A Rock Crystal Watch with a Cross-Beat Escapement

BRUCE CHANDLER

Professor of Mathematics, The College of Staten Island, City University of New York

CLARE VINCENT

Associate Curator, Department of European Sculpture and Decorative Arts, The Metropolitan Museum of Art

THE SUCCESS OF THE European clock depended upon the invention of a device which could control the release of power from its source, whether that source was a falling weight or a coiled spring. Such a device is called an escapement. Around the beginning of the fourteenth century, an escapement called the verge was invented.[1] During the next three centuries, great improvements were made both to the verge escapement itself and to the rest of the clock's mechanism. The only difficulty was that the verge escapement had mechanical limitations which made really accurate timekeeping impossible.[2] This problem was not a very serious one for the purposes of everyday life, but by the late sixteenth century European observational astronomy had advanced to a point which required much more accurate timekeeping than the verge escapement could provide. In the course of the seventeenth century, the advantage of using a pendulum for regulating a clock was discovered and rapidly perfected.[3]

Before the pendulum superseded earlier devices, the cross-beat escapement, with its significant advance in accuracy, was employed in clocks which were made to meet the increasingly exacting requirements of the astronomers of the period. In the history of Western technology, one solution of a problem is often followed by a rapid succession of improvements that render the previous ones obsolete. Sometimes in the process, older but nevertheless quite ingenious inventions are forgotten. The cross-beat escapement is one such long-forgotten device. Indeed, the place of the cross-beat escapement in the development of the mechanical clock in the West provides an excellent example of this process.

The inventor and first maker of cross-beat escapements was the Swiss clockmaker Jost or Jobst Bürgi (1552–1632).[4] Bürgi worked first for the landgrave of Hesse, Wilhelm IV, who was himself an enthusiastic

A list of frequently cited sources is given after the appendix to this article.

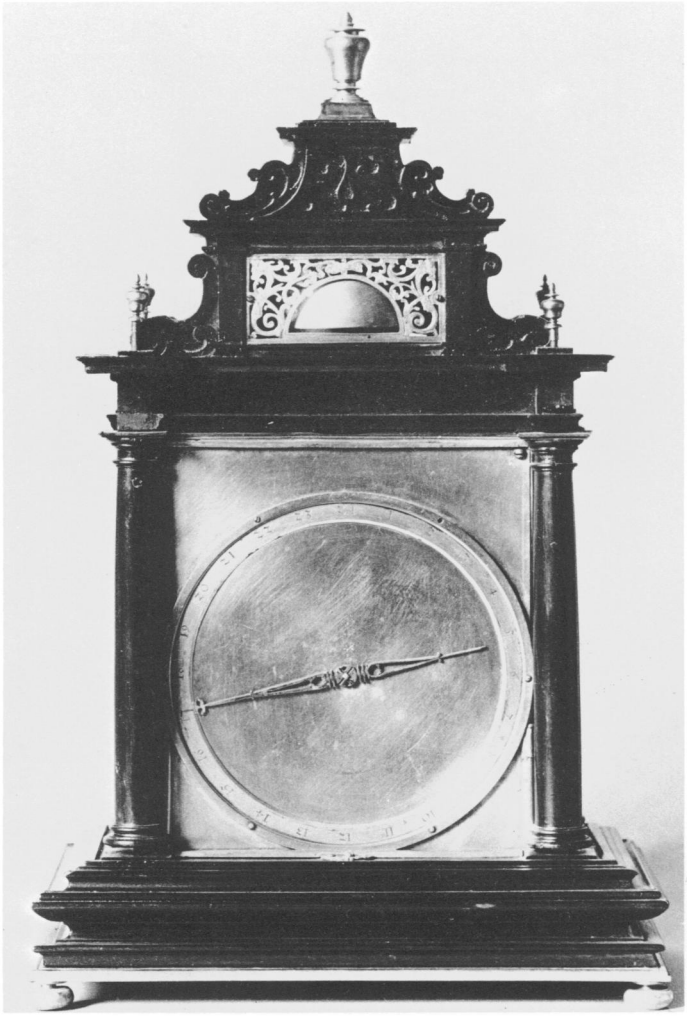
1. For a description of the verge escapement see G. H. Baillie, C. Clutton, and C. A. Ilbert, *Britten's Old Clocks and Watches and Their Makers*, 7th ed. (New York, 1956) pp. 4–5.

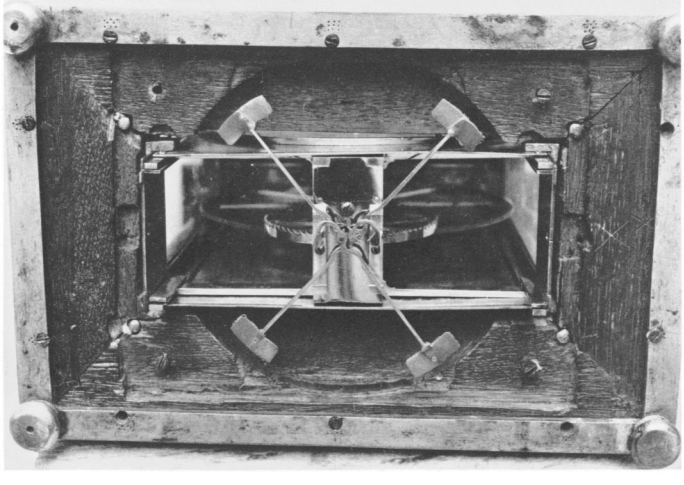
2. For a good technical discussion of the limitations of the verge escapement, as well as of other problems connected with the accuracy of verge escapement clocks, see von Bertele, "Timekeeping," pp. 9–18.

3. For the application of the pendulum to the clock see Baillie, Clutton, and Ilbert, *Britten's Old Clocks*, pp. 66–73; Lloyd, pp. 70–75; or Herbert Cescinsky and Malcolm R. Webster, *English Domestic Clocks* (London, 1913; new ed. 1969) pp. 14–29. For a good technical discussion of the pendulum see Defossez, pp. 86, 89, 95–108, and 121–152. For a recent summary of the dispute about the origins of the invention see S. G. Atwood, "The Development of the Pendulum as a Device for Regulating Clocks Prior to the 18th Century," in *The Study of Time II*, ed. J. T. Fraser and N. Lawrence (New York, 1975) pp. 417–450.

4. Maurice has suggested that Bürgi may have adapted the idea from a mechanical device for pumping water published by Jacques Besson in his *Theatrum instrumentum* as early as 1569 (Maurice and Mayr, p. 90, fig. 35, p. 92). For descriptions of the way in which the cross-beat escapement works see von Bertele, "Timekeeping," pp. 7–9, 22–23; Lloyd, pp. 64–67, figs. 8, 9; or von Mackensen, p. 50, fig. 5. For further information about Bürgi's life and work see the appendix.

METROPOLITAN MUSEUM JOURNAL 15





1. Experimental clock with a cross-beat escapement and with hour-striking and twelve-hour remontoire winding mechanisms, made by Jost Bürgi before 1600. H. 12⅝ in. (32.1 cm.). Kassel, Staatliches Landesmuseum, Astronomisch-Physikalisches Kabinett (photo: Staatliches Landesmuseum)

2. Underside of clock in Figure 1, showing the cross-beat escapement (photo: Dr. L. von Mackensen)

3. Experimental clock with concentric hour and minute hands and with hour-striking and remontoire winding mechanisms, made by Jost Bürgi. H. 20 in. (50.8 cm.). Dresden, Staatlicher Mathematisch-Physikalischer Salon (photo: Staatlicher Mathematisch-Physikalischer Salon)

4. Brass movement of clock in Figure 3 removed from its wooden case to show the cross-beat escapement (photo: Staatlicher Mathematisch-Physikalischer Salon)

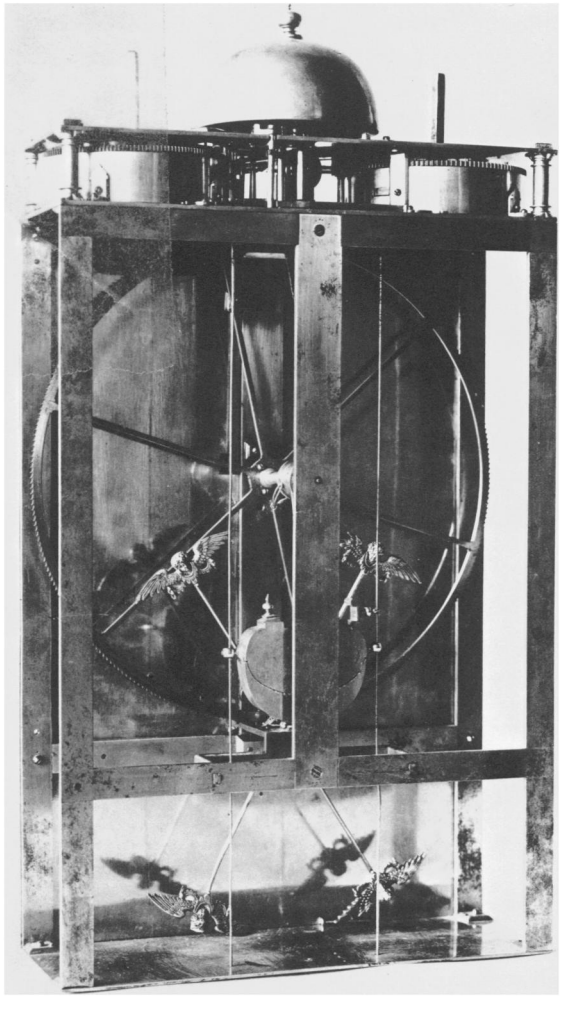
astronomer and patron of that science, and later for the Holy Roman Emperor, Rudolf II, in Prague. Besides being one of the great inventive clockmakers of history, Bürgi was also a mathematician and astronomer of no small accomplishment. He is believed by some to have made the clocks used by Tycho Brahe and Johannes Kepler for the astronomical observations upon which Kepler based his epoch-making discoveries about the true orbits of the planets.[5] Bürgi invented the cross-beat some time shortly before 1590. Magnificent examples of his cross-beat survive in clocks now in the Staatliches Landesmuseum in Kassel (Figures 1, 2),[6] the Staatlicher Mathematisch-Physikalischer Salon in Dresden (Figures 3–5),[7] and the Kunsthistorisches Museum in Vienna,[8] perhaps the most exquisite clock ever made (Figure 6). Although clocks and watches with cross-beat escapements were never made in quantity, the invention—

5. Lloyd, p. 63. See the appendix for a discussion of this question.

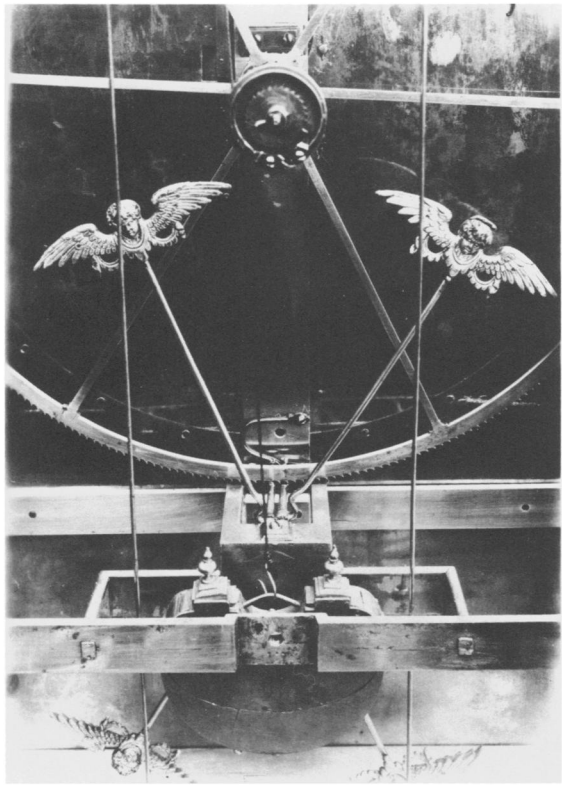
6. P. A. Kirchvogel, "Eine Standuhr aus dem 17. Jahrhundert," *Hessenland* 49 (1938) p. 167; von Bertele, "Timekeeping," pp. 20–21, figs. 24–28; idem, "Bürgi," p. 175, figs. 174–177; Lloyd, pp. 62–64, pls. 66–69; Maurice, I, p. 154, and II, p. 81, no. 637, figs. 637a,b; Giuseppi Brusa, *L'arte dell'orologeria in Europa* (Milan, 1978) figs. 167–170, p. 412; von Mackensen, pp. 51–52, 137, no. 20, and p. 47, fig. 2, p. 49, fig. 3.

7. Von Bertele, "Bürgi," pp. 182–184, 186, fig. 182; Lloyd, pp. 64–65, pls. 70–72; Helmut Grötzsch, "Die Kreuzschlaguhr und Globusuhr von Jost Bürgi—Wissenschaftliche Instrumente aus dem Arbeitsgebiet von Johannes Kepler," *Proceedings of the XIIIth International Congress of the History of Science, 1971* (Moscow, 1974) VI, p. 248; Maurice, I, p. 154, and II, p. 81, no. 636, figs. 636a,b; Helmut Grötzsch and Jürgen Karpinski, *Dresden Mathematisch- Physikalischer Salon* (Leipzig, 1978) pp. 21–28, figs. 60, 61; and von Mackensen, pp. 50–52, and p. 50, fig. 6, p. 51, fig. 7.

8. Von Bertele, "Timekeeping," pp. 3, 6–9, 21–22, figs. 6–8, 29, 30; idem, "Bürgi," pp. 181–182, figs. 161, 179–181; Lloyd, pp. 65–66, pls. 73–75, fig. 9; Vienna, Kunsthistorisches Mu-



5. Detail of the movement in Figure 4 showing the two separately pivoting arms of the cross-beat escapement with weighted ends in the shape of winged angels' heads. The alternate and independent beating of the two arms controls the motion of the extraordinarily large and fine-toothed great wheel mounted above and behind the arms of the cross-beat (photo: Staatlicher Mathematisch-Physikalischer Salon)



to judge from the examples by other makers that have survived and from the references to modified versions of the escapement which appear in eighteenth-century treatises on clockmaking[9]—was known and used in a number of cities in continental Europe. However, during the nineteenth century and the first

6. Astronomical table clock with hour, minute, and seconds dials. The quarter-striking movement has a modified cross-beat escapement and quarter-hour remontoire winding mechanism. The clock also indicates the age and phases of the moon and is fitted with a moving celestial sphere of rock crystal with a blued-steel armillary sphere inside, both visible through the outer case of rock crystal, silver, and gilt bronze. Movement made by Jost Bürgi in Prague between 1622 and 1627. H. 7½ in. (19.1 cm.). Vienna, Kunsthistorisches Museum (photo: Kunsthistorisches Museum)

7. Watch with hour-striking mechanism and cross-beat escapement. Movement made by Johann Poestdorffer in Dresden probably during the second quarter of the 17th century. L. 3$^{9}/_{16}$ in. (9.1 cm.) Dresden, Grünes Gewölbe (photo: Vincent)

8. Detail of the watch in Figure 7 (photo: Fine Arts Museums of San Francisco)

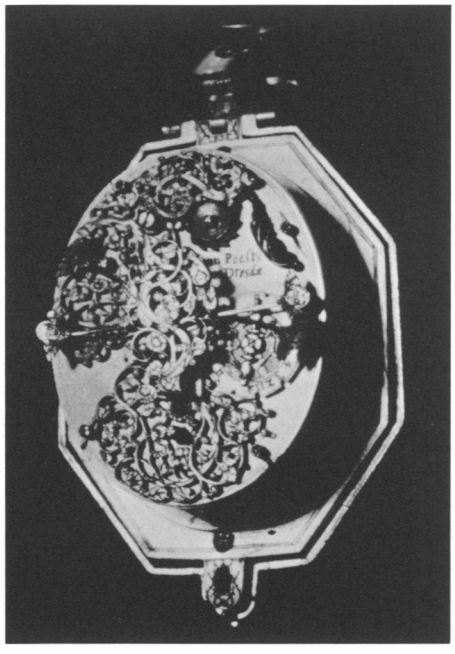
9. Backplate of the watch in Figure 7, showing arms of the cross-beat escapement projecting from behind the engraved and pierced scrolled cock (photo: Vincent)

half of the twentieth, Bürgi's invention seems to have been completely forgotten, and it was not until 1953, when Hans von Bertele studied the movements of some of Bürgi's surviving clocks, that the full signifi-

---

seum, *Katalog der Sammlung für Plastik und Kunstgewerbe* (Vienna, 1966) II, pp. 79–80, no. 322, pl. 55; Maurice, I, pp. 153–154, 162, and II, p. 81, no. 638, figs. 638a,b; Brusa, *L'arte dell'orologeria*, figs. 234–237, p. 415; von Mackensen, pp. 54–55, 57–58, and p. 55, fig. 10, p. 57, fig. 11; and Maurice and Mayr, pp. 92–97, figs. 36–50. The Vienna clock is a modified version of the original invention in which two balance wheels have been substituted for the two characteristic arms beating independently of each other.

9. For a discussion of the modified cross-beat in the treatises of Antoine Thiout and Ferdinand Berthoud, see Maurice, I, p. 152, p. 203, figs. 59, 61, 62.



cance of the cross-beat escapement was recognized.[10] Since that time, a number of clocks with cross-beat escapements have been discovered and published.[11]

To this growing list can be added a watch made in Dresden by Johann Poestdorffer, or Possdorffer, which is in the collection of the Grünes Gewölbe in Dresden (Figures 7–9).[12] The movement, signed on the backplate *Johann Poest-/dorffer Dresda.*, is a superb example of late-Renaissance watchmaking. In addition to indicating and striking the hours, it also shows the phases and age of the moon within its monthly cycle. The octagonal case is made of a single piece of rock crystal, faceted on the exterior and hollowed out to receive the movement. Thus, the highly decorative components of pierced, engraved, and gilded brass which make up the fittings or "furniture" of the backplate of the movement are clearly visible through the case, as is the motion of the two arms of the cross-beat.

The cover of the case is also of rock crystal, mounted in an octagonal frame of silver gilt with an openwork floral design. Beneath the hinged cover is the silver-gilt and enamel dial (Figure 8), the outer chapter ring for the hours, one through twelve, and the inner ring for the age of the moon. An aperture inside the inner ring reveals the day of the month. The moon's phases are shown graphically at the center of the dial. The dial is raised on a pierced frame which creates space under the dial for mounting the bell that strikes the hours. The openwork frames of the dial and cover are both functional and aesthetically pleasing—they allow the bell to be heard, and their pierced and engraved designs rival in quality those of the movement itself, demonstrating the very high order of skill of both the watchmaker and the casemaker. As is usual, the case is unmarked, and nothing is known of its maker.

The most unusual feature of the watch is the cross-beat escapement, apparently much more rarely employed in watches than in clocks; part of it can be seen in the photograph of the backplate of the movement

10. Von Bertele, "Timekeeping," pp. 2–24.

11. Hans von Bertele, "Early Clocks in Denmark," *Horological Journal* 96 (Dec. 1954) pp. 784–796; 97 (Mar. 1955) pp. 172–176; 97 (Apr. 1955) pp. 244–247; idem, "Bürgi," pp. 169–188; idem, "Jost Bürgi's Pupils and Followers," *Connoisseur* 135 (Apr. 1955) pp. 98–105; and Maurice, I, p. 153, and II, p. 62, no. 460, figs. 460a,b; p. 63, no. 461, fig. 461; p. 72, no. 552, figs. 552a,b; p. 73, no 558, fig. 558; p. 83, no. 657, fig. 657; p. 83, no. 658, figs. 658a,b; p. 87, no. 701, figs. 701a,b; and p. 89, no. 725, fig. 725.

12. Dresden, Grünes Gewölbe, inv. no. VI 7a. See Jean Louis Sponsel, *Das Grüne Gewölbe zu Dresden:* II. *Gefässe, Figuren und Uhren* (Leipzig, 1928) p. 206, pl. 28, lower left; Joachim Menzhausen, *Dresdener Kunstkammer und Grünes Gewölbe* (Vienna, 1977) p. 99, pl. 45, upper right; and *The Splendor of Dresden: Five Centuries of Art Collecting*, exh. cat. (Washington/New York/San Francisco, 1978) p. 166, no. 315. Menzhausen noted for the first time in 1977 the existence of the cross-beat escapement inside the watch.

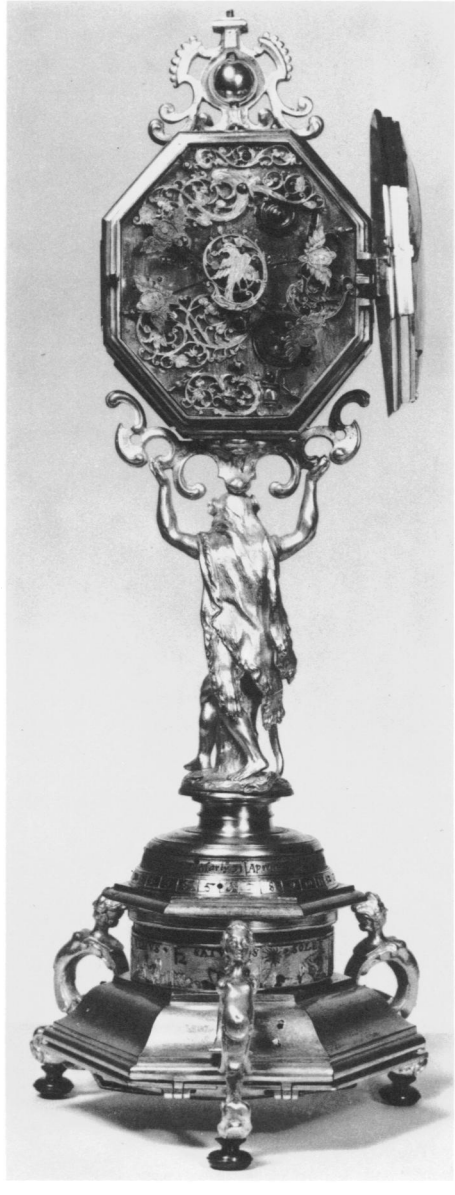
(Figure 9). The escapement consists of two staffs which cross each other under the pierced cock. The ends of each staff carry tiny weights of gilded brass shaped like winged angels' heads. These staffs with their weights are the visible parts of the cross-beat (notice the similarity to the escapement of the Bürgi clock in Figures 4 and 5). This unusual arrangement replaces the balance wheel that one would expect to find in a watch like this.

The exact route of transmission of the invention from Bürgi to other European clockmakers has not been explored.[13] There is evidence to connect Johann Poestdorffer with Prague, and perhaps at the time when Bürgi worked there.[14] This is the inscription on another watch by Poestdorffer in the collection of the Grünes Gewölbe, which reads: *Johan Poesdorffer Fecit, brag* [Prague].[15] Both Poestdorffer watches appear to have been made in the earlier part of the seventeenth century. They may have been the watches mentioned in early seventeenth-century Dresden inventories, but

13. Von Bertele began the attempt in the April 1955 issue of *The Connoisseur* (see note 11).

14. The Bürgi clock with cross-beat escapement in the Dresden Staatlicher Mathematisch-Physikalischer Salon did not enter the electoral collections until 1660 and was, thus, probably not in Dresden at a time early enough to have provided a model for Poestdorffer. See Grötzsch and Karpinski, *Dresden Mathematisch-Physikalischer Salon*, p. 21.

15. Dresden, Grünes Gewölbe, inv. no. VI 7. See Sponsel, *Das Grüne Gewölbe*, p. 206 and pl. 28, lower right; and Menzhausen, *Dresdener Kunstkammer*, p. 99 and pl. 45, upper left.



this cannot be established with any certainty.[16] Neither is there any documentary information concerning their maker. However, there was another Possdorffer or Poestdorffer, named Peter, who is known to have been working as a watchmaker (*Kleinuhrmacher*) in Dresden between 1657 and 1668. Peter Possdorffer was a journeyman (*Geselle*) in 1657.[17] It is possible, therefore, that he was either a son or a close relative of Johann. If Peter were a son, Johann would probably have been working in the first half of the century when we believe the watches to have been made, possibly at first in Prague and later in Dresden.

Although the Poestdorffer watch in Figure 7 is, to date, the only known example of an unmounted watch with a cross-beat escapement, at least two other watches (usually referred to as table clocks—*Tischuhren*—but actually watches set into mounts) also have cross-beat escapements. The two in question are strikingly similar to each other, and both were made in Augsburg in the second quarter of the seventeenth century. One, by Hans Buschmann, is in the Schatzkammer des Deutschen Ordens in Vienna (Figures 10 and 11),[18] and the other, by Hans Christoph Kreitzer, is now in the Museum der Zeitmessung Beyer in Zurich (Figure 12).[19] At present these two watches cannot be linked in any way with the Poestdorffer watch by document, by what is known of their makers, or by the evidence provided by the watches themselves. Yet the obvious similarities between them and the Poestdorffer watch suggest that there must have been some connection.

Although surviving clocks and watches with cross-beat escapements are extremely rare, the divergent locations of their makers indicate that the invention must have been fairly widely known in the seventeenth century. In the last third of the century, with the introduction of the pendulum for the clock and the spring balance for the watch, clockmakers abandoned Bürgi's device. The total eclipse of the cross-beat escapement in the latter part of the eighteenth century through the first half of the twentieth makes reconstruction of its history a challenge.

10. Table clock with cross-beat escapement. The clock has concentric hour and minute hands and a revolving sphere at the top which illustrates the phases of the moon. The case is made of rock crystal, silver (partly enameled), and gilt bronze. Movement signed by Hans Buschmann of Augsburg and probably made before 1632. H. 10¼ in. (26 cm.). Vienna, Schatzkammer des Deutschen Ordens (photo: Schatzkammer des Deutschen Ordens)

11. Table clock in Figure 10 seen from the back, with hinged rock-crystal door open to show the arms of the cross-beat escapement (photo: Schatzkammer des Deutschen Ordens)

12. Table clock with cross-beat escapement. The clock has concentric hour and minute hands and a revolving dial that indicates the age and phases of the moon. A quarter-striking mechanism lies behind the dial, while the separate hour-striking mechanism and a manually operated calendar are in the base. The case is made of rock crystal, silver (partly gilded), and gilt bronze. Movement made by Hans Christoph Kreitzer of Augsburg probably between 1630 and 1640. Zurich, Museum der Zeitmessung Beyer (photo: Theodore Beyer)

16. Inventories of the electoral collections in Dresden were made in 1595, 1610, 1619, and 1640. See Menzhausen, *Dresdener Kunstkammer*, p. 27. For the information concerning the entries for crystal watches in the electoral collections, the authors are indebted to Dr. Menzhausen.

17. Paul Pleissner, *Dresden in der Geschichte der Uhrmacherei* (Dresden, 1924) p. 8.

18. B. F. Dudik, *Kleinodien des deutschen Ritterordens* (Vienna, 1865) p. 165, lists this clock as first appearing among those mentioned in an inventory of the Deutschen Orden Kammerschatz of 1632. Dudik noted that the clock had a double balance (*doppelte Unruhe*). See also Ernst von Basserman-Jordan, *The Book of Old Clocks and Watches*, 4th ed., rev. Hans von Bertele (New York, 1964) figs. 120a,b; Maximilian Bobinger, *Kunstuhrmacher in Alt-Augsburg* (Augsburg, 1969) pp. 86–89, 109; and Maurice, I, pp. 153, 179, and II, p. 62, no. 460, figs. 460a,b. In the chapter by Eva Groiss in Maurice and Mayr (pp. 75–77), Hans Buschmann is documented as having been in Prague working for the Holy Roman Emperor, Ferdinand III (1637–57), in the middle of the seventeenth century, when it is probable that he made the drawing of a clock with a cross-beat escapement shown on p. 76, fig. 30; but the drawing is believed to date from at least twenty years later than the clock in the collection of the Deutschen Orden.

19. Maurice, I, p. 153; II, p. 63, no. 461, fig. 461, and see also p. 53, no. 351. The authors are indebted to Theodore Beyer for a more detailed description of the clock.

Appendix

JOST BÜRGI, CLOCKMAKER

Jost Bürgi was appointed clockmaker to the landgrave of Hesse, Wilhelm IV (1567–92), on July 25, 1579, and worked at the landgrave's court in Kassel. In 1592, he escorted one of his works, a clockwork-driven celestial globe, from the court at Kassel to the court of the Holy Roman Emperor in Prague. While Bürgi was in Prague Wilhelm died, but Wilhelm's successor, Landgrave Moritz (1592–1627), reappointed him, and Bürgi returned to Kassel where he continued to make both clocks and instruments of remarkable originality and technical perfection. On December 23, 1604, he was appointed clockmaker (*Kammeruhrmacher*) to Emperor Rudolf II (1576–1612), and received a patent of nobility on February 3, 1611. Bürgi remained Imperial Clockmaker until 1631. He died in Kassel the following year. For Bürgi at the court of Wilhelm, see Defossez, pp. 54–55, 59–60; Lloyd, pp. 61–63; Leopold and Pechstein, pp. 15–17; Bruce T. Moran, "Princes, Machines and the Valuation of Precision in the 16th Century," *Sudhoffs Archiv* 61 (1977) pp. 214–217, 222–225; von Mackensen, pp. 21–41; and Maurice and Mayr, pp. 87–89. For the astronomical interests of Landgrave Wilhelm IV, see the bibliography included by von Mackensen, p. 40.

Bürgi's work at the court of Emperor Rudolf II is discussed by C. Alhard von Drach, "Jost Bürgi, Kammeruhrmacher Kaisers Rudolf II," *Jahrbuch der Kunsthistorischen Sammlungen des Allerhöchsten Kaiserhauses* 15 (1894) pp. 15–44; by Defossez, pp. 57–59; in the chapter by Joseph Fremersdorf in Leopold and Pechstein, pp. 101–105; and by von Mackensen, pp. 31–34. See also Alphons Lhotsky, *Geschichte der Sammlungen, Festschrift des Kunsthistorischen Museums in Wien, 1841–1941* (Vienna, 1941–45) II, pt. 1, pp. 257–258; R. J. W. Evans, *Rudolph II and His World: A Study in Intellectual History, 1576–1612* (Oxford, 1973) pp. 187–188; and Rotraud Bauer and Herbert Haupt, eds., "Die Kunstkammer Kaiser Rudolfs II in Prag, ein Inventar aus den Jahren 1607–1611," *Jahrbuch der Kunsthistorischen Sammlungen in Wien* 72 (1976), p. 110, no. 2138, pp. 111–112, no. 2163, p. 118, no. 2289, p. 130, no. 2569.

Documents concerning Bürgi's life were first collected and published by von Drach, "Jost Bürgi," pp. 15–44. See also the chapter by Armin Müller in Leopold and Pechstein, pp. 107–113. For discussions of Bürgi's work see also Defossez, pp. 52–71; Erwin Voellmy, *Jost Bürgi und die Logarithmen* (Basel, 1948); Pierre Mesnage, "Un Chef-d'oeuvre de Jost Bürgi au Conservatoire des Arts et Métiers de Paris," *Journal Suisse d'Horologerie et de Bijouterie* (May–June 1949) pp. 198–207; von Bertele, "Timekeeping," pp. 3–9 and 18–23; idem, "Bürgi," pp. 169–188; Lloyd, pp. 61–69; Hans von Bertele, *Globes and Spheres* (Lausanne, 1961) pp. 15–17, 40–45, and 54–55; Maurice, I, pp. 146–158, 161–163, and II, p. 44, nos. 253–255, p. 76, no. 581, p. 81, nos. 635–638, and figs. 253, 254a–c, 255a,b, 581a–c, 635a,b, 636a,b, 637a,b, 638a,b; Leopold and Pechstein, pp. 22–80; von Mackensen, pp. 32–33, 46–60, 105–110, 128–140, and the chapters by Hans von Bertele and John H. Leopold included in von Mackensen; and Maurice and Mayr, pp. 87–102. Defossez did not recognize the fact that Bürgi's escapement was not an early prototype of the pendulum.

The earliest known mention of Bürgi's newly invented escapement appears in a manuscript in the Landesbibliothek in Kassel by the astronomer Christoph Rothmann, who was working at Kassel between 1584 and 1590. The manuscript (Ms. astron. 5, no. 7) is undated, but von Bertele ("Timekeeping," p. 4) believes it to have been written about 1585. There is some disagreement, however, about the date of the earliest surviving clocks with cross-beat escapements made by Bürgi. One, now in the Staatliches Landesmuseum in Kassel, was dated not later than 1600 by von Bertele ("Timekeeping," p. 20) on the grounds that its location in Kassel would indicate that it was made before Bürgi went to Prague. So far as is known, however, Bürgi did not take up permanent residence in Prague until 1604. Maurice (I, p. 154) disagrees with the early dating of this clock and another, now in the Staatlicher Mathematisch-Physikalischer Salon in Dresden, on the grounds that both have especially large great wheels, a technical feature typical of clocks known to have been made in Prague. Maurice argues that they were, therefore, made in Prague when Bürgi settled there. It should be noted, however, that Tycho Brahe's Hven clocks were described in his *Astronomiae Instauratae Mechanica*, which was published in Wandsbek in 1598 but which recorded instruments in use at least as early as 1587. Brahe's clocks also had large great wheels, the largest, in fact, having 1,200 teeth, and Brahe's clocks are not known to have been made in Prague. For

further discussion see Lloyd, p. 63. The most recent dating of the experimental clock in Kassel shown in Figures 1 and 2 (about 1595–1600) and the experimental clock in Dresden shown in Figures 3–5 (about 1625) appears in von Mackensen, p. 137, no. 20, and pl. 50, fig. 6. No evidence is given for the dating of the Dresden clock.

Although admitting that it was unlikely that proof of their authorship would ever be found, Lloyd (p. 63) believed that the lost clocks illustrated in Brahe's *Astronomiae Instauratae Mechanica*, showing the astronomer in his observatory at Hven, had all the characteristics known to have been incorporated in Bürgi's clocks. Von Bertele, however, was very much more cautious in attributing these clocks to Bürgi ("Timekeeping," pp. 4–5). It is probably not true that Bürgi made the clocks at Hven. On the other hand, in view of the fact that Brahe and Kepler were working for the emperor in Prague during the same period that Bürgi was there, first as a visitor and then as Imperial Clockmaker, it seems unlikely that Bürgi's extraordinary skills would have been ignored. See von Bertele, "Timekeeping," p. 4, and Ernest L. Edwardes, *Weight-driven Chamber Clocks of the Middle Ages and Renaissance* (Altrincham, 1965) pp. 90–91, n. 1. Such a supposition is certainly strengthened by the fact of Kepler's known admiration for Bürgi's work. See Rudolph Wolf, *Johannes Keppler und Jost Bürgi* (Zurich, 1872); Max Caspar, *Kepler*, trans. C. Doris Hellman (London, 1959) pp. 164–165; Grötzsch, "Die Kreuzschlaguhr und Globusuhr von Jost Bürgi," pp. 246–247; and Leopold and Pechstein, p. 102.

FREQUENTLY CITED SOURCES

Defossez—L. Defossez, *Les Savants du XVIIe siècle et la mesure du temps* (Lausanne, 1946)

Leopold and Pechstein—J. K. Leopold and K. Pechstein, *Der kleine Himmelsglobus, 1594, von Jost Bürgi* (Lucerne, 1977)

Lloyd—H. Alan Lloyd, *Some Outstanding Clocks over Seven Hundred Years, 1250–1950* (London, 1958)

Maurice—Klaus Maurice, *Die deutsche Räderuhr* (Munich, 1976) 2 vols.

Maurice and Mayr—Klaus Maurice and Otto Mayr, eds., *The Clockwerk Universe: German Clocks and Automata 1550–1650* (New York, 1980)

Von Bertele, "Bürgi"—Hans von Bertele, "Jost Bürgis Beitrag zur Formentwicklung der Uhren," *Jahrbuch der Kunsthistorischen Sammlungen in Wien* 51 (1955) pp. 169–188

Von Bertele, "Timekeeping"—Hans von Bertele, "Precision Timekeeping in the pre-Huygens Era," *Horological Journal* (December 1953) pp. 2–24

Von Mackensen—Ludolf von Mackensen, with contributions by Hans von Bertele and John H. Leopold, *Die erste Sternwarte Europas mit ihren Instrumenten und Uhren, 400 Jahr Jost Bürgi in Kassel* (Munich, 1979)