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A "WELL-TEMPERED FLUTE" BY T. BOEHM – THE FINAL STAGE OF ITS EVOLUTION AND THE STANDARDIZATION OF ITS TUNING SYSTEM

VOLODYMYR KACHMARCHYK[1], **NATALIIA KACHMARCHYK**[2]

SUMMARY. The article is dedicated to the development of the flute acoustic and tuning systems during the 18th-19th centuries. Based on the analysis of J. J. Quantz's treatise »Versuch einer Anweisung, die Flöte traversiere zu spielen« and the flute of its construction with two enharmonically unequal keys Es and Di s, the intonation and technological features of using pure tuning system in playing an instrument are revealed. Following Quantz's ideas was another German musician, the Leipzig master instrument maker J. G. Tromlitz. He strongly recommended maintaining the dominant position of the pure tuning system while performing on the flute. The defining stage in the development of the flute design and the establishment of the well-tempered tuning system as the basis of its acoustic features was the reform of T. Boehm. The models of the inverse conical bore flute with open ring keys (1832) and the cylindrical flute with flap keys (1847) created step-by-step give evidence of the evolution of T. Boehm's views on expanding the sound dynamics and improving the intonation capabilities of the instrument.

Keywords: Boehm's flute, pure tuning system, equal temperament, conical flute, cylindrical instrument, acoustic system, key mechanics.

Introduction

The scope of the achievements of the renowned German inventor and musician Theobald Boehm (1794-1881)[3] in improving the design of the flute in

[1] *Dr. habil of Arts, Professor at the National Music Academy of Ukraine named after P. I. Tchaikovskyi, Kyiv, Ukraine. E-mail: vladkachmarchyk@gmail.com*
[2] *Senior Lecturer, Luhansk State Academy of Culture and Arts, Kyiv, Ukraine. E-mail: nkachmarchik@gmail.com*
[3] The founder of Theobald Böhm Archiv, a tireless propagandist of the original design of the Boehm flute with an open G-sharp key, the great-grandson of the inventor Ludwig Böhm, recently took part in the celebrations on the occasion of T. Boehm's 225th anniversary. During the jubilee year 2019, he managed to hold a number of scientific and artistic events in honor of his famous ancestor, one of which took place in Kyiv on October 13-14, 2019. We express our sincere gratitude to Dr. Ludwig Bohm for providing electronic versions of Theobald Bohm's correspondence. to clarify some details of the inventor's work on improving the design of the flute.

the era of total spread of innovative technologies in all spheres of human activity, looks no less important and convincing than at the time of his revolutionary discoveries. Almost 190 years ago, the conical flute with annular keys he created was given a rather restrained welcome by the flutist community and did not receive adequate support from the conservative elite[4]. Only a small group of young performers-enthusiasts[5] saw in the improved design a great potential for the development of technical and sound capabilities of the instrument and performance skills in general.

Even more impressive was the second stage of the flute reform, completed by T. Boehm in 1847. In order to develop the sound-dynamic capabilities of the instrument and eliminate intonation defects, as well as to refute baseless accusations of plagiarism, he creates a model with a radically changed acoustic system and keys mechanics. However, even here were influential and authoritative critics who failed to properly appreciate the innovative achievements of the inventor, whose ingenious ideas were ahead of his time. Particularly surprising among the opponents is the name of the great opera reformer Richard Wagner (1813-1883), who compared the sound of the new instrument to “a cannonade” and forbade its use in the performance of his orchestral works[6]. Such a position of the composer against the background of his efforts to significantly expand the staff of the orchestra looks illogical at the very least. While using in some of his works the quadruple orchestra with eight French horns and considerably enhancing the group of brass instruments with louder varieties (bass trumpet, double bass trombone, Wagner's tuba) and an additional number of strings, Wagner unexpectedly abandons the cylindrical model of the flute, which by its sound-dynamic and intonational features was far more perfect than the then existing ones.

However, among the prominent artists were ardent supporters of the new instrument, from among whom stood out Hector Berlioz (1803-1869), who considered the improvement of T. Boehm revolutionary. He supported

[4] Among the most famous opponents of the instrument were Professor of Paris Conservatory Jean-Louis Tulou (1786-1865), the first flutist of the Dresden court chapel Anton Bernhard Fürstenau (1792-1852). Boehm's flute was also criticized by Leipzig Gewandhaus soloist Wilhelm Barge. (1836–1925), Paris virtuoso Louis Drouet (1792-1873) and other famous performers.

[5] Proponents of the improved flute were the soloists of the Grand Opera Louis Dorus (1812-1896) and the Italian Opera Paul Camus (1796-1869) and the teacher of the preparatory classes of Paris Conservatory Victor Coche (1806-1881).

[6] It is known that it was at the request of R. Wagner that the cylindrical flute was banned in Munich court orchestra, the home town of the inventor, where for a long time he remained the first flutist. Under the pressure from Chief Conductor Hermann Levi (1839-1900), T. Boehm's student Rudolf Tillmetz (1847-1915) had to abandon the more advanced model of the teacher and return to the conical flute, which was much inferior in technical and sound capabilities. Manfred Hermann Schmid, *Die Revolution der Flöte. Theobald Boehm 1794-1881,* Katalog, Tutzing, 1981, S. 155.

musicians who mastered the new model and tried to introduce it into the educational process of Paris Conservatory[7].

It is worth noticing that the research into Boehm's reform, which began with the fundamental work of Christopher Welch (1832-1915) in the late 19th century[8], focused mainly on the achievements of the inventor in the development of key mechanics, chromatization of the instrument, its sound and intonation qualities[9]. This perspective of scientific research is clear and beyond any doubt. After all, it was in these areas that T. Boehm achieved convincing results, which allowed him to create a perfect model that would later confidently take the prominent place in the orchestra and for more than two centuries will retain its status without systemic improvements. At the same time, in addressing issues related to the intonation characteristics of the new flute design, researchers often overlook the basic principles of the instrument's acoustic system, which the master relied on when calculating the location of tone holes and working on the internal structure of the instrument.

The tuning of the flute before the reform of T. Boehm

Even though wind instruments are not among the instruments with a fixed frequency and the performer can adjust the intonation with the help of the labial apparatus, breathing and fingering, the acoustic system of each of them is formed on the pitch of a certain system. We find confirmation of this in Johann Joachim Quantz's (1697-1773) treatise “Versuch einer Anweisung, die Flöte traversiere zu spielen” (1752), in which the author explains the main reasons for creating his own flute design with two keys Es and Dis[10] as follows: “Therefore E flat must be a comma higher than D sharp. If there were only one key on the flute, both the E flat and the D sharp would have to be tempered, as on the keyboard, where they are stuck on a single key, so that neither the E flat to the B flat, the ascending fifth, nor the D sharp to the B, the descending major third, would sound truly”[11].

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[7] Hector Berlioz, *Concert de Conservatoire*, Revue et Gazette musicale de Paris 5e Annèe N 13 (1 Avril 1838), pp. 142-143.

[8] Christopher Welch, *History of the Boehm Flute,* London, Rudall, Carte & Co., 1896.

[9] From among the most famous ones are Karl Lenski, Karl Ventzke, *Das Goldene Zeitalter der Flöte Frankreich 1832-1932.* Celle, Moeck Verlag, 1992. Karyn Ann Berger, *Flute Intonation: a Comparison of Modern and Theobald Boehm Flutes Scales,* DMA, University of Cincinnati, 1999. Jaap Frank, *Fall und Aufstieg der hölzernen Boehm-Flöte*, *Tibia* 2 (2000), pp. 113-115.

[10] One of the J. J. Quantz’s flutes with two Es and Dis keys is in the Dayton C. Miller Collection in the Library of Congress (DCM 0916: Johann Joachim Quantz / Flute in C) https://www.loc.gov/resource/dcmflute.0916.1

[11] Johann Joachim Quantz, *Versuch einer Anweisung, die Flöte traversiere zu spielen* (Berlin, 1752). Quoted from: Johann Joachim Quantz, *On Playing the Flute*, trans. with notes and an introduction Edward R. Reilly, second edition, Boston, Northeasten University Press, 2001, p. 46.

From the above statement of the German flutist, it is obvious that in the formation of the acoustic system of instruments of his own production, Quantz used a pure tuning system, in which the flats were tuned a coma[12] higher than the sharps[13]. Rejecting the tempered tuning system as the basis for determining the location of the tone holes of the diatonic scale of the flute, the German musician relied on his previous experience of playing the violin[14], where a universal system of tuning strings is not limited by the design of the instrument. Unlike the string instruments, the process of correcting intonational deviations between different tuning systems on the flute is much more complicated than that on the violin, so, in order to eliminate them, the author offers in his treatise a special system of embouchure pitch control. Its principle lay in moving the instrument head on the lower lip and in changing the plane of covering the labial hole. By turning the instrument towards the performer or turning it away, the flutist could raise or lower the pitch intonation. However, the use of a special "rotary" technique of the embouchure, as well as additional options for fingering, did not always yield the desired result. Evidence of this is the sharp criticism of the unsatisfactory intonation on the flute, which often sounded from famous musicians – Alessandro Scarlatti (1660-1725)[15], Wolfgang Amadeus Mozart (1756–1791)[16], Georges Bizet (1838–1875), music historian Charles Burney (1726-1814) et al. Most often, the intonation shortcomings were seen as the fault of the performers, rather than the defects of the instrument's design and the inconsistency of its basic tuning system with the clavier.

In the flute production and flute performance, the uniform tempered tuning system does not receive an adequate support, despite the fact that after the appearance in 1722 of the first volume of J. S. Bach's "Well-Tempered Clavier," a new way of tuning keyboard instruments, which "could be played purely in all twenty-four tonalities"[17], is becoming widespread. Among the

[12] The coma represented 1/9 of the whole step and was equal to ≈ 22 cents.

[13] J. J. Quantz, *Versuch*, S. 35.

[14] As a city multi-instrumentalist musician J. J. Quantz played many instruments and at the initial stage of his career he performed on the violin.

[15] Confirmation of this can be considered the reaction of Alessandro Scarlatti, who at the request of J. J. Quantz regarding the possibility of obtaining permission to visit, at first said no: "My son, you know, I hate wind instruments, they all play out of tune all the time." J. J. Quantz, "Herrn Johann Joachim Quantzens Lebenslauf von ihm selbst entworfen," in Friedrich Wilhelm Marpurg, *Historisch-kritische Beyträge zur Aufnahme der Musik*, Band I, Berlin, 1755, S. 228.

[16] In the letters to his father, W.A. Mozart claimed that he could not stand the flute and went blunt if he had to write for it all the time. Hermann Abert. *Mozart:* in 2 parts, trans. from German, introd. article, comments by Konstantin Sakva, Part 1, Book 2 (1775-1785), Moscow, Music, 1988, p. 108.

[17] Johann Nikolaus Forkel, *Johann Sebastian Bach, his Life, Art, and Work*, trans. from German by E. Sazonova; ed. by N. Kopchevsky, Moscow: Music, 1987, pp. 28-29, 32-33.

authoritative flutists of the 18th century J. J. Quantz was not the only opponent of standardizing the flute tuning system on the basis of a equal tempered system. Another German flutist, the Leipzig master instrument maker Johann George Tromlitz (1725-1805) was an ardent adherer of Quantz's ideas. More than six decades (1791), after Quantz created a flute model with two separate keys for Es and Dis, Tromlitz supported their use. He confirms the intonational differences between sharps and flats and emphasizes that "Fis and Ges, Gis and As, Bb and Ais, Cis and Des, etc., are different notes"[18]. This is recorded in the fingering table, which clearly presents the three separate options ─ for sharps, flats and diatonic scale.

In his fundamental treatise "Auführlicher und gründlicher Unterricht die Flöte zu spielen" (1791) Tromlitz reveals in detail the principle of tuning flutes of his own production, created based on a pure tuning system. Comparing the principle of tuning the flute and the tempered clavier J. G. Tromlitz emphasizes: "The tuning system [of the flute] is much more complex than that of keyboard instruments. And so on our instrument (on each of its three types) you can play more purely than on the keyboard [instruments], in which no interval, except the octave, can be absolutely perfect"[19].

Highlighting the obvious advantages of the flute, the main scale of which was formed on a pure tuning system, the Leipzig master confirms this system's priority over the tempered one. And, if in the orchestra and ensemble without the participation of the clavier to achieve intonation purity for the flute with instruments with a non-fixed tuning system was possible, the in-tune performance with a tempered harpsichord was quite problematic. To address this issue, J. G. Tromlitz proposes a radical way to abandon the latter, despite the fact that the clavier was part of the orchestra at the time. Thus, he argued, it would be possible to "get an orchestra made up of good and right people who play in tune"[20].

According to Tromlitz, flutists had numerous problems during the transition from the pure to the well-tempered tuning system. Technical difficulties were caused by the placement of tone holes on the instrument, which due to their remote location, according to acoustic calculations, required a wide extension of the fingers and created inconvenience during play. He considered psychoacoustic factors to be no less significant, emphasizing: "everyone who is accustomed to hearing sounds in a pure tuning system, tries to play all the intervals in a certain tonality purely. Therefore, such a performer will never be fully in tune with the clavier"[21].

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[18] Tromlitz J. G. *Auführlicher und gründlicher Unterricht die Flöte zu spielen,* Leipzig, A. F. Böhme, 1791, S. 14.
[19] Ibidem, S. 57.
[20] Ibidem, S. 58.
[21] Ibidem, S. 48.

Offering different types of fingering and a wide arsenal of embouchure intonation corrections on the flute, J. G. Tromlitz also questions the possibility of “finding someone who can temper [sounds] while playing [the flute] in the same way as when tuning the clavier at leisure”[22].

To correct the existing intonation discrepancies between the instruments, it was necessary not only to change the principle of forming the main scale of the flute from pure to evenly tempered system, but also to "re-tune" the performer's hearing. In order to train the flutist's hearing in a tempered tuning system, Tromlitz considered it an effective way to learn the skills of tuning a harpsichord, which “will point to those who are looking for the right direction” in achieving the purity of performance[23].

The recommendation of the author of the treatise to develop the performers’ hearing on a “correctly tempered flute”[24], which he had not mentioned before, looks rather unexpected. This dual approach to the use of both pure and tempered tuning in flute performance remained common among flutists later. Professor of Paris Conservatory François Devienne (1759-1803) in his “Nouvelle méthode théorique et pratique pour la flute” is limited to the placement of only one common table for sharps and flats, in which different versions of enharmonic sounds are observed in only two enharmonic pairs (*ais*^{2}-*bb*^{2} and *his*^{2}-*c*^{3})[25], and for the remaining notes it is left unchanged. In contrast, F. Devienne's colleagues – Antoine Hugot (ca.1761?–1803) and Johann Georg Wunderlich (1755–1819), – in the official manual “Méthode de Flûte du Conservatoire” return to the Baroque tradition and place separate tables for sharps and flats[26], which emphasizes the existence of intonation differences between them. Such uncertainty in the standardization of the flute continued to negatively affect the intonational purity while performing on the instrument and was particularly detrimental in the concerts with a well-tempered clavier, and later the piano.

It is obvious that the well-tempered system at the beginning of the 19th century gradually became the standard not only for instruments with a fixed pitch, but also increasingly penetrated into the performance practice on instruments with a non-fixed system. The claim that uniform temperament is necessary only for instruments with a fixed tuning is sharply criticized by both acoustic scientists and famous musicians and Master of Musical instruments.

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[22] Ibidem

[23] Ibidem, S. 118.

[24] To achieve this, Tromlitz recommends playing D major and comparing the purity of performance with a well-tuned clavier. Ibidem, S. 118.

[25] François Devienne, *Nouvelle méthode théorique et pratique pour la flute,* Paris, 1794, p. 2.

[26] Antoine Hugot and Johann Georg Wunderlich, *Méthode de Flûte du Conservatoire,* Paris, Imprimerie du Conservatoire Paris. 1804, pp. iv-v.

The advantages of using a equal tempered system in vocal and instrumental performance were convincingly pointed out in 1809 by the prominent German scientist-acoustician and inventor of musical instruments Ernst Chladni: “Some persons are disposed to think that equal temperament exists only for instruments with fixed sounds; but ... every good singer, every good performer, tempers his intervals unconsciously. <…> Equal temperament is the most conformable to nature, because, on account of the equal division of the discrepancies between all the intervals except the octave, the inaccuracy of each interval is too small to offend the ear”[27].

However, despite the fact that “some of the objectors to equal temperament, became wiser as they grew older; some important authors have, however, persistently held to their opinions against it”[28]. Quite categorically stood against the uneven temperament and “large and small semitones” in his “Violinschule” (1832) German violinist and composer Louis Spohr, who emphasized: “By correct intonation, that of equal temperament is of course understood, as there is no other fit for modern music. The young violinist, therefore, requires to be instructed in this one only. The unevenly tempered tuning system is no longer spoken about in this school”[29].

In the current situation in the production and improvement of flutes at the turn of the century, the most noticeable activity is observed in its chromatization and equipping with key mechanics. The design of the instrument with six main holes of the diatonic scale together with the Es key, which has long remained the basic model for performers, is gradually being equipped with additional keys. However, in most cases, in determining the location of tone holes masters did not rely on accurate mathematical and acoustic calculations, and often copied them from the older instruments to the existing models, the diatonic scale of which was mostly formed on pure or unevenly tempered systems. Sometimes, an unskilled master, as noted by J. G. Tromlitz, was primitively reproducing the outer shape of the flute, “but could not tune it because he did not understand the difference between Es and Dis, or did not even know which key was for which note”[30]. The instrument made in this way created even greater intonation difficulties for the performer.

Analyzing the performing capacities of the flute before T. Boehm’s reform, it should be noted that the mechanical and acoustic potential of the most common at the time seven-to-nine-key instruments was exhausted, and a significant improvement in sound quality, intonation and technical resource

[27] Richard Rockstro, *A Treatise on the Construction, the History and the Practice of the Flute,* London, Rudall Carte, 1890, p. 114.
[28] Ibidem, p. 115.
[29] Louis Spohr, *Violinschule,* Vienna, Haslinger, ca.1832, S. 3, cit. by R. A. Rockstro, Treatise, p. 115.
[30] J. G. Tromlitz, *Aufühlicher* (1791), p. 14.

was not achieved. Further increase in the number of separate, disconnected keys became impossible due to anatomical limitations. Only a comprehensive solution to these problems made it possible to create a full-fledged model of the flute for its effective use in the widespread transition to a equal tempered tuning system.

The main directions of T. Boehm's reform

In the implementation of his intentions to improve the intonation and technical features of the flute, T. Boehm acts step-by-step, gradually solving some local problems of acoustics and mechanics of the instrument. As an example of this is his first modified model of the instrument, known as "Boehm's Newly-invented Patent Flute"[31], which the master made in 1831 for his friend, the owner of the London workshop Gerock & Wolf, of Mr. R. Wolf. Trying his best to preserve the existing fingering of the old instruments, he introduces "small changes in the shape and location of the keys", which made it possible to get rid of "intonation inaccuracies", achieve "firmness, evenness and richness of sound" and ensure the "simplicity of fingering"[32]. The absence of more detailed comments on the instrument tuning system in the Gerock & Wolf brochure does not make it possible to establish based on which system - pure or well-tempered – "the intonation inaccuracies" were corrected.

The German inventor achieved many more significant results in reforming the mechanical and acoustic system in 1832. The idea to improve the "Newly-invented" flute came to him after meeting with the famous English flutist Charles Nicholson in London. He impressed T. Boehm with his powerful sound. "This power was the result of the extraordinary size of the holes of his flute"[33].

Pointing out the acoustic advantages of the flute of his English counterpart, T. Boehm, at the same time, harshly criticizes "the inconsistent placement, as on all the instruments of the conventional design, of tone holes, which did not correspond to acoustic measurements[34]. For this reason, Nicholson had to rely on an outstanding talent and a marvelous embouchure in order to overcome the intonational shortcomings and the evenness of the flute registers.

Ch. Nicholson's flute had no advantages other than amplified sound, but this important factor for Boehm, the performer and inventor, became decisive in the emergence of a new strategy for further improvement of the

[31] As states Christopher Welch, the flute in question was not patented. Ibidem, p. 85.
[32] Ibidem, p. 86.
[33] Ibidem, p. 20.
[34] Ibidem, pp. 20-21.

instrument. After visiting London, T. Boehm is convinced of the need to create a new, more advanced model: “After recent numerical research, I have come to the conclusion that without a total modification of the fingering system, no significant improvement of the instrument can be achieved. I decided not to take Nicholson's flute or any other <…>, but wanted to use the invaluable time and effort to create a perfect new flute design that had good intonation, soft, smooth and powerful sound, and comfortable mechanics would allow one to accurately perform each musical phrase”[35].

The German inventor clearly identifies the main areas for flute improvement based on an integrated approach to the instrument reform. Focusing on the intonational shortcomings of the “ordinary flutes,” the master corrects the placement of tone holes, the location of which is determined by a monochord.

The monochord-mathematical method of acoustic calculations for determining the location of tone holes was used by J. G. Tromlitz. In 1785, he created in this way “<...> the experimental sample of the flute that stood out in the evenness of timbre and sound volume”[36]. However, due to the uneven and remote placement of the tone holes, which required a wide stretching of the fingers and caused significant inconveniences while playing, the original design was not further developed.

T. Boehm successfully solves the problems of fingering, using annular key ligaments, which allowed to simultaneously close fourteen tone holes with nine fingers and place them in accordance with the acoustic calculations[37]. Thus, the dependence on anatomical limitations in determining the number and location of tone holes was overcome. The use of new mechanics made it possible to improve significantly the purity of intonation of the inverse conical bore flute with open ring keys (Konische Ringklappenflöte), as T. Boehm emphasizes in his booklet “Theobald Böhm's Neu construirte Flöte”. The excellent intonation qualities of the new model of the instrument were recognized even by its critics. One of them was German virtuoso flutist A. B. Fürstenau, who stated in his “Die Kunst des Flötenspiels”: “Mr. Boehm's flute has many advantages, especially its smoothness and ease of sound, excellent purity of intonation and extraordinary sound volume”[38].

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[35] Karl Lenski and Karl Ventzke, *Das Goldene Zeitalter der Flöte Frankreich 1832-1932,* Celle, Moeck Verlag, 1992, S. 33.

[36] Fritz Demmler, *Johann George Tromlitz: (1725-1805); ein Beitrag zur Entwicklung der Flöte und des Flötenspiels*, 2. Aufl., Buren: Knuf, 1985, S. 56.

[37] Theobald Boehm, *Theobald Boehm's neu construirte Flöte,* München: Falter, ca. 1834, S. 2.

[38] A. B. Fürstenau criticizes the more powerful sound-dynamic features of the conical flute by T. Boehm, noting: “… at the same time it [the flute] sounds too plain and monotonous, which is why it lacks a wonderful glaze, especially in the middle register, that is, what distinguishes the flute from other instruments.” At the same time, he proposes “… performers who prefer loud sound and noisy passages to further adapt Mr. Böhm's flute for playing in large rooms,” Anton

Positive evaluation of A. B. Fürstenau of the intonational perfection of his compatriot's flute, as well as the characteristics of its intonation preferences by the master himself, unfortunately, do not provide comprehensive information about the tuning system of the instrument, which Boehm relied on in acoustic calculations of tone holes. A certain confirmation of the master's use of a equal tempered system as the basis for the formation of the acoustic system of the conical flute can be a table of fingering, in which the performance of sharps and flats are represented by identical options.

Created in a short time, the model Konische Ringklappenflöte (1832)[39] with enlarged tone holes really became the best instrument at that time, standing out among the flutes of other masters. It embodied all the latest ideas of T. Boehm. However, despite the obvious achievements in the development of mechanical and acoustic potentials of the new design, which improved its intonational and sound-dynamic features, some shortcomings could not be overcome. Among the existing problems that remained unresolved, Boehm later pointed out: "As regards the sounding and the quality of the lower and higher tones there was yet much to be desired; but further improvements could be secured only by a complete change in the bore of the flute tube"[40].

The cylindrical flute - as the final stage of the total reform by T. Boehm

The most vulnerable thing of the old flutes, as well as the 1832 models, was the inverted conical shape of the bore. "I was never able to understand why, of all wind instruments with tone-holes and conical bore, the flute alone should be blown at its wider end; it seems much more natural that with rising pitch, and shorter length of air column, the diameter should become smaller"[41], wrote the master. A two-year course in theoretical and

Fürstenau, *Die Kunst des Flötenspiels,* op. 138, Leipzig: Breitkopf und Härtel, n.d. 1844, S. 1-2. A sharp criticism of the sound volume of the German master's flute is voiced by the Professor of Paris Conservatory J. L. Tulou, who believed that the flute should "enchant with its softness, tenderness in the expression of deep feelings, and not surprise with strength and fury" Lenski K., Ventzke K. *Das Goldene* (1992), S. 63.

[39] Boehm's 1832 inverse conical bore flute with open ring keys is in the Dayton C. Miller Collection in the Library of Congress (DCM 1056: Theobald Boehm / Flute in C) https://www.loc.gov/resource/dcmflute.1056.1

[40] Theobald Boehm, *The flute and flute-playing in acoustical, technical, and artistic aspects*, trans. by D. C. Miler, Case School of Applied Science, Cleveland, Ohio, Savage Press, 1908, p. 2; Theobald Boehm, *Die Flöte und das Flötenspiel in akustischer, technischer und artistischer Beziehung*, Leipzig-Berlin, Zimmerman, 1871.

[41] Boehm Th. *The flute,* p. 4.

experimental acoustics, which he is studying under the guidance of his colleague, university professor Dr. Carl von Schafhäutl, allows him to gain not only fundamental knowledge of acoustics, but also an understanding of ways to “totally” reform the design of the flute, whose basis acoustic system was to be a uniform temperament. Endeavoring to produce an entire pure scale in one key, wrote the inventor,” the tones were always thrown out of the proportions of the equal temperament, without which the best possible tuning of wind instruments with tone-holes cannot be obtained. Therefore, in order to determine with perfect accuracy the points at which the tone-holes shall be bored, one must avail himself of the help of theory”[42].

The firm beliefs of the inventor in the inevitability of the use of a equal tempered tuning system in the formation of the main scale of the cylindrical flute later became the basis of all acoustic and mathematical calculations.

Changing the internal shape of the flute bore from inverse to cylindrical required the actual creation of a new instrument, and T. Boehm is actively involved in this complex process. By using a monochord string to determine the length of the flute, the dimensions of which were compared with the length of the air column, he creates a prototype of a cylindrical model consisting of twelve parts[43]. Each part of the instrument corresponded to a semitone, had a small protrusion and was a kind of nozzle, which made it easy to connect them together. The presence of the protrusion made it possible to adjust the length of the air column and fine-tune each sound of the chromatic scale of the first octave.

One of the reasons that forced T. Boehm to make changes in the theory of calculations was the impossibility of free movement of the sealed plug in the upper part of the flute head. According to acoustic calculations, the distance from the center of the labia to the tube for each sound is a variable, so to achieve stable intonation in the upper and lower registers it was necessary to find the average position of the sealed plug.

It is known that J. J. Quantz, who invented the movable stopper to correct the purity of the tuning system, failed to find a rational way to overcome similar shortcomings. To eliminate intonation errors, he used six different sized middle parts. T. Boehm, after a series of experiments, finds the optimal distance of the plug from the center of the labia, which was equal to 17 mm. This arrangement of the plug with a stable setting of the labial apparatus made it possible to maintain a stable purity of intonation in all registers.

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[42] Ibidem, p. 15.

[43] A sample of the experimental design of the flute is in the Dayton C. Miller Collection in the Library of Congress (DCM 0471: [Attributed to Theobald Boehm] / Flute) https://www.loc.gov/resource/dcmflute.0471.0

Theoretical calculations to determine the location of tone holes did not always give the desired results to the master. Therefore, he was forced to adjust them with the help of an experimental sample of the flute and practical experiments.

Two years of the fundamental study of acoustics and careful experiments allowed T. Boehm to finally create a model of the flute, "<...> on which all the notes sounded not only fuller and stronger than on other instruments, but every nuance to the most delicate *piano* was to be achieved without losing tone or lowering the pitch. Since their sound extraction with constant positioning was very easy and the structure was absolutely clean, the performance became simpler, more confident and intonationally more accurate compared to all other flutes, where almost every sound required a different positioning"[44]. Thus, the second stage of the total reform of the instrument design was successfully completed.

Completion of the cylindrical flute, according to Boehm, did not lead to the creation of an ideal design. He was completely satisfied only with the sound of the instrument in the first and second octaves, and the third remained less intonationally stable on the flute. Theoretically, ensuring the stability of the purity of intonation in all registers could be achieved using a special mechanism for mobile movement of the sealed plug of the upper part of the flute head. However, it was almost impossible to implement this idea in the design of the flute. The master saw the way out in designing a set of orchestral flutes of different tuning systems, the two-octave range of which would sound ideal. And although he failed to fully realize his plans, a partial solution to these problems can be considered the creation of the alto flute, which was the final completion of the instrument's reform.

Conclusions

The creation of the flute by T. Boehm became a starting point in the standardization of its design and a defining stage in the transition from a pure to a equal tempered system in the production of instruments. The use of an experimental sample instrument to correct the tuning of each sound of the main scale made it possible to find a compromise between mathematical calculations and the actual structure of individual sounds and to achieve the necessary intonational consistency between them. Overcoming all the obstacles, T. Boehm achieves this goal by presenting to the flutist community an instrument "on which it was possible to play purely in all twenty-four tonalities"[45]. In order to implement these ideas in performing practice and to

[44] K. Lenski, K. Ventzke, *Das Goldene* (1992), S. 41.
[45] Johann Forkel, *Johann Sebastian Bach, his Life* (1987), p. 32.

master the better capabilities of the instrument, he offers 24 etudes for flute[46] in all tonalities and other works with an increased number of sharps and flats[47]. Thus, the German flutist provides the necessary conditions for the introduction of a well-tempered flute in performance practice and its promotion.

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[46] T. Boehm, *24 Caprices-Etüden op. 26,* Meinz, B. Schott’s Söhne, 1852; T. Boehm, *24 Etüden op. 37,* New York, Carl Fischer Inc., 1908.

[47] Boehm's creative work for the flute includes more than a hundred opuses.

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