

Automating time determination: The Photographic Zenith Tube (PZT) of the Neuchatel Observatory*

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Introduction

Accurate time determination is a practice that has acquired great social, economic and scientific importance since the modern period.¹ Astronomy and observatories played a major role in this practice until the use of atomic time. During the 19th and early 20th centuries, meridian circles were the most accurate instruments for determining time.² In the mid-twentieth century, new methods of time determination were introduced with new scientific instruments such as the Photographic Zenith Tube (PZT).³ The material turn in humanities and social science has fostered interest in the materiality of scientific instruments. However, the material culture of the mid-twentieth century has attracted less attention from historians of scientific instruments.⁴ This is particularly true of the PZTs, whose study is still relatively incomplete. The instruments that are still preserved are usually kept in museum

storerooms or are forgotten in observatories.⁵ One of the objectives of this article is to draw attention to these artefacts, starting with the case of the PZT of the Neuchâtel Observatory.

Since its founding in 1858, the Neuchâtel Observatory (hereafter the Observatory) has dedicated itself to time determination and it to remain at the forefront of the practice from a methodological and instrumental point of view.⁶ In our study devoted to the evolution of the operating chains, we follow the way in which the Observatory seeks to control and then eliminate the influence of the human factor (personal equation, see note 10). We define the term operating chain as the set of operations that end up on the time data (Fig. 1).⁷

To better understand this instrument, a collaboration to carry out a material study of the instrument was set up between a conservator-restorer, the Université de Neuchâtel

(UNINE), the Haute Ecole Arc conservation-restoration (HE-Arc CR) and the MIH.⁸ In addition, a historical analysis was carried out based on the archives kept at the Archives de l'État de Neuchâtel (AEN) and at the MIH's 'L'Homme et le Temps' study center. Finally, in order to understand the evolution of this technical object, we were able to access various archives in England thanks to a grant from the SIS. We had the opportunity to consult the Tyne & Wear Archives of the Discovery Museum in Newcastle upon Tyne, which holds the collections of the firm Grubb & Parsons, the Archives of the Royal Observatory in Greenwich at the Cambridge Library and the Greenwich Observatory repository.⁹

The aim of this article is to better understand the place of the PZT in the evolution of twentieth-century astronomical instrumentation (Fig. 2). This instrument consists of a vertical tube placed above a mercury bath that directs

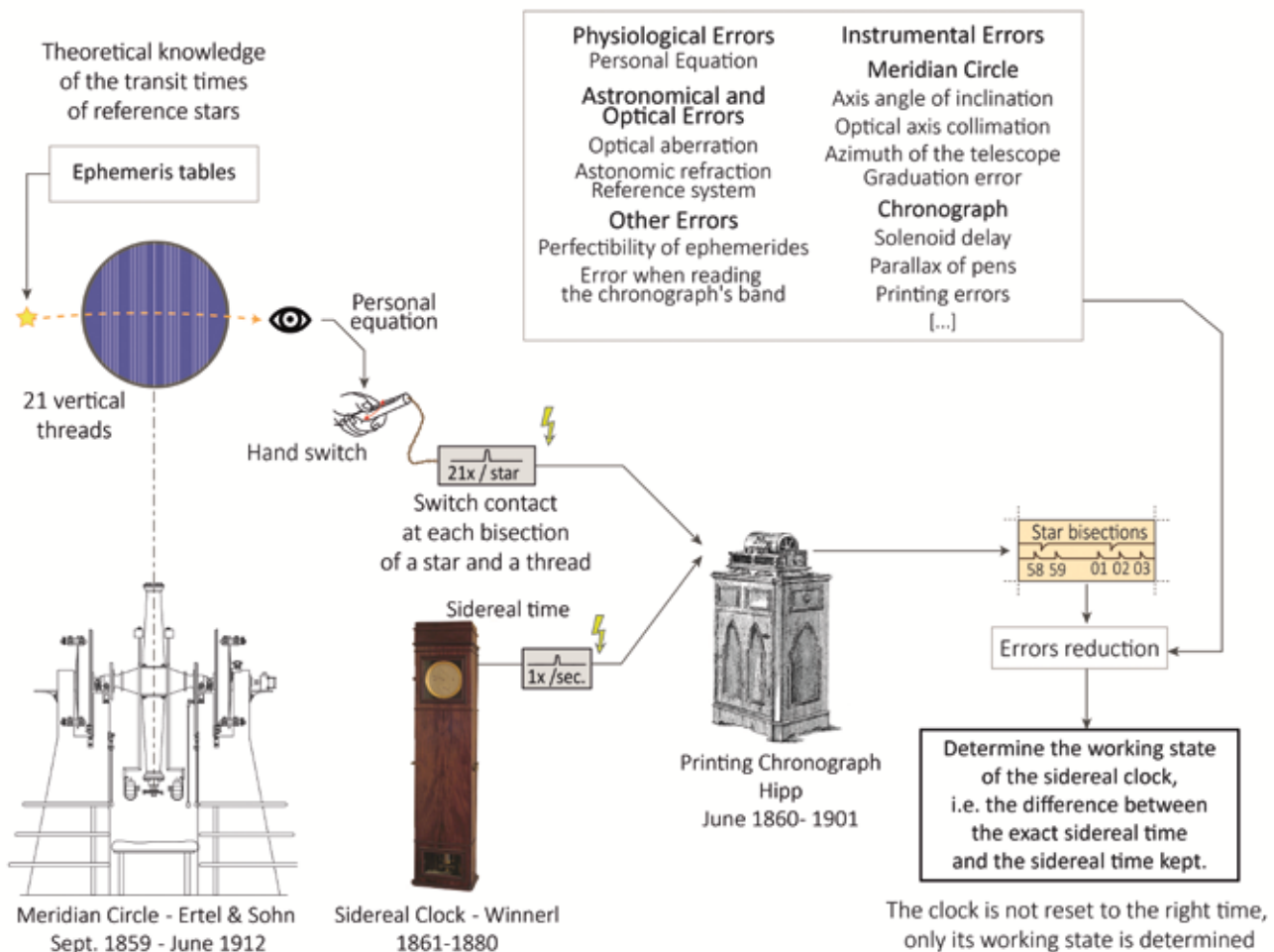
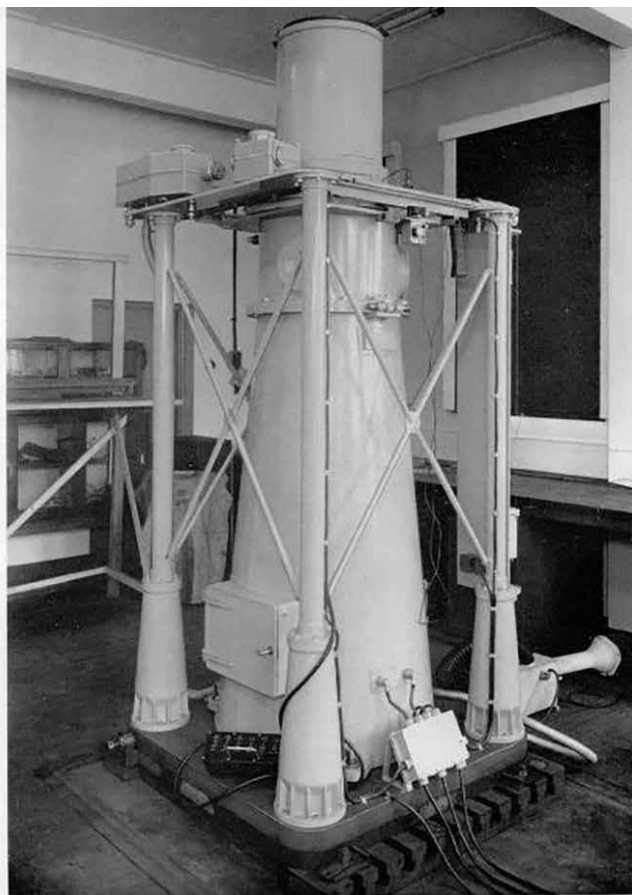


Fig. 1 Operating chain for time determination at the Neuchâtel Observatory in 1861. Diagram by Julien Gressot and Romain Jeanneret. © Gressot & jeanneret.



10 INCH PHOTO ZENITH TUBE, TYPE 1A

This telescope is the same in principle as the Greenwich P.Z.T. but the design has been simplified in many ways by some sacrifice in convenience with little loss of precision. The telescope was built for the Neuchâtel Observatory where it has been in satisfactory service since 1954. The access door to the mercury trough is seen at the foot of the conical tube; the photograph was taken in the mechanical test laboratory at the Works.

the first Astronomer Royal of the Greenwich Observatory, developed an instrument known as the Well Telescope.¹¹ The innovations of George Bidell Airy (1801–1892),¹² the sixth Astronomer Royal of Greenwich Observatory, with his Reflex Zenith Tube (RZT, 1851), were a milestone, although they were not followed up at the time due to disappointing results.¹³ However, research into the oscillating motion of the Earth's axis changed the situation and led to renewed interest in Zenith instruments at the end of the 19th century. This earth movement, now known as the Chandler Wobble, was observed by the German astronomer Friedrich Küstner (1856–1936) in Berlin and by the American astronomer Seth Carlo Chandler (1846–1913) in the United States at about the same time in the late 1880s.¹⁴ The American astronomer was aware of the data produced with Airy's instrument and commented that 'nothing in modern astronomy is so melancholy a record of futile result from a promising project [...] pursued with admirable perseverance under disheartening circumstances, as the history of the Greenwich Reflex Zenith Tube'.¹⁵ Once this movement was better known, the calculations of the RZT observations were taken up again considering this variation, demonstrating the great precision of the instrument. Thus, instrumental practice preceded scientific theory, which, once known, allowed the correct use of the observational results.

In 1909, after several instrumental developments which are beyond the scope of this paper, a grant was awarded by the International Geodetic Association to install a photographic reflex zenith tube at the Gaithersburg station.¹⁶ This instrument combines photography with the principles of zenith instruments. This station (International Latitude Observatory) worked in cooperation with other observatories on the same latitude: Carloforte in Italy, Mizusawa in Japan, Tschardjui in Russia and Ukiah in California to study the Chandler Wobble. The instrument, built by William Gaertner & Co, a Chicago-based manufacturer of scientific instruments, was delivered to Gaithersburg in 1911. It was then placed at the United States Naval Observatory (USNO) in Washington in 1915, where it was used to study latitude variation.¹⁷ In the early 1920s, John Willis (1901–1979), an astronomer working at the USNO, suggested using the PZT for time determination and modified the instrument accordingly. From 1934 onwards, a continuous series of time determinations was carried out, demonstrating the high instrument's potential.¹⁸ Indeed, this technical innovation improved the accuracy of the data by a factor of ten, allowing the optical means to keep pace with the advances made by quartz astronomical clocks.¹⁹

Fig. 2 View of PZT 1A at Grubb & Parsons, Grubb & Parsons, Astronomical Instruments, publication n°14-A.I.48, 1957, p.11.

light onto a photographic plate that records the passage of the stars at the zenith. This scientific instrument improves the accuracy of astronomical time measurement by eliminating several types of instrumental errors (azimuth, collimation, trunnion error, bending error, ...) and the personal equation (reaction time and physiological delay of the observer) using photography¹⁰. In addition, the instrument is automated to allow it to operate without human intervention during the observation cycle. The aim here is to see how the elimination of the human factor takes place and the consequences on the relationship between the astronomer and his scientific apparatus. It is also about better identifying the decision-making process leading to a change in technology and selecting a technical innovation in a small scientific institution in the mid-20th century.

In this article, we will first outline the histori-

cal development of zenith instruments leading to the PZT without trying to be exhaustive. It is only a question here of giving some milestones, before observing the development of the instrument at the Observatory.

Historical Development

PZTs are the result of a long technical evolution. To better understand its emergence, we will briefly summarise some of the stages in the development of zenith observation methods. This method consists of observing the passage of a star on the meridian line - the north-south axis - in a reduced sector of the sky, i.e. at the zenith. The reduction of the field of observation to the zenith makes it possible to limit instrumental errors, because there is less physical strain on a vertical instrument than on a horizontal one. The first known experiments of this type date back to 1676, when John Flamsteed (1646–1719),

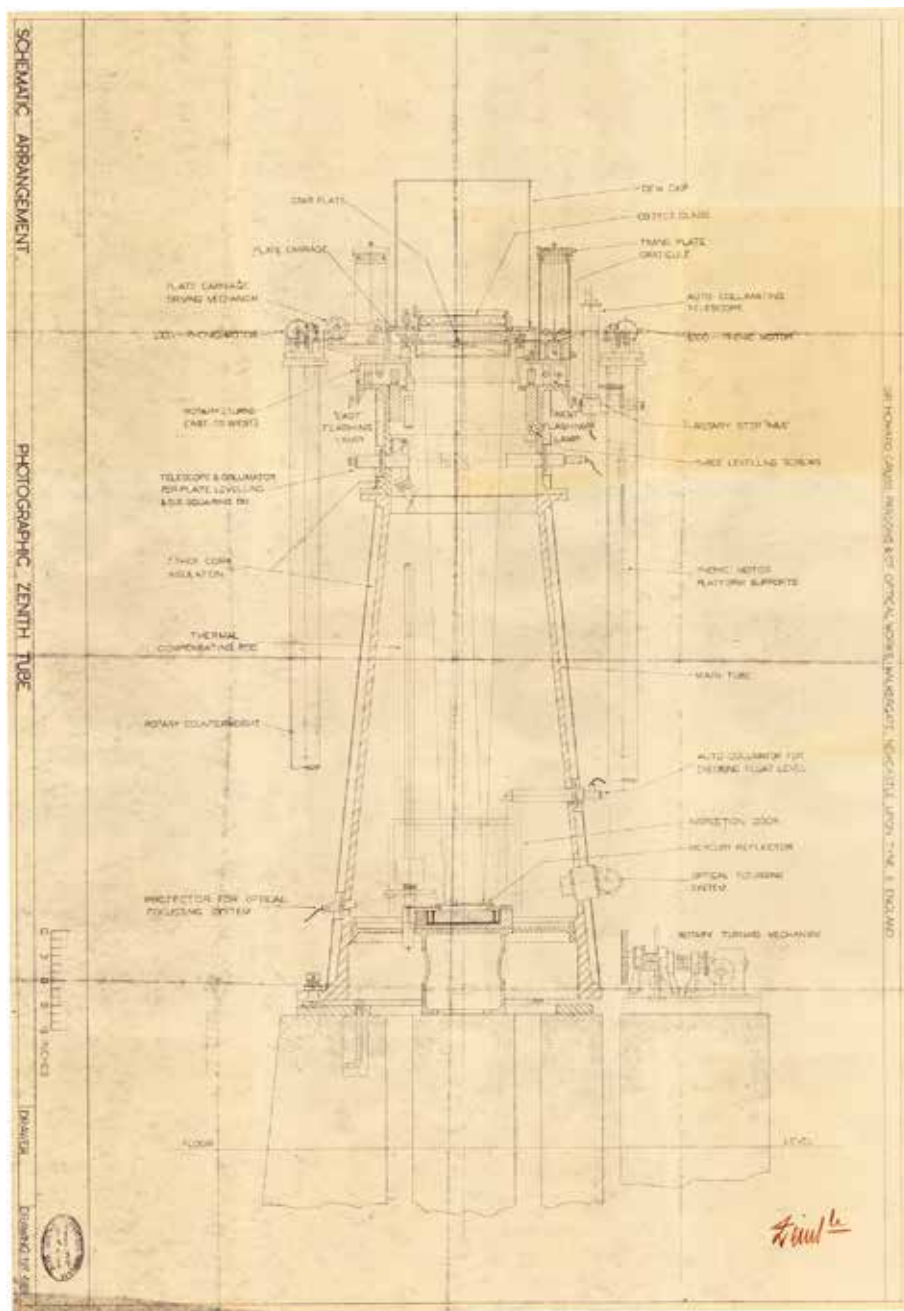


Fig. 3 Drawing 4181 - Sectional view of PZT 1A, *Plans de la lunette zénithale PZT, "L'Homme et le Temps"*. ©MIH.

In 1946, the PZT aroused the interest of the International Astronomical Union (IUA), whose Commission 19, on latitude variations, pointed out ‘the great interest that there would be in establishing photographic zenith tubes at different points on the earth, not only to improve knowledge of the movement of the pole, but also to collect indispensable data relating to the movements of the pole itself in declination, as well as data useful for the determination of the constants of the solar system’.²⁰ The PZT is therefore considered to be of interest mainly for its scientific vocation, rather than for its practical purpose. However, it is the combination of the two aspects that interests the Greenwich and Neuchâtel observatories, as we shall see.

The Order

In the mid-20th century, several observatories (Greenwich, Brussels, Mount Stromlo, Cape of Good Hope, Neuchâtel, etc.) sought to equip themselves with PZTs. The Neuchâtel Observatory was founded in 1858 with two main objectives.²¹ First, it was to certify the quality of chronometers, and secondly to transmit time signal to the watchmaking localities. After the successive use of two meridian circles, the Observatory seeks to obtain a PZT²².

After the 1946 IUA meeting, Edmond Guyot (1900–1963), third director of the Observatory, proposed to install a PZT. The director argued that ‘the Neuchâtel Observatory,

which has always endeavoured to maintain its time service at the height of modern requirements, cannot ignore this new progress in the field which is dear to it’.²³ For the director, it was therefore a question of maintaining the position of the Observatory at the forefront of time measuring practices. Two advantages of the PZT were highlighted by Guyot. Firstly, the improvement in the accuracy of time determination and secondly the possibility of participating in an international research programme with the study of latitude variations.²⁴ In August 1947, the Neuchâtel Observatory contacted the USNO.²⁵ In response to Neuchâtel’s requests, the USNO indicated that the instrument developed by the American institution is a prototype manufactured in their workshops and that it was not marketable.²⁶ The Observatory then enquired about possible alternatives and turned to the company Grubb & Parsons, based in Newcastle-upon-Tyne. Since 1943, this factory had been developing a PZT in close collaboration with the Greenwich Observatory based on the USNO’s work.²⁷ For Greenwich, the main aim was to improve the quality of time determination, as indicated by the astronomer royal Harry Spencer Jones (1890–1960):

‘The provision of a 10-inch photographic zenith telescope is required in order to increase the accuracy of time determinations. This is a necessary step in the attainment of a high precision in the radio time-signals distributed from the Royal Observatory. A great step forward has been made in this direction since the beginning of the war by the use of quartz clocks for prediction purposes, the careful control of line lags, the elimination of mechanical relays etc. It is the errors inherent in time determinations by visual observations with a transit instrument that at present impose the limit on the accuracy that is attainable.’²⁸ Despite the difficulties in obtaining clear answers from the USNO, the Neuchâtel executive authorities submitted a report in March 1948 to the Grand Council to purchase a PZT.²⁹ To justify this haste, Jean Humbert (1899–1953), the State Councilor in charge of the dossier, indicated that ‘we could not wait indefinitely, as we would be the last to arrive’.³⁰ This notion of delay is regularly used to defend the acquisition of the PZT. Thus, the report added that ‘progress continues to be made and we must strive to move forward so as not to be left behind. The way to do this is to modernize and complement existing facilities as circumstances warrant’.³¹ Investing in an innovation such as the PZT is therefore more than just a technical issue and involves the political and economic spheres. Indeed, through the Observatory’s instrumentation, it is a question of demonstrating the superiority of the Swiss watchmaking industry. The Neuchâtel PZT therefore also serves as



Fig. 4. The PZT of the Neuchâtel Observatory in its context of use. Placed in a hut with two floors. We see here the upper part of the instrument with the rotary and all the devices allowing the photographic recording while the lower part has a mercury bath and the cooling systems of the tube of the instrument. FP-NEG-2859-02.tif © Bibliothèque de la Ville de La Chaux-de-Fonds, Département audiovisuel, Fonds Fernand Perret.

an example for maintaining the reputation and promoting Swiss chronometers, whose accuracy is certified by the PZT time.

On 13 May 1949, George Sisson, director of the Grubb & Parsons telescope factory, sent Edmond Guyot a quotation with two possible models of PZT. The first was for £28,000 for a 'Greenwich type' telescope and the second for £22,000 for a simplified telescope.³² The letter also stated that Grubb & Parsons considered Greenwich's intentions 'somewhat complicated'.³³ These sums exceeded the financial possibilities of the Neuchâtel Observatory, which sought to reduce the price. To seek financial support, the institution turned to the watch industry, which agreed to participate in sponsoring the PZT.³⁴ Meanwhile,

discussions continued with the English manufacturer who proposed a model II as a new alternative, intended for the Mount Stromlo Observatory.³⁵ On 6 February 1950, Grubb & Parsons explained to Greenwich that Model II was similar to the Washington's PZT and represented their vision of an instrument made in the 'simplest of ways'.³⁶ The Greenwich Observatory questioned the difference in price between Model I (£27,000) and Model II (£12,000).³⁷ The Type II simplifications were deemed 'drastic' by Dr Perfect and an agreement between Grubb & Parsons and the Greenwich Observatory was required before new models could be proposed.³⁸ Indeed, George Sisson conceded the latter point as Perfect stated that 'as the "father of the PZT" the Astronomer Royal [Harold Spencer Jones] is not uninterested [in its various developments]'.³⁹ Thus, Greenwich participated in the development of the PZT in return for a fee on the sale of each instrument of £1000 on the Type I and £500 on the other models.⁴⁰

In June 1950, Grubb & Parsons submitted a new proposal to the Observatory with a Type 1A PZT (Fig. 3); a compromise between Model I and II, in response to Greenwich's criticism that Model II removed many essential features.⁴¹ Greenwich found it essential to

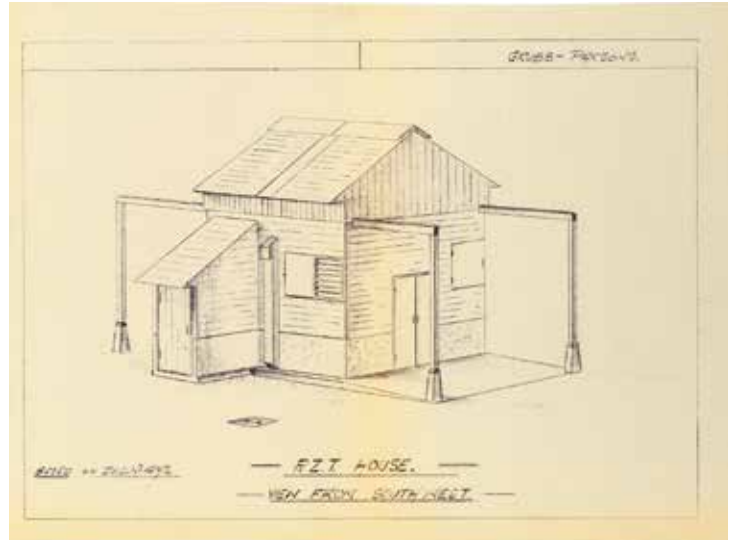


Fig. 5 Drawing 4976 of the PZT hut, (view from the southwest), "L'Homme et le Temps", © MIH.

use a photographic chronograph, an autocollimator rather than microscopes to determine the position of the rotary, and a different connection between the carriage and the plate. Other features recommended but considered less important were a wider shutter and a different level. Grubb & Parsons deplored the fact that they had to develop three models of PZT and stated that 'It is unfortunate that we should be faced with the prospect of making three different types of P.Z.T., but of course astronomers are all men of rugged individuality where telescopes are concerned'.⁴² The objective of Grubb & Parsons and Greenwich was therefore to achieve mass production of PZTs. However, the very high objectives of the British Observatory did not allow adaptation to other local contexts. Thus, this point demonstrates that in the mid-20th century, the construction and design of large-scale astronomical instruments were always shaped by the local context.

On 21 November 1950, the order for a PZT 1A (see Fig. 2) was placed by the Observatory for an amount rising to 13,700 pounds sterling, or about 152,000 Swiss francs.⁴³ It took more than three years for the Observatory to obtain its instrument. These long delays illustrate the fact that the PZT was still an experimental instrument under development. On 8 March 1954, Broadbent, an engineer from Grubb & Parsons, went to Neuchâtel to assemble the PZT, which was commissioned on 3 April 1954.⁴⁴ In May 1954, after a review with George Sisson, Edmond Guyot announced that the PZT was now ready for proper use.⁴⁵ However, it took about two more years to calibrate the instrument and for it to be considered satisfactory.⁴⁶ In the end, three instruments were built in parallel

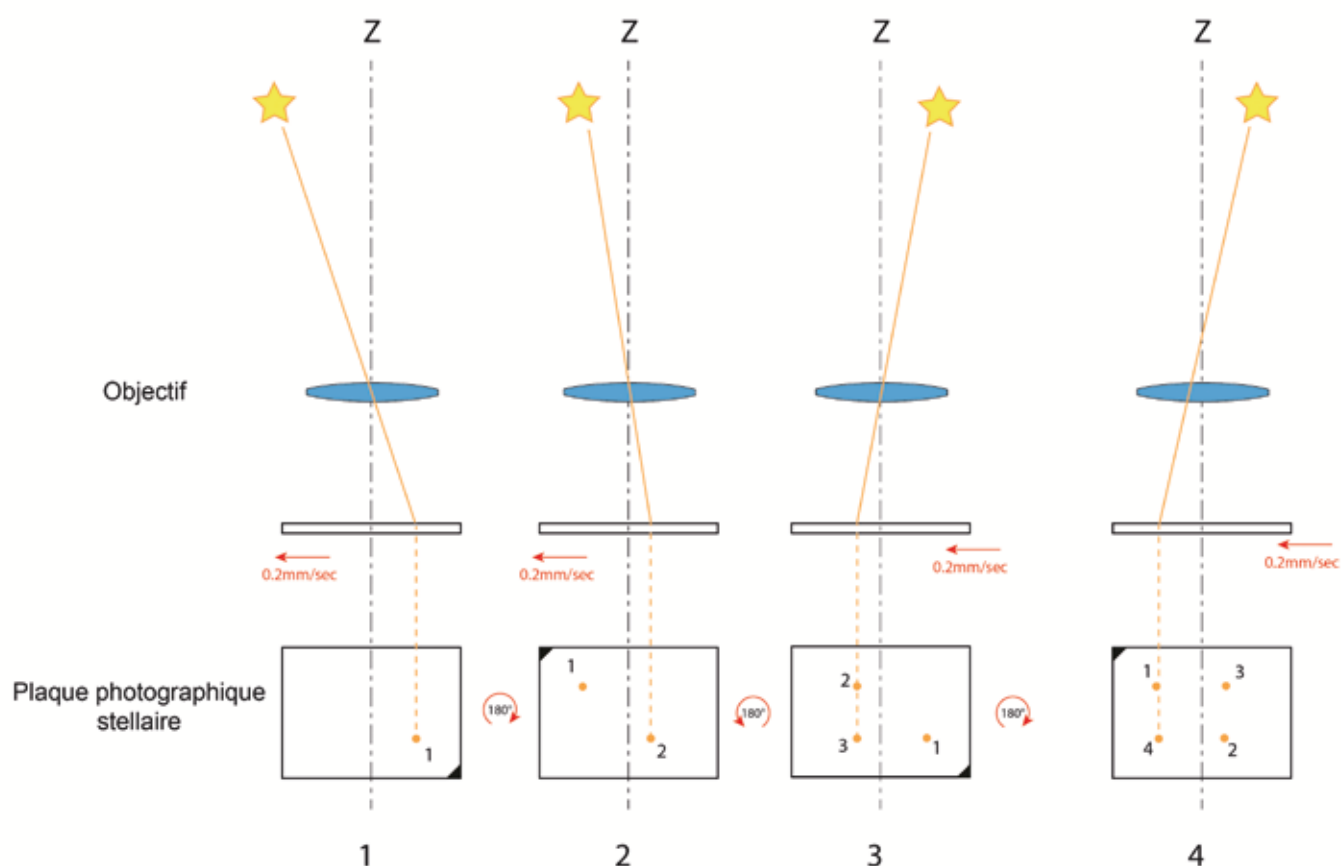


Fig. 6 Print operation on the photographic plate. Diagram by Romain Jeanneret © Gressot & jeanneret.

by Grubb & Parsons: the Neuchâtel model 1A (1954), the Greenwich model (1955) and the Mount Stromlo model (1956).⁴⁷ After this batch of PZTs, Grubb & Parsons abandoned this manufacture and their wish to develop a marketable model failed.

The PZT In Use

The object (see Figs 4 and 5) is now in pieces, preserved in several MIH depots with a series of accessories distributed in boxes. Some of the devices have disappeared, notably certain cables, which makes it difficult to understand the object. To grasp the modalities and the evolution of time determination at the Observatory, we carried out operating chains, a tool of synthesis of the various operations leading at the end of the chain to the exact time (See Fig. 1 for the example of the operating chain of 1861).

The basic principle of PZT is the use of photography to record the passage of a star at zenith on a photographic plate. The light from the star is captured by a tube directed at the zenith, then reflected by a mercury bath before reaching a photosensitive plate oriented towards the nadir (Fig. 6). The star is photographed twice before the zenith transit and

twice afterwards, forming the four vertices of a rectangle on a stellar photographic plate.⁴⁸ In 1954, Guyot described the operation of the PZT as follows:

‘Its objective has an aperture of 25cm and a focal length of 3.43m. The main tube of the instrument supports at its upper end a part that can turn 180° around a vertical axis: the rotary. The objective and the [stellar photographic] plate are integral with the rotary and turn around at the same time. The device, which works like a robot, is designed in such a way that a single press of a button triggers the automatic cycle of exposures. For each star, four 21-second exposures are made, separated by an interval of 11 seconds, during which the rotary rotates 180° each time. As far as possible, the times of the 4 exposures are symmetrical in pairs with respect to the time of passage through the meridian.’⁴⁹

Thus, according to Guyot, the instrument works like a ‘robot’. From then on, it is sufficient to switch on the machine at the appropriate moment and the act of observation is carried out automatically, without direct human intervention. We are witnessing here

the transition from an active observer to an operator in charge of preparing the instrument but without a direct role in the observation process.

To ensure that the image is taken in sharp focus, the stellar photographic plate is driven by a carriage that follows the movement of the star.⁵⁰ During the measuring cycle, another photographic plate, the so-called chronographic plate, records the position of the carriage every two seconds. By comparing the two plates with a measuring device, it is possible to determine the operating state of a quartz clock. The predictive calculations of the movements of the stars are contained in the ephemerides or star catalogues and allow the quartz clock to be checked.⁵¹

Increased Workload - Outsourcing of Calculations

The Observatory is a small institution with a small staff. However, the PZT leads to an increase in work time with the preparation of the instruments on the one hand and the measurements and calculations for error reduction on the other. From 1954 onwards, comparisons of stellar and chronographic photographic plates were first carried out with a Zeiss

stereocomparator before a Hauser P-324 was used from 1957 onwards.⁵² These devices are used to measure the coordinates on the plates precisely with the help of a binocular microscope. The measurements are then cleaned of errors (environmental and instrumental) and statistical operations carried out to obtain time data. Due to a reduced staff, these time-consuming calculations are outsourced. For this purpose, the Observatory first used the IBM centre in Mannheim, then the Lausanne computing centre.⁵³ From February 1968 onwards, the reduction calculations were carried out at the University of Neuchâtel's computing centre on an IBM 1130 computer.⁵⁴ Thus, the PZT allows the networking of the Observatory with the computing centres that were developing at that time.⁵⁵ The ephemeris catalogues, used for the observations at the meridian circle, could not be used with the PZT - the observation being done in different zones of the sky. In consequence, the Observatory asked other scientific establishments to calculate the positions of usable stars (Greenwich, then Brussels and finally the Rechen-Institut of Heidelberg). Compared to the meridian circles in use until 1959, the main differences were in the replacement of the mechanical sidereal clock by a quartz clock, the use of photography and the observation reduced to the zenith. Apart from these adaptations, the principle of time determination remained the same. Thanks to the reduction of certain errors, the accuracy of the data obtained with the PZT was initially improved by a factor of ten, and reached the thousandth of a second. However, new sources of error have arisen and are evaluated in a study carried out by Walter Schuler, a collaborator of the Observatory.⁵⁶ Indeed, the exposure of light points on a photosensitive gelatin, its development and the measurement of their positions introduce new types of errors. The expansion of the glass plate between the night exposure and the measurement in a temperature-controlled room or the development and drying of the gelatin cause deformations in the periphery of the plate.

To reduce the manpower requirements, the observation cycle was fully automated in 1959. From then on, it was no longer necessary to have a person on site all night, but only to prepare the instrument.⁵⁷ Thus, not only is the act of observation eliminated, but the human being is no longer directly present at the time of data entry. However, throughout its existence a member of the Observatory staff has been attached to overseeing the PZT, devoting most of his time to it. The changes of the duties of this individual demonstrate that the automation of the PZT, shifted the tasks from the act of observation to the preparation of the machine and error reduction calculations instead of reducing the workload.

Atomic time thwarted the destiny of the Neuchâtel PZT with the abandonment of astronomical time determination. However, the PZT was still used until 1982 for the international research programme on latitude variations centered on the Mizusawa Observatory.⁵⁸ In 1982, the Observatory decided to discontinue the service of the PZT, judging that it was no longer necessary either for the institution or for the study of latitude variations. From then on, it was dismantled before being given to the MIH, demonstrating a desire to make the scientific instrument a heritage item, which is now kept in the museum's reserves.

Conclusion

The choice to use a technical innovation at the cutting edge of time measurement is a matter of technical, scientific, economic, and political considerations. The implementation of a PZT involved the interests of the Neuchâtel watchmaking industry, which wished to demonstrate its superiority in terms of precision. Meanwhile, the political authorities wanted to provide a high-quality tool to support the flagship industry of the canton of Neuchâtel.

Automation and photography were seen as ways of making time determination more objective to have more accurate time. Despite the promising beginnings, the PZT has not become widespread. Several institutions that had planned to acquire such an instrument abandoned their plans due to the high price of the instrument and doubts over the scientific necessity of such an investment. Grubb & Parsons developed only three instruments, all of which were of different models, and did not manage to transform its production into a generic instrument. Thus, the use of the PZT was ultimately limited by the gradual abandonment of astronomical time, by high cost, by the presence of new error typologies and by significant manpower constraints.

However, the PZT allowed the Observatory to study its quartz clock battery and to maintain the know-how and practice in the field of time measurement until the transition of the institution into a time-frequency laboratory. Indeed, other institutions that stopped using meridian instruments like the Geneva Observatory have simply lost this field of competence and had to reorient their activities. The strategy chosen by the Observatory has thus allowed it to remain a reference in the field of time measurement.

This article only aimed at outlining some salient aspects of the PZT to draw attention to its scientific interest and its place in 20th-century astronomical instrumentation. Further research and studies will be required to understand in detail how the instrument worked, and to preserve this 20th-century astronomical heritage with the view of presenting it to the

public.

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Keywords: *Time Determination, Photographic Zenith Tube (PZT), Neuchâtel Observatory, Time Automation, Grubb & Parsons*

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20. J.H. Oort, ed., *Transactions of the International Astronomical Union Seventh General Assembly held at Zürich august 11 to august 18, 1948*, Vol. 7, (Cambridge: Cambridge University Press, 1950), p. 64.

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22. Julien Gressot & Romain Jeanneret, 'Construire le cercle méridien Ertel und Sohn de l'Observatoire de Neuchâtel (1858–1861):

entre besoins scientifiques, possibilités techniques et contraintes économique-politiques', Daniel Belteki, Jean Davoigneau, Julien Gressot & Jeanson Loïc, eds., 'Circles of Precision: Meridian Circles as Assemblages During the 19th and 20th Centuries', *Cahiers François-Viète*, (2023), III.14 [accepted].

23. Edmond Guyot, 'Une nouvelle méthode de détermination de l'heure avec la lunette zénithale', *Journal Suisse d'Horlogerie*. (1946), Nr 7-8, pp. 333-335, p. 334.

24. *Id.*

25. Letter from the Department of Public Economy to Jean Humbert, 12 August 1947, AEN, 1EP-364.

26. Letter from Edmond Guyot to Jean Humbert, 2 July 1947, AEN, 1EP-364, lunette zénithale photographique 1947-1955. On 10 July, Humbert wrote to the Foreign Affairs Division to intercede through the legation in Washington: Jean Humbert au département politique fédéral, Division des affaires étrangères, 10 juillet 1947, AEN, 1EP-364, lunette zénithale photographique 1947-1955.

27. Since 1943, the Greenwich Observatory has been developing a PZT with Grubb & Parsons. Correspondence relating to these discussions can be found in the Cambridge library, notably in the GBR/0180/RGO 9/110 et GBR/0180/RGO 9 /111.

28. Letter from Harry Spencer Jones to C.S. Wright, 19 July 1943, Cambridge Library, GBR/180/RGO-9-110, Correspondence on photographic zenith tubes, 1943–1954.

29. 'Rapport du Conseil d'État à l'appui d'un projet de décret concernant l'octroi d'un crédit pour l'agrandissement de l'observatoire cantonal et pour l'achat de divers instruments, séance du 15 mars 1948, BOGC, 113, 1947-1948, pp. 702-740.

30. *Ibid.*, p. 737.

31. *Ibid.*, p. 703.

32. Letter from George Sisson to Edmond Guyot, 13 May 1949, AEN, 1EP-364, lunette zénithale photographique. It should be noted, however, that at this time the models are still under development and that there are no definitively fixed characteristics of the PZT.

33. *Id.* In this paper we refer to the Greenwich PZT although it was later disposed of in Herstmonceux.

34. Letter from the Chambre Suisse d'horlogerie to Sydney de Coulon, 21 November 1949, AEN, 1EP-364, lunette zénithale photographique, 2.

35. To see the differences between models, see : GBR/0180/RGO 103.

36. Letter from George Sisson to Harold Spencer Jones, 6 February 1950, Cambridge

Library, GBR/180/RGO 9-110, Correspondence on photographic zenith tubes, 1943–1954.

37. Letter from Harold Spencer Jones to George Sisson, 13 February 1950, Cambridge Library, GBR/180/RGO 9-110, Correspondence on photographic zenith tubes, 1943–1954.

38. Letter from George Sisson to Harold Spencer Jones, 11 April 1951, Cambridge Library, GBR/180/RGO 9-110, Correspondence on photographic zenith tubes, 1943–1954.

39. Letter from D.S. Perfect to Harold Spencer Jones, 4 April 1951, Cambridge Library, GBR/180/RGO 103, Photographic Zenith Tube: Records, c.1940s-1980s.

40. Letter from George Sisson to Harold Spencer Jones, 11 April 1951, Cambridge Library, GBR/180/RGO 9-110, Correspondence on photographic zenith tubes, 1943–1954.

41. Letter from George Sisson to Edmond Guyot, 30 June 1950, AEN, 2IND-79, lunette zénithale photographique (PZT), achat auprès de la maison SIR HOWARD GRUBB PARSONS de Newcastle, correspondance, rapports, etc. 1949-1954. To see differences between the models, see the various plans held at the Cambridge Library: RGO 101/3/4/1, 101/3/4/2 and 101/3/4/3, as well as GBR/0180/RGO 103. The Tyne & Wear and MIH archives also hold various plans. I would like to thank Emma Saunders of the Cambridge Library for her valuable assistance.

42. Letter from George Sisson to D.S. Perfect, 3 April 1951, Cambridge Library, GBR/180/RGO 103, Photographic Zenith Tube: Records, c.1940s-1980s.

43. Letter from George Sisson to Edmond Guyot, 15 November 1950, AEN, 1EP-364, lunette zénithale photographique. Letter from Edmond Guyot to George Sisson, 21 November 1950, AEN, 2IND-79, lunette zénithale photographique (PZT), achat auprès de la maison SIR HOWARD GRUBB PARSONS de Newcastle, correspondance, rapports, etc. 1943–1954.

44. Letter from Edmond Guyot à Sisson, 26 February 1954, AEN, 2IND-79.

45. See Rapport du directeur 1954, AEN, 2IND-98, p. 3.

46. See Rapport du directeur 1956, AEN, 2IND-98, p. 5.

47. Grubb and Parsons, 'Astronomical instruments', 17, 1956, Tyne & Wear Archives, Accession 5350, catalogues, leaflets, articles, etc.

48. The result is actually a parallelogram. To obtain a rectangle, the passage of the star at the zenith would have to be exactly in the middle of the recording cycle.

49. Edmond Guyot, 'À l'Observatoire cantonal de Neuchâtel. De la lunette méridienne à la lunette zénithale photographique', *La Suisse horlogère*, Nr 32 and 33 (1954), pp.779-780 and 811-812.

50. User's manual P.Z.T., AEN, 2IND-79, p. 1.

51. We will not go into detail on this point, but the photographic plate is an opportunity to consider selecting one at an affordable price, the one offered by Grubb & Parsons being considered too expensive. The T & W Archives holds material on Grubb & Parsons measuring devices, see the collection: Star plate measurement m/c, DS.GP/4/pn/1/28. In the end, the Zeiss instrument, used to compare the triple refractor plates, was used.

52. Rapport du directeur 1957, AEN, 2IND-98, p. 5.

53. Rapport du directeur 1956, AEN, 2IND-98, p. 6 ; Rapport du directeur 1964, AEN, 2IND-98, pp. 4-5.

54. Rapport du directeur 1968, AEN, 2IND-98, p. 6.

55. On the history of electronic computers, see Michel Deguerry

& René David, *De la logique câblée au calculateur industriel. Une aventure du Laboratoire d'Automatique de Grenoble* (Grenoble: Eda Publishing, 2008); Jean Marguin, *Histoire des instruments et machines à calculer; trois siècles de mécanique pensante 1642-1942* (Paris: Hermann, 1994); Robert Ligonnière, *Préhistoire et histoire des ordinateurs: des origines du calcul aux premiers calculateurs électroniques*, (Paris: Robert Laffont, 1987).

56. Schuler Walter. Étude théorique et expérimentale de la lunette zénithale photographique (PZT) de Neuchâtel (Genève: Édition Médecine & hygiène, 1967).

57. Ch. Wyser, Jean-Pierre Blaser & Walter Schuler, 'L'automatisation de la lunette zénithale photographique', *Publications de l'Observatoire de Neuchâtel (Suisse)*, 7, (août 1959), pp. 1-10.

58. Claude Boucher, 'La genèse du Système International de Référence Terrestre (ITRS)', *Revue XYZ*, 145-4 (2015), pp. 53-56; Dennis McCarthy & Brian Luzum, 'Path of the mean rotational pole from 1899 to 1994', *Geophysical Journal International*, 125-2 (1996), pp. 623-629.

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