckäquivalente und der Gravitation, Berlin 1912.

Saluz, Eduard: Der Ingenieur als Uhrmacher—Sigmund Riefler und seine freie Federkrafthemmung, in: Deutsche Gesellschaft für Chronometrie, Jahresschrift 51, 2012, pp. 89 – 100.

Saluz, Eduard: Die genaueste Pendeluhr der Welt—aber wozu? in: Deutsche Gesellschaft für Chronometrie. Jahresschrift 52, 2013, pp. 125 – 138.

Testorf, Friedrich: Die Elektrizität als Antriebskraft für Zeitmessinstrumente, Halle 1910.

J. Neher Söhne, Thurmuhrenfabrik und mechanische Werkstätte [corporate literature], München ca. 1899.

Winbauer, Alois: Elektrische Normaluhr, in: Österreichisch-Ungarische Uhrmacher-Zeitung 3, no. 1, 1883, pp. 2

Annotations

1 Riefler, Dieter: 155 Jahre Clemens Riefler, Nesselwang, 2016, p. 17

2 Riefler, Sigmund: Doppelradhemmung für Chronometer mit vollkommen freier Unruhe und für Pendeluhren mit freiem Pendel, in: Bayerisches Industrie- und Gewerbeblatt 22, 1890, no. 10, S. 113 – 119.

3 Riefler, Sigmund: Hemmung für Chronometer und andere tragbare Uhren mit vollkommen freischwingender Unruh und für Standuhren mit gänzlich freischwingendem Pendel, in: Deutsche Uhrmacher-Zeitung 14, 1890, no. 5, pp. 34 – 36.

4 Saluz, Eduard: Der Ingenieur als Uhrmacher—Sigmund Riefler und seine freie Federkrafthemmung, in: Deutsche Gesellschaft für Chronometrie, Jahresschrift 51, 2012, pp. 89 – 100.

5 Ermert, Jürgen: Präzisionspendeluhren in Deutschland von 1730 bis 1940, bislang vier Teilbände, Overath 2013 ff.

6 Ermert, Jürgen: Präzisionspendeluhren in Deutschland von 1730 bis 1940, Bd. 5, Overath (will be published soon).

7 Riefler, Dieter: Riefler Präzisions-Pendeluhren von 1890 – 1965, 2. Auflage, München 1991, p. 28

8 Riefler, Dieter: Riefler Präzisions-Pendeluhren (see note 7), p. 29

9 Riefler, Sigmund: Die Präcisions-Uhren mit vollkommen freiem Echappement und neuem Quecksilber-Compensationspendel, München 1894, p. 3

10 Riefler: Die Präcisions-Uhren (see note 9), p. 5

11 Riefler: Die Präcisions-Uhren (see note 9), p. 6

12 Riefler: Die Präcisions-Uhren (see note 9), p. 13

13 Riefler: Die Präcisions-Uhren (see note 9), p. 14

14 Riefler: 155 Jahre (see note 1), p. 18

15 Riefler, Sigmund: Das Nickelstahl-Compensationspendel D. R. P. 100870, München 1902.

16 Riefler: Riefler Präzisions-Pendeluhren (see note 7), p. 38

17 Riefler: Das Nickelstahl-Compensationspendel (see note 13).

18 Giebel, Karl: Das Pendel, 2. Auflage, Halle 1951, pp. 124 ff.

19 Kummer, Hans-Jochen: Ludwig Strasser—Ein Uhrenfachmann aus Glashütte, München 1994, p. 42.

20 Pavel, Heinrich: Die Schichtungskompensationspendel von Sigmund Riefler, in: Deutsche Gesellschaft für Chronometrie. Jahresschrift 54, 2014, pp. 157 – 172.

21 Riefler: 155 Jahre (see note 1), p. 20

22 Riefler: Riefler Präzisions-Pendeluhren (see note 7), p. 136

23 Bain, Alexander: Improvements in the Application of Moving Power to Clocks and Timepieces. Patentschrift GB 8783 vom 11. Januar 1841.

24 Foerster, Wilhelm: Das electromagnetische Echappement von Tiede und die Pendeluhr im luftdicht verschlossenen Raume, in: Astronomische Nachrichten no. 1636, 69, 1867, pp. 55 – 57.

25 Winbauer, Alois: Elektrische Normaluhr, in: Österreichisch-Ungarische Uhrmacher-Zeitung 3, no. 1, 1883, pp. 2 f.

26 Riefler: Riefler Präzisions-Pendeluhren see note 7), p. 51.

27 Riefler: Riefler Präzisions-Pendeluhren (see note 7), p. 52.

28 Riefler: Riefler Präzisions-Pendeluhren (see note 7), p. 51.

29 Steinheil, Carl August: Beschreibung und Abbildung der von dem k. Akademiker und Conservator, Professor Dr. Steinheil erfundenen galvanischen Uhren, in: Kunst- und Gewerbeblatt des polytechnischen Vereins für das Königreich Bauern 29, 1843, pp. 127 – 142.

30 Bain, Alexander: A Short History of the Electric Clocks, London 1852, pp. 22 – 28.
31 Riefler, Sigmund: Präzisions-Pendeluhren und Zeitdienstanlagen für Sternwarten, München, 1907.
32 Ermert: Präzisionspendeluhren, Bd. 5 (see note 6).
33 J. Neher Söhne, Thurmuhrenfabrik und mechanische Werkstätte [Firmenschrift], München ca. 1899.
34 Ermert: Präzisionspendeluhren, Bd. 5 (see note 6).
35 Ermert: Präzisionspendeluhren, Bd. 5 (see note 6)
36 Ermert: Präzisionspendeluhren, Bd. 5 (see note 6)
37 Riefler: Die Präcisions-Uhren (see note 9), p. 18
38 Riefler, Sigmund: Tabellen der Luftgewichte, der Druckäquivalente und der Gravitation, Berlin 1912.
39 Saluz, Eduard: Die genaueste Pendeluhr der Welt—aber wozu? in: Deutsche Gesellschaft für Chronometrie. Jahresschrift 52, 2013, pp. 125 – 138.
40 Adelsberger, Udo/Scheibe, Adolf: Die Gangleistungen und technischen Einrichtungen der Quarzuhren der Physikalischen Technischen Reichsanstalt in den Jahren 1932-1944. Band 1: Die Quarzuhren der PTR und der Nachweis der Schwankung der astronomischen Tageslänge, Typoskript Berlin, Heidelberg und Braunschweig 1950.
41 Die Präcisions-Uhren (see note 9), p. 2
42 Riefler: 155 Jahre (see note 1), p. 21
43 Riefler: 155 Jahre (see note 1), p. 19
44 Wilhelm Foerster: Über die gegenwärtige Entwicklungsstufe der Zeitmessung und Zeitregelung. In: Deutsche Uhrmacher-Zeitung, 34. Jhg (1910), no. 17, p. 280 f.
45 Riefler: 155 Jahre (wie Anm. 1), p. 20
46 Riefler: Riefler Präzisions-Pendeluhren (see note 7), p. 142
47 Riefler: Riefler Präzisions-Pendeluhren (see note 7), p. 136
48 Ermert: Präzisionspendeluhren, Bd. 5 (see note 6).

Bernhard Huber

After studying physics and mathematics, Bernhard Huber received his doctorate in engineering from the University of Erlangen. Afterwards, he was responsible for setting up various development departments within the Philips Group, most recently as overall manager for all IT activities, then as a member of the German management of an international IT service provider. Mechanical timepieces, books and libraries have been his passion for many years. After retiring in 2003, he developed the library of the DGC in Nuremberg into the largest specialist library for the field of time measurement in Europe, combined with countless accompanying activities.