Musik Akademie Basel

The development and analysis of a Microtone-Duplex trumpet

An experiment towards extending the tonal and timbre possibilities of the trumpet

Master thesis of: Anastasios Tataroglou
Master 's program: Free Improvisation
Professors: Alfred Zimmerlin, Fred Frith

April 2017

Contents:

1. Prologue

The motivation to get to know my instrument better, to interfere with it and to enlarge its possibilities, led me to develop a special instrument which is a mixture of different ideas of brass instrument construction from the last three centuries.

This thesis consists of the idea, the development, the analysis and the reflections on the Microtone-Duplex trumpet.

The plan, as it was updated in December 2016, included the presentation of the Microtone-Duplex, historical information about instruments of the past, contemporary trumpet players who work with modified instruments, analysis of the construction of the Microtone-Duplex, analysis of new frequencies and other details, limits and new possibilities, and at the end reflections of an improviser on the new instrument. While working on building the trumpet and while controlling different steps of the process I was many times surprised by the results. There were a lot of moments when I had to decide how to proceed with my experiment and what was finally more important to achieve. Whenever possible the decisions were taken according to the first plan, otherwise towards solving problems in another way by looking for alternatives.

It would be very ambitious for a practitioner of improvisation to get involved in a scientific work without any previous experience in the field of scientific research although a lot of effort was made in order to leave aside emotions and on the one hand to deal as objectively as possible with expectations, on the other hand with the distance between theory and practice. For a scientific experiment I should a) have had under control many parameters which I couldn't (laboratory conditions such as human body temperature of the instrument while measuring, funding and the time which could have allowed deeper pre-research and pre-experiments in order to try out some ideas and to refuse others before applying them on my instrument), and b) have had a clear plan consisting of detailed steps with measurements and analysis for each single step as well as working with a group of scientists in the fields of material physics and acoustics who could have provided support and knowledge on the analysis and on the further decisions of my experiment. An important amount of information should have been considered while making the conclusions of the present work, like the condition of the instrument before any modification (for another reason measurements were made a year ago by Rainer Egger, but unfortunately I didn't keep the results of that analysis).

This work is therefore not a scientific work, although the findings, the experience and the whole documentation could be a useful tool for developing further experiments in the future in a more scientific way.

Apparently, the question on which I have worked during the last five months is this:

> ***Is it possible to integrate microtone flute-type keys and a second bell with a slide function on a modern trumpet? What are the limits and how can a tonal accuracy be achieved?***

Towards answering the question in the next pages it's important to mention that this thesis helped me to develop patience towards the target, openness to results independent of my taste, and a deeper understanding—not only of my instrument, but also of two eternal partners which are the Yin and the Yang of all achievements of human beings: Theory and Practice. Last but not least, I need to mention that the Microtone - Duplex is a project which is mostly funded through online crowdfunding campaign and thereat I want to thank from the bottom of my heart all the people who supported it and made the financial part of this experiment possible.

Special thanks to my professors Alfred Zimmerlin and Fred Frith for their mentorship on my approach of performing on this instrument and for their motivating attitude on the writing of this thesis; to Gerd Friedel and Janine Meier for giving their best in building a wonderful result and finding solutions to all problems we met during the building process; to Rainer Egger for providing his knowledge, his experience and his assistance in measuring and analysing the new instrument; to Schola Cantorum Basiliensis professor and virtuoso of baroque trumpet Jean-Francois Madeuf for his advice, his information on sources of historic experiments on trumpets and his general support in the beginning; to the trumpet players Stephen Altoft and Axel Dörner for the information about their instruments and their different approaches to using microtonal material in trumpet performance; to the collector Bruno Kampmann for his kind support with information and photos about instruments from his collection; to my brother Konstantinos Tataroglou for the photography and the 3D modeling; and finally to my partner Fabienne Rotzetter for her amazing psychological support.

2. Introduction – Presentation of the Microtone - Duplex trumpet

This work started from a need of mine to interfere in the possibilities of the trumpet in terms of tone and timbre. Techniques which could allow changes in these two elements had limits in the speed, in the precision and in the smoothness of transformations within them. Inspiration and ideas through different musical engagements led to my decision to modify my trumpet by bringing in to the present different ideas from the history of trumpet construction. The evolution of technology which took place in the last three centuries clearly affected the instrument's construction with amazing results. As a result of this process we lost a lot of the sounds of the past and this has become an important field of research in different disciplines (musicology, anthropology, psychology, medicine, education, and musical practice, for example). On the other hand, perfectionism sets qualitative elements aside to be addressed mostly by experts. For example, specialization in music performance created the need nowadays for a deep understanding of the practice of different eras of the history of music on specific historic instruments. While considering the timbral palette of the trumpet, I decided to experiment by integrating qualitative elements from different eras that are deeply connected to the history of the sound of the instrument. The result of this experiment is the Microtone-Duplex trumpet.

The Microtone-Duplex trumpet

The Microtone - Duplex is a trumpet which has integrated keys (flute type) for microtones and enrichment of the timbre, a modification in the tuning slide with which the musician can perform a glissando, and a second bell. The modifications were created in the workshop of Rainer Egger (specialist of historic brass instruments in Basel) by Gerd Friedel, assisted by Janine Meier between 15th December 2016 and 8th February 2017. Further improvements are still in progress, since the artistic research is ongoing.

2.1 Keys for microtones

The idea of using keys on the trumpet was introduced and developed by Anton Weidinger (1766-1852), an Austrian trumpet virtuoso in the classical era. Basing his ideas on earlier designs, Weidinger experimented with a 5-keyed trumpet in 1792, a version of the instrument on which a full chromatic scale became possible, albeit with some loss of the instrument's usual power. It remained fashionable well into the 19th century when it was superseded by the valve trumpet. Joseph Haydn and Johann Nepomuk Hummel composed their famous trumpet concertos for Weidinger and his keyed trumpet[1]. The first attempt to integrate keys on

Keyed trumpet in G made by Egger after Alois Doke, Linz, c. 1823. Original: Musikmuseum, Basel

a valve trumpet was patented in 1845 by McFarlane on a Cornopean instrument[2] and in 1859 Adolphe Sax added three or five keys to brass instruments for corrections, trills and alternative fingerings[3]. Unfortunately only very few of those instruments have survived until today.

1 Christian Ahrens: Art. *Trompete*, in: MGG2 Sachteil Bd. 9, Sp. 879-897. Speziell zu Weidinger cf. Sp. 892.
2 Patents GB #577, #594, F #2627
3 Patent F #39371

Left: Cornopean with additional key by McFarlane, 1845, Right and down: Saxhorn with 5 additional keys by Sax. From the collection of Bruno Kampmann.

The first idea of this experiment was to integrate five keys on the trumpet, each one intended to achieve a different interval from the harmonics of the natural length of the instrument. The size and the position of the holes for the keys can be calculated for a specific length and shape of tube (conical, cylindrical etc.), which is affected by the use of the valves. The second part was to record afterwards the kinds of microtones which can be produced after the combination of keys with valves. These intervals were 1/3 tone, ¾ tone, minor 3rd, major 3rd and tri-tone. While measuring the positions and the tunings of the holes on an old instrument of the same dimensions as mine, we realized that all holes for intervals over the ¾ tone proved to have a quite unstable intonation in each harmonic. Only one or two of the harmonics (usually 3rd and 4th) were close to the expected interval and the rest quite far from it. It should be possible to make improvements on those intervals for the whole range of the instrument by trying different sizes and shapes of holes in different positions but the cost limits didn't allow for further and deeper experimentation towards a more precise result. For this reason I decided to create only three holes in my trumpet (1/3 tone, ½ tone, ¾ tone).

The levers (left) and the microtone keys (right) of the Microtone-Duplex.

2.2 Slide and second bell

A bit more than one year ago when I first experimented with two bells, I used the bell of a soprano trombone in Bb. By using an adaptor I managed to fix the second bell in the slide tube of the 2nd valve. The result was a second bell which could be used only by pressing the 2nd valve. The tuning was in harmonics of D (written Bb trumpet) when only the 2nd valve was pressed, and in B natural when the 3rd valve was added. The intonation became lower while going to the higher harmonics and for example the 6th harmonic, which is an A natural, sounded like a slightly high G. More disadvantages are that this bell is too small to fix a trumpet mute in it, the quality of sound is poor (in other words - not flexible enough to manipulate) and technically it needed another way of blowing which makes it difficult to combine with the original bell of the instrument.

Historically, attempts to make brass instruments with two or more bells can be traced back to the end of 18th century[4]**.** Although many musicians and instrument makers have experimented with this idea, the various results haven't created any broad recognition and therefore such double bell brass instruments are not often seen in concerts of any musical style. There are almost no instruments in mass production nowadays with two bells. The ones that are in use are custom modifications and the ones which appear to be mass-produced by companies are not commercially successful. In the past there were some mass-produced instruments like the "Echo" cornets (made by Besson, Courtois et al. from the late 19th century until after the WWI; nowadays cheap instruments are produced in India), Harrelson's Medusa model (the only one ever built by the company), a two bell Ambassador cornet

4 Joshua E. Long, "The double bell Euphonium, I beg your pardon?", University of Hartford, 2012

Left: A Yamaha Bb trumpet with the bell of a soprano trombone of the first Duplex, Middle: The second bell adapted on the slide of the 2nd valve, Right: General view. From the collection of the author.

(one of a kind special order in the '70s), the Jazzophone (developed in Germany and wider Bohemian area in the 1920s[5]), and the Schiller two bell trumpet (still in production). As a result the brass players who are interested in those constructions have to create them mostly individually. Despite this limitation, there are musicians involved in contemporary music who work on the idea of double-belled brass instruments (Marco Blaauw, Matthias Höfs et al.) so we can even listen to the rare formation of a whole double-belled brass quartet (Ensemble musikFabrik[6]).

Regarding the Microtone-Duplex, the first plan was to replace the soprano trombone's bell with a trumpet bell in the slide tube of the 2nd valve in order to improve intonation problems of the previous experiment and stabilty of mutes in it. The plan included a slide mechanism with the possibility to slide between A and C# (Bb notation). This way I could achieve the effect of glissando within a major 3rd and by fixing it in different positions I would achieve trills which would be difficult to achieve before. This plan didn't get into experimentation because after calculations I realized that it would be impossible to arrive at the desired result because of limits in the motion of the slide and in the length of the second bell. The glissando function would be limited to around ¾ tone and would be a not very stable construction with a problematic control while playing.

5 The Jazzophone, the Normaphone and other sax shape or double-belled trumpets: https://marge.home.xs4all.nl/jazzophoneen.htm#.WPTZLGclGR1 Last visit on 19.04.2017, 14:05h

6 Marco Blaauw, trumpet, Christine Chapman, horn, Bruce Collings, trombone and Melvyn Poore, tuba

The solution was to integrate the second bell parallel to the basic bell of the trumpet. In this case the slide function wouldn't be a realistic plan and for this reason we modified the main tuning slide of the trumpet by adding a mechanism which made possible a glissando of a bit more than a semitone.

The glissando mechanism closed (up) and open (down).

It is important here to refer to a special element of the second bell. By having to change the position of the second bell I thought of creating the possibility to use both bells at the same time. Towards this target it was necessary to create a specific valve which, except of only switching between the two bells of the instrument, should be constructed in a way to let the air flow into both bells. This element was impossible (or with a “poor” result) with the already existing valves and thus Gerd Friedel constructed a specific valve which allows that possibility. The special effect of this construction is that, in a middle position, it affects the intonation by making it around ¼ tone deeper. The advantage comparing to the first plan is that the second bell of the instrument can perform in the entire chromatic range of the trumpet.

The valve that performs the change of bell and its lever.

3. The palette of timbres of the Microtone-Duplex

Before presenting the results of the analysis on the new microtonal possibilities of the trumpet it is important to understand the palette of timbres it enables. In order to specify the timbres it is necessary to leave aside those elements which were already possible before the modifications (sounds from extended techniques, mutes, removal of slides, playing with half valves etc). All the timbres which were possible to produce before the modifications stay the same without being affected.

3.1 Timbre of the keys

The addition of the keys gave the instrument the possibility to sound like the keyed trumpets of the end of the 18th century. This timbre, which is the reason why this idea was replaced by valve trumpets, is between the sound of a trumpet and a clarinet. It could be described like a weak and non-edgy sound. The existence of a hole on a bell functions like a small bell and that means that a big amount of sound goes out of the hole and it doesn't arrive to the end of the bell. That makes possible to use mutes in the bell and, when a hole opens, the change of the timbre is much more intensive. There is also a big difference by applying this technique in different dynamics. If for instance we play a trill, at low dynamics we can hear much louder the timbre of the open hole, but the timbre of the mute is much louder at higher dynamics. Furthermore, a hole which is not clearly open nor closed enough can produce a distorted sound which could be described as an “electronic low-fi sound”. Additionally, there is a possibility to create a slight articulation on a long note (it sounds more like a modulation or a beating, or even a tremolo effect) when we hold a high interval microtone key and we add one of its lower neighboring keys in any rhythmical way. The combinations which make this effect possible are the following ones:

- Pressing the ¾ tone key and adding the ½ tone or the 1/3 tone key.
- Pressing the ½ tone key and adding the 1/3 tone key.

This happens because the biggest amount of sound comes out of the key closer to the mouthpiece (which produces the highest difference of pitch than those closer to the bell). In this case, opening any other key of lower pitch at the same time doesn't affect the main pitch but creates only this special sound effect.

3.2 Timbre of the combination of both bells

There are of course a lot of different ways to combine the two bells by using various mutes and switching from one to the other. The special type of this switching valve, in positions between 0 and 1 can give different amount of volume of each bell's sound and it functions like a mixer of the sounds of the bells. As the microtone keys are only on the main bell of the trumpet there is a clear question as to whether both bells can produce two different pitches at the same time. While attempting this I realized that it is possible to produce two slightly different pitches at same time. It is unclear how this valve influences the pitch of the sound of the opened key while the air inside the instrument changes directions and reflects differently in the tubes. It surely tends to lower the pitch of the instrument. But in a very short point at a middle position of the valve, when the volumes of sound of each bell are equal, there is a small “fight” between the two pitches, a beating, which affects the vibration of the lips and can be felt from the musician as this reflects into the tubes of the instrument. It could be very useful to find this position precisely and to be able to fix a part in the mechanism which could hold that position without occupying the finger of the musician. The problem is that this position differs because it depends on the different mutes (with some mutes it doesn't even work at all) which don't filter the same volume of air and sound. That makes it difficult to calculate this position because mutes reflect an amount of sound and air back into the instrument.

4. Analysis of the intonation of the keys and conclusions.

4.1 Effects to the body of the instrument and obstacles during the processing of the data

The installation of the keys added more weight to the instrument[7] and changed its balance. Another important element which affects the intonation of the instrument and the way it vibrates is the amount of metal that's stuck on the bell. The more metal stuck on the bell, the less freedom of vibration there is. The position of the additional metal affects different harmonics of the sound. That creates additional difficulties to analyze research data and to process them in order to find a way towards fine improvements.

Taking the decision to modify the instrument so drastically is of course a huge risk that sometimes makes it impossible to go back to the previous condition of the instrument, although improvements are always possible. An important result of the modification of my trumpet is that the instrument lost its previous condition. The addition of the slide mechanism and of the keys affected the intonation irregularly, which practically creates difficulties to achieve a good intonation around the middle of the range of the instrument. This happens because by bending up in order to improve the intonation of the low register, the player feels the middle area of the instrument too low and therefore the analogies in the technique of playing are disturbed. The middle harmonics (especially 4^{th} and 5^{th}) feel too low and there is a psychological need to play higher. In addition some notes on the high register moved higher (notes of the 6^{th} harmonic). All these effects make it difficult to understand why the intonation of the keys cannot be precise and why it is sometimes unpredictable. For that it would be necessary to receive assistance from other fields of science and technology (physics, engineering, acoustics etc.).

Even if in theory the results of laboratory measurements seem to be sometimes correct (or false), practice is a different matter, with some wrong correspondences or the opposite. The machine that measures intonation[8] sends sine waves into the instrument but the human lips produce always a spectrum of frequencies which are amplified through the instrument. For this reason I had to measure the instrument both with the machine and with real playing. Brass instruments require quite precise playing and can be quite flexible for the player to make intonation corrections with the lips by bending up or down even a whole semitone (it

7 All modifications applied to a Bach Stradivarius trumpet with a standard 25 leadpipe and a 43 bell.
8 BIAS 7, Artim G.m.b.H. (Acoustic rating technology for instrument makers), Austria. www.bias.at.

depends on which area of the range of the instrument—bending up over the 4th harmonic is from hard to impossible) but one of the necessary conditions is the freedom of the metal to vibrate. Real playing tests were made in the workshop during the modifications[9] by using a smartphone application (n-Track Tuner) which calculates the pitch with precision of commas of cents. For achieving the best results out of testing the intonation of the keys I had to use the following steps:

- Finding the correct intonation of the tones before keys (natural or with valves)
- Opening the microtone key by keeping the same air stream and only supporting/slightly accelerating the air stream with a small movement of the tongue up. [10]

According to the machine measurements we achieved the following results, from which I will try to draw some conclusions on which further improvements are going to be based. This is a risk, because there is no brass instrument which can be perfectly in tune due to natural limits in the behavior of the materials. It is always the responsibility of the player to adapt his playing to the instrument. In the tables below are the results of the measurements rounded and converted to fractions. For fractions above 1/5 there is approximation of x/5 (as this describes better the intonations between x/3 and x/4) and for fractions below 1/5 the approximation of 1/10, 1/20 is used). The complete results of the measurements can be found in the Appendix. Before going on with an analysis of the keys it is necessary to understand the balance of the harmonics of the instrument in its natural length (no use of valves).

Resonanzen =		0	1	2	3	4	5
	0	1	82.91	-596	"E2"	"3Cent"	460.4
	1	2	229.82	-31	"Bb3"	"-32Cent"	5.5
	2	3	350.03	8	"F4"	"-4Cent"	0.7
	3	4	469.09	4	"Bb4"	"3Cent"	0.3
	4	5	588.22	-4	"D5"	"-5Cent"	0.3
	5	6	708.74	18	"F5"	"18Cent"	2.5
	6	7	823.31	-22	"Ab5"	"-23Cent"	3.3
	7	8	936.63	1	"Bb5"	"0Cent"	0

Table No1. 0-Harmonic, 1-Frequence (Hz), 2-Cent deviation, 3-Absolute pitch, 4-Cents, 5-Number that indicates the necessity of improvements (high number-high necessity)

9 According to the principle I set in advance that: first it has to be correct in real playing conditions and from this result I am going to work with further analysis.

10 That accelerates the air stream and corrects the intonation inaccuracy. The inaccuracy happens because of the principle that the pitch of the sound is related to the pitch of the vibration of the lips. Vibration of the lips on a stable frequency while opening a key (or pressing a valve) means that the new sound will have a lower pitch than is appropriate.

The 1st harmonic (possible to produce only with extended technique) has a deviation of almost minus 600 cents, which is a tri-tone lower. This is not a big surprise. It is a normal deviation that is necessary for brass instrument makers in order to build instruments with accurate higher harmonics (for example the 1st harmonic of a trombone in Bb has to be close to Eb). The 2nd harmonic, which is the first normally playable, is the Bb3 (absolute pitch) which became 32 cents lower (value of necessity to improve 5.5 – the highest). The measurement shows the 3rd, 4th, and 5th harmonic (F, Bb and D) not really affected by the modifications, but then we have the 6th harmonic (the high F) which became 18 cents higher (normally around....), the 7th harmonic (naturally too low) 23 cents lower and the 8th (high Bb) with 0 cents of deviation. So it should make sense to compare this information (and the addition of other valve combinations which are in the Appendix) while creating conclusions from the analysis of the measurements with keys and valves. While increasing the length of the instrument by adding valves it is expected to meet decreased microtone intervals from the left columns towards the ones on the right (on the following tables). It should be important to consider the behavior of the harmonics and the way that trumpet players use them on playing.

The 2nd harmonic of the trumpet looks always to have very low intonation. This is anyway the harmonic that the player can most easily manipulate with their technique while the correction of the pitch while playing can be achieved with bending up. The 7th harmonic is practically never used in the context of classical music because of its—in any case—low intonation and when it is necessary to play this note we use alternate fingering (for example when we need a high absolute Ab pitch we produce it with the 8th harmonic of the 1st valve which is always more precise). The 8th harmonic is usually used with the following valve combinations: a) 0, b) 2, c) 1, d) 1-2, e) 2-3. In the rest of fingerings (1-3 and 1-2-3) the 8th harmonic is quite unstable in terms of intonation and attack precision and therefore not really used. Alternate fingerings in the high register are a separate field of study because the variety of results can be a necessary tool for achieving different results. The most important register for analyzing this data is between the 3rd and 6th harmonic so the area of analysis is going to be limited between these harmonics. The conclusions are going to be classified per harmonic and per valve combination in order to better understand the behavior of the key while the length of the instrument is increasing.

The pitches which are produced over the 5th harmonic of the combination between 2nd and 3rd valve belong to the pitches which are preferably played with alternative fingerings.

The same with the pitches over the 4th harmonic of the valve combinations 1-3 and 1-2-3. Therefore they are included in the statistics in order to have a more realistic overview but there are no comments about them. On the statistics below each table there are the average interval of the key, amount of combinations with a result below the average, amount of combinations with a result above the average and the density of combinations with an interval between the two closest "satellites" of the average interval. I considered the last number an important quantitative data which shows the percentage of density around the average interval, as a small deviation can be corrected by the player and concluding that the bigger the density in this microtonal area, the more successful the role of the key on the average interval that is produced.

4.2 Analysis of the 1st key *(measurement before corrections)*

Harmonic	Valve 0	Valve 2	Valve 1	Valve 1-2	(Valve 3)	Valve 2-3	Valve 1-3	Valve 1-2-3
2nd	-1/20tone	-1/6tone	-1/6tone	-1/4tone	(-1/3tone)	-2/5tone	-1/3tone	-1/3tone
3rd	1/5tone	1/5tone	1/5tone	1/5tone	(1/20tone)	1/10tone	1/6tone	1/4tone
4th	1/4tone	1/4tone	1/4tone	1/4tone	(1/6tone)	1/6tone	1/3tone	1/3tone
5th	1/4tone	1/5tone	1/5tone	1/4tone	(1/8tone)	1/8tone	1/4tone	1/3tone
6th	2/5tone	1/3tone	2/5tone	2/5tone	(1/4tone)	1/4tone	1/3tone	2/5tone
7th	1/6tone	1/6tone	1/4tone	1/4tone	(1/6tone)	1/8tone	1/4tone	1/3tone
8th	1/5tone	1/4tone	1/3tone	1/3tone	(1/4tone)	1/4tone	2/5tone	1/2tone

Table No2. Decreasing classification of the combinations of the 1st key (the closest to the bell) with the valves. Green for intervals lower than the average, Orange for intervals higher than the average.

Average interval of the key in the register between the 3rd and the 6th harmonic without the results of the 3rd valve[11]: **¼ tone**

Amount of combinations with an interval below ¼ tone: **10**

Amount of combinations with an interval over ¼ tone: **9**

Amount of combinations with an interval of ¼ tone: **9**

Density of combinations with an interval between 1/5 tone-1/3 tone: **74%**

2nd Harmonic: The intonation of the 1st key on all combinations with valves stays quite low as a result of the general intonation the 2nd harmonic on the whole instrument is affected (-32 cents without valves according to table no1 – further measurements to be found in the Appendix).

11 The 3rd valve itself is not used in the classical trumpet practice because of its anyway low intonation.

3rd Harmonic: The intonation of the key on this harmonic is 1/5 of a tone in average. There is a small correspondence with the lower intonation of the natural harmonic (according to table No1).

4th Harmonic: The 4th harmonic is stable in the first four combinations and we can see a higher correspondence to the target (1/3 of a tone) in the last two columns. The average intonation is 1/4 of a tone.

5th Harmonic: The 5th harmonic tends to have lower intonation in both the table No1 and No2 and it is the most unstable in the group of the first four combinations. The average intonation is 1/4 of a tone.

6th Harmonic: The 6th harmonic has the highest intervals, of which most are between 1/3 of a tone and a semitone. These are described as 2/5 of tone intervals. According to Table No1 this harmonic is 18 cents higher than it should be. The average intonation of the key on this harmonic is 1/3 of a tone.

4.3 Analysis of the 2nd key *(measurements before corrections)*

Harmonic	Valve 0	Valve 2	Valve 1	Valve 1-2	(Valve 3)	Valve 2-3	Valve 1-3	Valve 1-2-3
2nd	-1/10tone	-1/20tone	-1/10tone	-1/6tone	(-1/4tone)	-1/3tone	-1/4tone	-1/3tone
3rd	2/5tone	1/3tone	1/3tone	1/3tone	(1/6tone)	1/5tone	1/4tone	1/3tone
4th	1/2tone	2/5tone	2/5tone	2/5tone	(1/3tone)	1/4tone	2/5tone	1/2tone
5th	2/5tone	2/5tone	2/5tone	1/3tone	(1/4tone)	1/4tone	2/5tone	1/2tone
6th	1/2tone	1/2tone	1/2tone	1/2tone	(2/5tone)	2/5tone	1/2tone	1/2tone
7th	1/4tone	1/4tone	1/3tone	2/5tone	(1/4tone)	1/4tone	2/5tone	2/5tone
8th	1/6tone	1/4tone	2/5tone	1/2tone	(1/3tone)	2/5tone	1/2tone	2/3tone

Table No3. Decreasing classification of the combinations of the 2nd key (the middle one) with the valves. Green for intervals lower than the average, Orange for intervals higher than the average.

Average interval of the key in the register between the 3rd and the 6th harmonic without the results of the 3rd valve: **2/5tone**

Amount of combinations with an interval below 2/5 tone: **9**

Amount of combinations with an interval over 2/5 tone: **9**

Amount of combinations with an interval of 2/5 tone: **10**

Density of combinations with an interval between 1/3 tone-1/2 tone: **85%**

2nd Harmonic: The intonation of the 2nd key in all combinations with valves stays quite low as a result of the general intonation of the 2nd harmonic of instrument (see Appendix).

3rd Harmonic: The intonation of the key in all combinations of the 3rd harmonic is low and it corresponds in an average of 1/3 of a tone.

4th Harmonic: The intonation of the key in all combinations of the 4th harmonic is higher than on the 3rd harmonic and it has an average of 2/5 of a tone.

5th Harmonic: The intonation of the key in all combinations of the 5th harmonic is in average between 1/3 and 2/5 of a tone (0,37 of a tone).

6th Harmonic: The intonation of the key in all combinations of the 6th harmonic has the most stability as it has an average of 1/2 of a tone. According to the table No1 this harmonic is 18 cents higher. This could explain why the 2nd key gives these results on that harmonic (see Appendix).

4.4 Analysis of the 3rd key *(measurements before corrections)*

Harmonic	Valve 0	Valve 2	Valve 1	Valve 1-2	(Valve 3)	Valve 2-3	Valve 1-3	Valve 1-2-3
2nd	1/4tone	1/10tone	1/20tone	-1/20tone	(-1/6tone)	-1/5tone	-1/5tone	-1/4tone
3rd	3/5tone	3/5tone	1/2tone	1/2tone	(1/3tone)	1/3tone	2/5tone	1/2tone
4th	2/3tone	3/5tone	2/3tone	2/3tone	(1/2tone)	1/2tone	3/5tone	3/5tone
5th	2/3tone	3/5tone	3/5tone	1/2tone	(2/5tone)	2/5tone	3/5tone	3/5tone
6th	2/3tone	2/3tone	3/4tone	3/4tone	(3/5tone)	3/5tone	2/3tone	2/3tone
7th		1/5tone	2/5tone	1/2tone	(2/5tone)	2/5tone	1/2tone	3/5tone
8th			1/6tone	1/3tone	(1/4tone)	2/5tone	3/5tone	3/4tone

Table No3. Decreasing classification of the combinations of the 3rd key (the one closer to the mouthpiece) with the valves. Green for intervals lower than the average, Orange for intervals higher than the average.

Average interval of the key in the register between the 3rd and the 6th harmonic without the results of the 3rd valve: **3/5tone**

Amount of combinations with an interval below 3/5tone: **7**

Amount of combinations with an interval over 3/5tone: **10**

Amount of combinations with an interval of 3/5tone: **11**

Density of combinations with an interval between 1/2tone-2/3tone: **82%**

2nd Harmonic: The intonation of the 3rd key on all combinations with valves stays quite low as a result of the general intonation of the 2nd harmonic on the whole instrument (See Appendix).

3rd Harmonic: The intonation of the key in almost all combinations of the 3rd harmonic is low and it corresponds in an average of 1/2 of a tone.

4th Harmonic: The intonation of the key in almost all combinations of the 4th harmonic is higher than the 3rd harmonic and it has an average of 3/5 of a tone.

5th Harmonic: The intonation of the key in all combinations of the 5th harmonic is in average between 1/2 and 3/5 of a tone (0,55 of a tone).

6th Harmonic: The intonation of the key in all combinations of the 6th harmonic has an average of 2/3 of a tone.

5. Improvements and further measurements

In order to improve intonation problems of the microtone keys first it was necessary to change the dimensions of the holes. All holes were replaced with new ones with a diameter of 11mm. (previous holes were 10mm).

The key holes (left hole 11mm, right hole 10mm)

5.1 Analysis of the 1st key *(measurements after corrections)*

Harmonic	Valve 0	Valve 2	Valve 1	Valve 1-2	Valve 3	Valve 2-3	Valve 1-3	Valve 1-2-3
2nd	no tone effect	-1/10tone	-1/10tone	-1/5tone	(-1/3tone)	-2/5tone	-1/3tone	-1/3tone
3rd	1/4tone	1/4tone	1/4tone	1/4tone	(1/10tone)	1/10tone	1/5tone	1/4tone
4th	1/3tone	1/4tone	1/3tone	1/3tone	(1/5tone)	1/5tone	1/3tone	2/5tone
5th	1/3tone	1/3tone	1/3tone	1/3tone	(1/5tone)	1/5tone	1/3tone	2/5tone
6th	1/2tone	2/5tone	2/5tone	2/5tone	(1/3tone)	1/3tone	2/5tone	1/2tone
7th	1/4tone	1/4tone	1/4tone	1/4tone	(1/5tone)	1/5tone	1/3tone	1/3tone
8th	1/4tone	1/3tone	2/5tone	2/5tone	(1/3tone)	1/3tone	1/2tone	1/2tone

Table No4. Decreasing classification of the combinations of the 1st key with the valves. Green for intervals lower than the average, Orange for intervals higher than the average.

Average interval of the key in the register between the 3rd and the 6th harmonic without the results of the 3rd valve: **1/3tone**

Amount of combinations with an interval below 1/3tone: **10**

Amount of combinations with an interval over 1/3tone: **8**

Amount of combinations with an interval of 1/3tone: **10**

Density of combinations with an interval between 1/4tone-2/5tone: **79%**

As a result of the replacement of the hole with a bigger one, the average intonation of the 1st key became 1/3 of a tone as planned in the beginning of the experiment. Still 10 combinations of valves with this key stay below 1/3 of a tone. The 3rd harmonic in all combinations stays below this interval. Also 5 out of 12 combinations of the last three columns (combinations with valves 2-3, 1-3 plus one combination with 1-2-3) belong to this group. Compared to the measurements before corrections, all tones below the average are found in the same groups.

The combinations which are above 1/3 of a tone are reduced by one (8 in total instead of 9 before the correction). 6 of them can be found in the 6th harmonic which is in general too high in the instrument even before keys. Compared to the first measurement before corrections, all intervals which are above the average belong to the same groups (6th harmonic and last column).

5.2 Analysis of the 2nd key *(measurements after corrections)*

Harmonic	Valve 0	Valve 2	Valve 1	Valve 1-2	Valve 3	Valve 2-3	Valve 1-3	Valve 1-2-3
2nd	1/6tone	no tone effect	no tone effect	-1/6tone	(-1/4tone)	-1/3tone	-1/4tone	-1/4tone
3rd	1/2tone	2/5tone	2/5tone	1/3tone	(1/5tone)	1/4tone	1/3tone	1/3tone
4th	1/2tone	2/5tone	1/2tone	1/2tone	(1/3tone)	1/3tone	1/2tone	1/2tone
5th	1/2tone	1/2tone	1/2tone	1/2tone	(1/3tone)	1/3tone	2/5tone	1/2tone
6th	2/3tone	1/2tone	3/5tone	1/2tone	(2/5tone)	1/2tone	1/2tone	3/5tone
7th	1/3tone	1/3tone	2/5tone	2/5tone	(1/3tone)	1/3tone	2/5tone	1/2tone
8th	1/4tone	1/3tone	1/2tone	1/2tone	(2/5tone)	1/2tone	1/2tone	2/3tone

Table No5. Decreasing classification of the combinations of the 2nd key with the valves. Green for intervals lower than the average, Orange for intervals higher than the average.

Average interval of the key in the register between the 3rd and the 6th harmonic without the results of the 3rd valve: **½ tone**

Amount of combinations with an interval below ½ tone: **10**

Amount of combinations with an interval over ½ tone: **3**

Amount of combinations with an interval of ½ tone: **15**

Density of combinations with an interval between 2/5 tone-3/5 tone: **75%**

As a result of the replacement of the hole with a bigger one, the average intonation of the 2nd key became half of a tone as planned in the beginning of the experiment. The combinations with a result below the average tone are increased by one (10 instead of 9

before the replacement). 6 of them can be found in the 3rd harmonic of most combinations and 6 of them belong to the combinations with the valves 2-3, 1-3 and 1-2-3. Compared to the measurement before the replacement, the notes below the average interval are still in the same positions except for the 5th harmonic of the valve combination 1-2, which improved.

The combinations which are above half a tone are reduced by 6 (3 in total instead of 9 before the correction). All of them belong to the 6th harmonic.

5.3 Analysis of the 3rd key *(measurements after corrections)*

Harmonic	Valve 0	Valve 2	Valve 1	Valve 1-2	Valve 3	Valve 2-3	Valve 1-3	Valve 1-2-3
2nd	1/3tone	1/6tone	1/10tone	no tone effect	(-1/10tone)	-1/5tone	-1/6tone	-1/5tone
3rd	2/3tone	3/5tone	3/5tone	1/2tone	(2/5tone)	2/5tone	2/5tone	1/2tone
4th	3/4tone	2/3tone	2/3tone	3/5tone	(1/2tone)	1/2tone	3/5tone	2/3tone
5th	3/4tone	2/3tone	2/3tone	2/3tone	(1/2tone)	1/2tone	3/5tone	2/3tone
6th	3/4tone	3/4tone	3/4tone	3/4toe	(3/5tone)	2/3tone	3/4tone	3/4tone
7th	1/10tone	1/4tone	2/5tone	1/2tone	(2/5tone)	1/2tone	3/5tone	3/5tone
8th	1/20tone	1/20tone	1/5tone	2/5tone	(1/4tone)	1/2tone	3/4tone	3/4tone

Table No6. Decreasing classification of the combinations of the 3rd key with the valves. Green for intervals lower than the average, Orange for intervals higher than the average.

Average interval of the key in the register between the 3rd and the 6th harmonic without the results of the 3rd valve: **3/4tone**

Amount of combinations with an interval below ¾ tone: **20**

Amount of combinations with an interval over ¾ tone: **0**

Amount of combinations with an interval of ¾ tone: **8**

Density of combinations with an interval between 2/3 tone - 3/4 tone: **60%**

As a result of the replacement of the hole with a bigger one, the average intonation of the 3rd key became 3/4 of a tone as planned in the beginning of the experiment. The combinations with a result below the average tone are increased by 12 (20 instead of 8 before the replacement). There are no combinations with an interval above 3/4 of a tone and the 60% of them have a result between 2/3 and 3/4 of a tone.

The result of the 3rd key reminded me strongly of the first idea of the experiment when I wanted to integrate 2 extra keys for minor and major 3rd interval. As explained in the presentation of the instrument, the reason I didn't go on with this idea is those holes had an unexpected and unpredictable result in each of their harmonics (some even with an interval

lower than the harmonic without key – this is “against” the principle that while opening a hole we should have a higher interval in the same harmonic than with closed hole). Thus I would dare to conclude that, *when modifying a **modern trumpet** by adding keys, the intonation of the keys becomes more unstable when the key is closer to the beginning of the bell (and vice versa: the closer the key to the end of the bell, the more stable the intonation it produces)*

5.4 General conclusions

After one round of corrections on the instrument it is clear that the position and the dimensions of the keys are in the right direction. Further corrections need to be done to improve the intonation of the harmonics for the valves that are mostly affected.

Concluding the measurements above and the ones in the Appendix, the most affected harmonics of the instrument are the 2nd and the 6th while the valves with the bigger intonation problems are the 2nd and the 3rd as well as their combination.

Harmonic	Valve 0	Valve 2	Valve 1	Valve 1-2	Valve 3	Valve 2-3	Valve 1-3	Valve 1-2-3
2nd	-37 cents	-59 cents	-58 cents	-70 cents	(-91 cents)	-99 cents	-85 cents	-86 cents
3rd	-7 cents	-14 cents	-3 cents	-2 cents	(-25 cents)	-19 cents	+3 cents	+20 cents
4th	0 cents	-9 cents	+2 cents	+6 cents	(-14 cents)	-9 cents	+17 cents	+29 cents
5th	-8 cents	-13 cents	-1 cents	-6 cents	(-26 cents)	-19 cents	+4 cents	+26 cents
6th	+11 cents	+2 cents	+15 cents	+20 cents	(-6 cents)	+5 cents	+31 cents	+42 cents
7th	-27 cents	-29 cents	-17 cents	-15 cents	(-33 cents)	-28 cents	-3 cents	+16 cents
8th	+3 cents	-3 cents	+11 cents	+18 cents	(-6 cents)	+5 cents	+33 cents	+49 cents

Table no7 Intonation of each combination of valves (without using keys) in all harmonics. Brown for the 2nd harmonic (low in all combinations), blue for the tones with max. 10 cents deviation, yellow for the too low ones, magenta for the two high ones, white for those not used in general.

The theoretical expectation to create decreasing microtonal intervals as long as the keys are combined with the valves (see the order of valve combinations in the tables) is not the case, as seen in the measurements. Apart from the fact that the combinations of valves 1-3 and 1-2-3 are used only for their 2nd and 3rd harmonics in the classical playing, the 3rd harmonic requires an extension of the slide of the 3rd valve in order to improve the anyway high intonation (table no7, last two columns). This is one parameter which doesn't explain how the use of the 1st valve compensates the inaccuracy of the 2nd and 3rd valve and their combination. Some other parameters should—*or could*—be found in comparison to the specifications of the historic instruments with keys. These instruments had different bells (more cylindrical cone with longer height in historical instruments / more conical with shorter height and sharper opening of the bell in modern instruments), different weight (historical

instruments are lighter than the modern ones), different mixture of brass with copper (around 60% copper for historical / varying but generally higher percentage in modern instruments), different thickness in different parts of the bell and of the tubes (0,35mm then / 0,5-0,6mm nowadays), different size of holes in relation to the shape of the bell and they are considered as low instruments. When a performer plays those instruments, (s)he plays on the high register of the instrument which corresponds to the middle register of a modern trumpet. That creates the need of mostly small steps of a tone or a semitone between the harmonics which are performed with the keys. The fact that the keys historically are not placed in absolute positions (because of extra crooks which change the tonality of the instrument between Bb-F) means that their positions are calculated in order to compensate between those tonalities. Important to mention is that also in the historic instruments the intonation of the keys in the low register don 't sound in tune. That means that, apart from the low intonation of the 2nd harmonic of the Microtone - Duplex, the low intonation of the microtone keys in this harmonic shouldn't be surprising.

Another quite important fact to consider is that keyed trumpets were not designed to produce microtones. Using the tonal material of the classical scales is a safe path through which minor tonal inaccuracies can easily be controlled and corrected by the player. Microtonal accuracy in the brass instruments needs quite a high level of technique and control of all parameters of playing (breath, lips, instrument etc.). Microtonal music is not a part of brass instruments' history and therefore it is not deeply explored yet in comparison to other instruments. Surely, while the vibration of the lips is actually simulating the vibration of the vocal folds, a microtonal approach on the use of the brass instruments should be compared to microtonal singing. Hereon the precision of microtonal playing of trumpet should be trained considering the ability for precise listening and singing. It is important that these skills are well developed in order the microtonal material to become a part of the nature of the musician.

Further improvements to be tried in the near future are connected to the general tonal balance of this trumpet in order to approach the normal tonal conditions of a normal trumpet. By doing that and correcting the inaccuracies in the whole range I also expect to achieve better accuracy in the microtonal part.

Further experiments which could arise as next steps after the Microtone - Duplex would be the construction of two keyed trumpets (with all characteristics of historic instruments without valves) which will perform either in 19 and 24 division system. When this target is

achieved, research should provide the knowledge through which construction of a modern trumpet with different microtone keys could be realized much more efficiently.

6. Reflections on improvising on the Microtone - Duplex

Improvising on this new trumpet soon became a challenge. The surprise of all these new sounds and possibilities can be a trap for the improviser. A lot of times in the last three months I felt unable to use the instrument precisely and became confused by the amount of choices. While reflecting on my playing and discussing with my professors, I realized that I was tending to perform on the extremes: on the one hand a minimalistic approach in terms of sound manipulation and tonal material, on the other hand an episodic playing with very fast change of material which shows a difficulty to go into details and to explore the instrument more deeply. At first glance, discovering a new world in your hands looks like a nice and refreshing procedure. It is of course quite necessary to get lost in the possibilities of a new instrument that nobody else has played before, but also nobody can teach you the way to play it.

Reflecting on improvising with an instrument like the Microtone - Duplex made me focus on what I miss in order to develop my own musical language and use the instrument efficiently. The idea to create a series of Etudes which could let me focus on specific technical difficulties while using musical elements in order to let the technique grow with more sense and less automatisms is an idea through which the practice of the instrument can become systematic and bear fruits. This series of Etudes consists of text compositions[12] (basically suggestions) which give the musician plenty of space of open choices regarding the sound and the musical element that s/he wants to work on (rhythmical patterns, pitch, duration, dynamics and so on). The focus is mainly on different combinations of parts of the instrument which could become the basis for creating open musical pieces or for a deep exploration of limited technical combinations through which the player is challenged to discover jewels.

A lot of elements that are the core of the Etudes were discovered by luck during concerts, rehearsals, courses, or while practicing. For example at the Etude No. 6, I tried removing the second bell and using this hole as a mouthpiece during a concert, receiver because I wanted to see what could happen in a low dynamic soundscape when I reversed

12 After trying “Aus den sieben Tagen”, K. Stockhausen (1968) as a basis for improvisation.

the direction of the air stream by using the lead pipe as resonator, and also how the valves influence pitch. During this experiment I used different techniques (like flutter-tongue) and the result reminded me of the blackbird and its unique song. Another element that was discovered while improvising on the instrument, is the “beating” sound (page 10, 3.1 Timbre of the keys) created when two keys are combined. It was a big surprise to hear it during an improvisation I played with a colleague at a quiet part of the piece. My actual intention was to change key but I somehow pressed two at the same time and while letting one key I noticed this small change in the sound. Furthermore, after an exploration of the keys during practice I noticed the distorted sound that is produced when a key isn't clearly open nor closed. This led me taking the decision to slightly modify the 2nd key (after finishing with corrections and measurements) to a key that has mainly the function of distorting the sound.

The list of such examples is long, and it is still quite early to make any deep reflection on the Microtone – Duplex. For this I would need much more time than the almost three months of having the instrument and learning it. The combinations of sounds are as many as the possibilities of the instrument and the limits can be found in the limits of imagination. The Etudes come this short experience and they have the following characteristics:

—they include limits and targets

—the limits are there in order to be explored and to be broken

—the targets are to be discovered and they should be in a dialectic relation to the limits while they redefine each other.

6.1 Nine Etudes

Improvisation Etude No.1

All the fingers of the right hand may explore intimate situations with the keys,
while the left hand plays with the beating position of the switch valve.

Improvisation Etude No.2, “Three elements”

Remove the second slide.
Thumb on the second valve, first finger on the third valve,
second and third finger on the keys.
Merge the sounds.

Improvisation Etude No.3

All tones you can play between F sharp and G 3/4tone.
Play with tension in every dynamic you choose to play.

Improvisation Etude No.4

A whole-tone “romance”
only with the secondary bell and a mute.

Improvisation Etude No.5

Swift the third valve in a close position until the minimum of air can pass.
Remove slide of the first valve.
Make music with all possible sounds. Be aware of the rhythm.

Improvisation Etude No.6, “Haiku der Amsel”

Remove the bell and
put the mouthpiece instead
talk to the blackbird.

Improvisation Etude No.7

Put four drops of water in the third slide.
Remove the second slide.
Make music with the first valve.
Use the second and the third valve to color the music.

Improvisation Etude No.8, “Counterpoint”

On the one: mellow and soft,
on the other: rough and edgy.
Create two characters and let them open.

Improvisation Etude No.9

Put one mouthpiece into each bell.
Keep the third key permanently open.
You can use any other element you like but
stay on the rhythm of 5/8.

7. Appendix

13 All measurements of 7.1 and 7.2 chapters made by Rainer Egger using BIAS 7. Written analysis and calculations by the author.

7.1 Tables of measurements of the Microtone - Duplex after the first installation of keys / before corrections

Measurements of natural length – no valves[14]

Measurement No.1

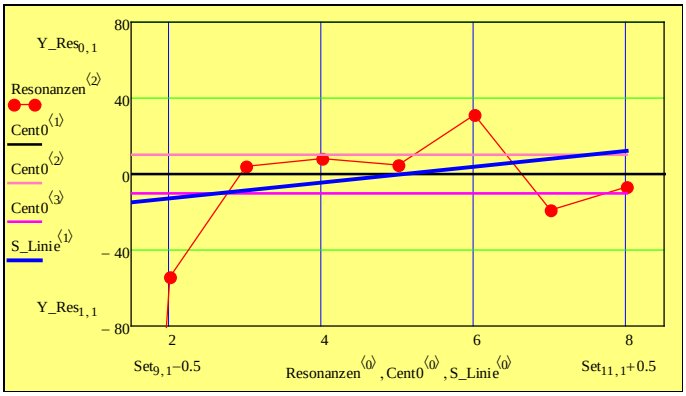
Natural length of the instrument plus 1st key (the closest to the bell, “1/3 of a tone”).

1st Harmonic:	F#	+4 cents		
2nd Harmonic:	C	-7 cents	C	
3rd Harmonic:	G	+41 cents	G 1/5tone	
4th Harmonic:	C	+56 cents	C 1/4tone	(C# -44 cents)
5th Harmonic:	E	+52 cents	E 1/4tone	(F -48 cents)
6th Harmonic:	G	+79 cents	G 2/5tone	(Ab -21 cents)
7th Harmonic:	Bb	+29 cents	Bb 1/6tone	
8th Harmonic:	C	+41 cents	C 1/5tone	

0-Harmonic, 1-Frequence (Hz), 2-Cent deviation, 3-Absolute pitch, 4-Cents, 5-*Number that indicates the necessity of improvements (high number-high necessity)*

Resonanzen =

	0	1	2	3	4	5
0	1	82.96	-643	"E2"	"4Cent"	516.1
1	2	233.23	-54	"Bb3"	"-7Cent"	12.5
2	3	359.16	4	"F4"	"41Cent"	0.3
3	4	483.55	8	"B4"	"-44Cent"	0.8
4	5	607.91	5	"Eb5"	"-48Cent"	0.3
5	6	734.15	31	"Gb5"	"-21Cent"	5.5
6	7	848.38	-19	"Ab5"	"29Cent"	2.5
7	8	958.65	-7	"Bb5"	"41Cent"	0.6



1) black middle horizontal line: ideal intonations
2) pink lines: 10 cents deviation which is considered as normal
3) blue thick diagonal line: direction of the general intonation from deep harmonics towards high harmonics
4) red points: intonation of harmonics
5) x axis: number of harmonics
6) y axis: intonation accuracy in cents

14 All written notes for Bb trumpet/ tables with absolute pitch

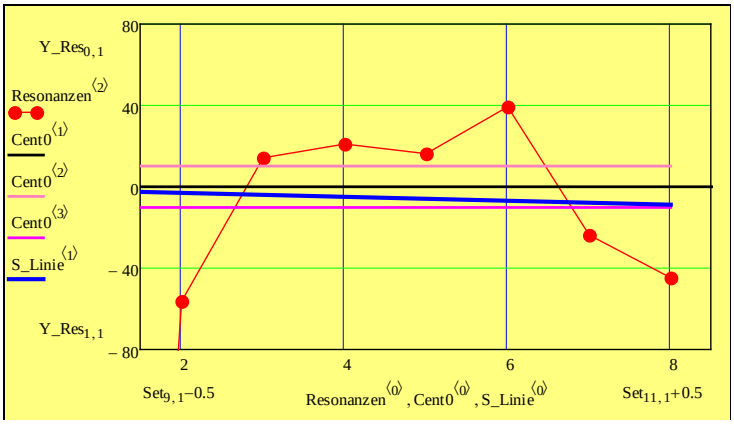
Measurement No.2

Natural length of the instrument plus 2nd key (middle key)

1st Harmonic: F#	+16 cents			
2nd Harmonic: C	-16 cents	C		
3rd Harmonic: G	+75 cents	G 2/5tone	(Ab	-25 cents)
4th Harmonic: C	+92 cents	C 1/2tone	(C#	-8 cents)
5th Harmonic: E	+88 cents	E 2/5tone	(F	-12 cents)
6th Harmonic: G	+111cents	G 1/2tone	(Ab	+11 cents)
7th Harmonic: Bb	+48 cents	Bb 1/4tone		
8th Harmonic: C	+27 cents	C 1/6tone		

Resonanzen =

	0	1	2	3	4	5
0	1	83.54	-656	"E2"	"16Cent"	530.9
1	2	236.27	-56	"Bb3"	"16Cent"	13.2
2	3	366.37	14	"Gb4"	"-25Cent"	1.1
3	4	493.91	21	"B4"	"-8Cent"	
4	5	620.59	16	"Eb5"	"-12Cent"	
5	6	748.09	39	"Gb5"	"11Cent"	7.3
6	7	857.77	-24	"Ab5"	"48Cent"	3.1
7	8	951.15	-45	"Bb5"	"27Cent"	9.4



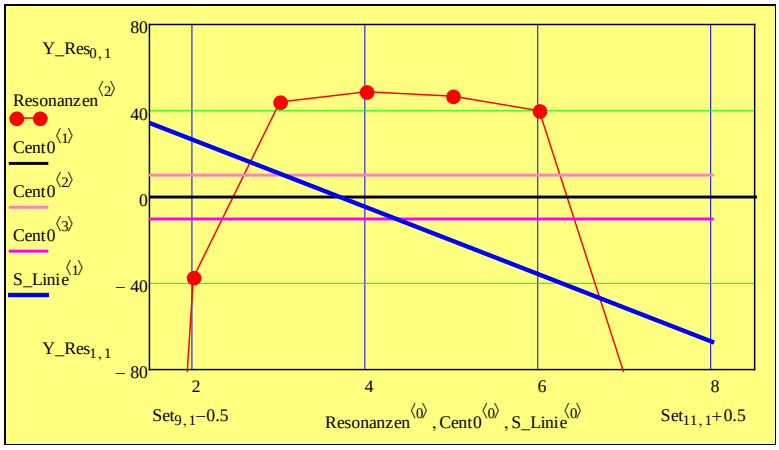
Measurement No.3

Natural length of the instrument plus 3rd key (closest to the mouthpiece, “3/4 of a tone”)

1st Harmonic: F#	+37 cents			
2nd Harmonic: C	+52 cents	C 1/4tone	(C#	-48 cents)
3rd Harmonic: G	+122cents	G 3/5tone	(Ab	+22 cents)
4th Harmonic: C	+137cents	C 2/3tone	(C#	+37 cents)
5th Harmonic: E	+136cents	E 2/3tone	(F	+36 cents)
6th Harmonic: G	+129cents	G 2/3tone	(Ab	+29 cents)
7th Harmonic: Bb	+5 cents	Bb		
8th Harmonic: C	-6 cents	C		

Resonanzen =

	0	1	2	3	4	5
0	1	84.57	-651	"E2"	"37Cent"	525.7
1	2	241.2	-37	"B3"	"-48Cent"	7.1
2	3	376.31	44	"Gb4"	"22Cent"	9.2
3	4	506.9	49	"B4"	"37Cent"	10.8
4	5	637.99	47	"Eb5"	"36Cent"	10.2
5	6	755.92	40	"Gb5"	"29Cent"	8.1
6	7	836.71	-84	"Ab5"	"5Cent"	24.2
7	8	933.29	-94	"Bb5"	"-6Cent"	29



Measurements of 2nd valve.

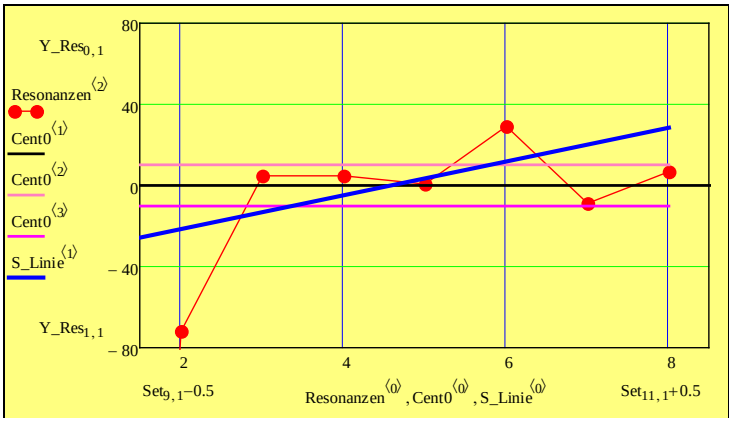
Measurement No.4

Instrument with 2nd valve plus 1st key

1st Harmonic:	E	+50 cents	
2nd Harmonic:	B	-31 cents	(Bb 1/3tone)
3rd Harmonic:	F#	+35 cents	F#1/6tone
4th Harmonic:	B	+46 cents	B 1/4tone
5th Harmonic:	D#	+41 cents	D#1/5tone
6th Harmonic:	F#	+69 cents	F#1/3tone (G -31 cents)
7th Harmonic:	A	+31 cents	A 1/6tone
8th Harmonic:	B	+47 cents	B 1/4tone

Resonanzen =

	0	1	2	3	4	5
0	1	75.92	-690	"D2"	"50Cent"	573.2
1	2	217.04	-72	"A3"	"-31Cent"	19.1
2	3	337.76	5	"E4"	"35Cent"	0.3
3	4	453.79	5	"A4"	"46Cent"	0.4
4	5	570.21	1	"Db5"	"41Cent"	0
5	6	689.28	29	"F5"	"-31Cent"	4.9
6	7	801.85	-9	"G5"	"31Cent"	0.9
7	8	908.37	7	"A5"	"47Cent"	0.6



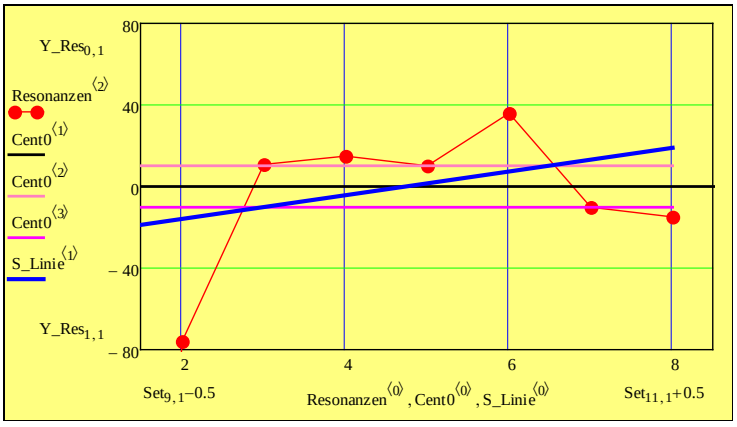
Measurement No.5

Instrument with 2nd valve plus 2nd key

1st Harmonic: F	-37 cents		
2nd Harmonic: B	-12 cents		
3rd Harmonic: F#	+65 cents	F#1/3tone	(G -35 cents)
4th Harmonic: B	+80 cents	B 1/3tone	(C -20 cents)
5th Harmonic: D#	+75 cents	D#1/3tone	(E -25 cents)
6th Harmonic: F#	+101cents	F#1/2tone	(G +1 cents)
7th Harmonic: A	+55 cents	A 1/4tone	(Bb -45 cents)
8th Harmonic: B	+50 cents	B 1/4tone	(B +50 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	76.49	-701	"Eb2"	"-37Cent"	587.5
1	2	219.5	-76	"A3"	"-12Cent"	21.1
2	3	343.82	11	"F4"	"-35Cent"	1.2
3	4	462.73	15	"Bb4"	"-20Cent"	1.8
4	5	581.37	10	"D5"	"-25Cent"	1
5	6	701.92	36	"F5"	"1Cent"	6.8
6	7	813	-10	"Ab5"	"-45Cent"	1
7	8	909.68	-15	"A5"	"50Cent"	1.8



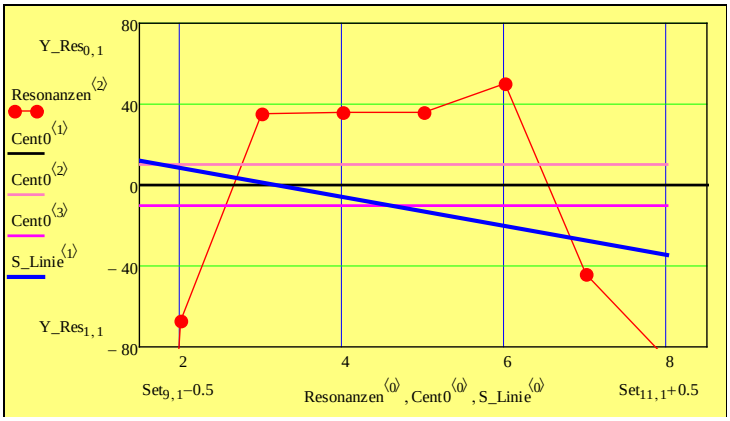
Measurement No.6

Instrument with 2nd valve plus 3rd key

1st Harmonic: F	-18 cents		
2nd Harmonic: B	+19 cents	B 1/10tone	
3rd Harmonic: F#	+110cents	F#3/5tone	(G +10 cents)
4th Harmonic: B	+122cents	B 3/5tone	(C +22 cents)
5th Harmonic: D#	+122cents	D#3/5tone	(E +22 cents)
6th Harmonic: F#	+136cents	F#2/3tone	(G +36 cents)
7th Harmonic: A	+42 cents	A 1/5tone	(A +42 cents)
8th Harmonic: B	+0 cents	B	

Resonanzen =

	0	1	2	3	4	5
0	1	77.33	-704	"Eb2"	"-18Cent"	590.1
1	2	223.38	-67	"A3"	"19Cent"	17.4
2	3	352.76	35	"F4"	"10Cent"	6.5
3	4	474.26	36	"Bb4"	"22Cent"	6.9
4	5	597.48	36	"D5"	"22Cent"	6.9
5	6	716.15	50	"F5"	"36Cent"	11.1
6	7	807.02	-44	"G5"	"42Cent"	9.1
7	8	883.67	-86	"A5"	"0Cent"	25.3



Measurements of 1st valve.

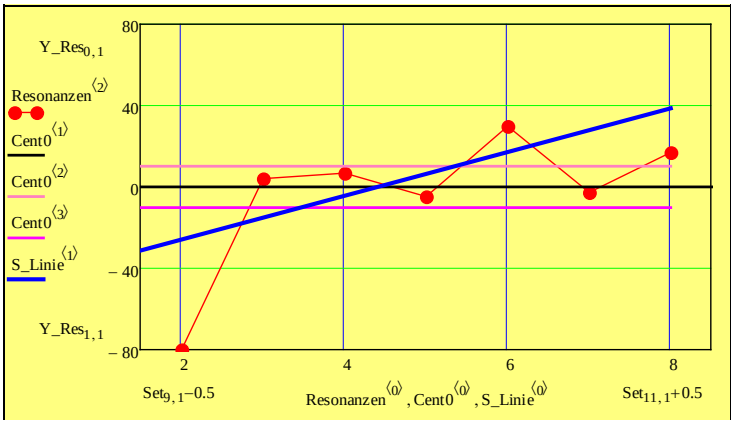
Measurement No.7

Instrument with 1st valve plus 1st key

1st Harmonic: Eb	+30 cents		
2nd Harmonic: Bb	-32 cents	(A 1/3tone)	
3rd Harmonic: F	+41cents	F 1/5tone	
4th Harmonic: Bb	+54cents	Bb1/4tone	(B -46 cents)
5th Harmonic: D	+43cents	D 1/5tone	
6th Harmonic: F	+78cents	F2/5tone	(F# -22 cents)
7th Harmonic: Ab	+44 cents	Ab1/5tone	
8th Harmonic: Bb	+65 cents	Bb1/3tone	(B -35 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	70.83	-717	"Db2"	"30Cent"	607.7
1	2	204.72	-80	"Ab3"	"-32Cent"	22.6
2	3	320.06	4	"Eb4"	"41Cent"	0.3
3	4	430.44	7	"A4"	"-46Cent"	0.5
4	5	538.76	-5	"C5"	"43Cent"	0.3
5	6	653.65	30	"E5"	"-22Cent"	5.1
6	7	762.62	-3	"Gb5"	"44Cent"	0.2
7	8	866.26	17	"A5"	"-35Cent"	2.3



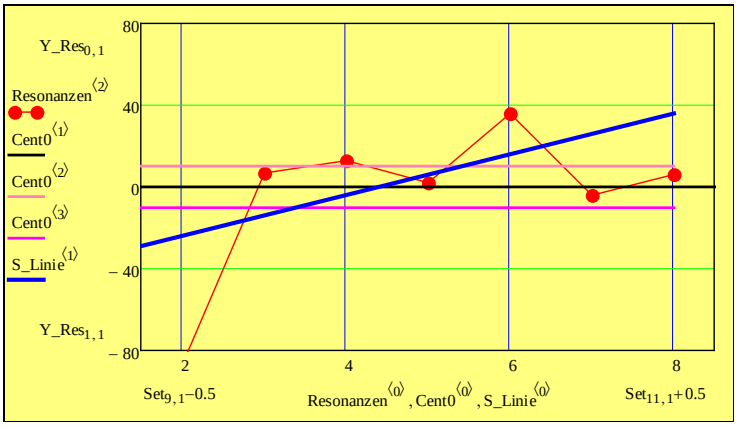
Measurement No.8

Instrument with 1st valve plus 2nd key

1st Harmonic: Eb	+41 cents		
2nd Harmonic: Bb	-14 cents	Bb	
3rd Harmonic: F	+69 cents	F 1/3tone	(F# -31 cents)
4th Harmonic: Bb	+86 cents	Bb2/5tone	(B -14 cents)
5th Harmonic: D	+75 cents	D 2/5tone	(Eb -25 cents)
6th Harmonic: F	+109cents	F 1/2tone	(F# +9 cents)
7th Harmonic: Ab	+69 cents	Ab1/3tone	(A -31 cents)
8th Harmonic: Bb	+79 cents	Bb2/5tone	(B -21 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	71.29	-732	"Db2"	"41Cent"	626.1
1	2	206.93	-87	"Ab3"	"-14Cent"	25.7
2	3	325.29	7	"E4"	"-31Cent"	0.6
3	4	438.42	13	"A4"	"-14Cent"	1.4
4	5	548.89	2	"Db5"	"-25Cent"	0.1
5	6	665.77	36	"E5"	"9Cent"	6.8
6	7	773.7	-4	"G5"	"-31Cent"	0.3
7	8	873.27	6	"A5"	"-21Cent"	0.4



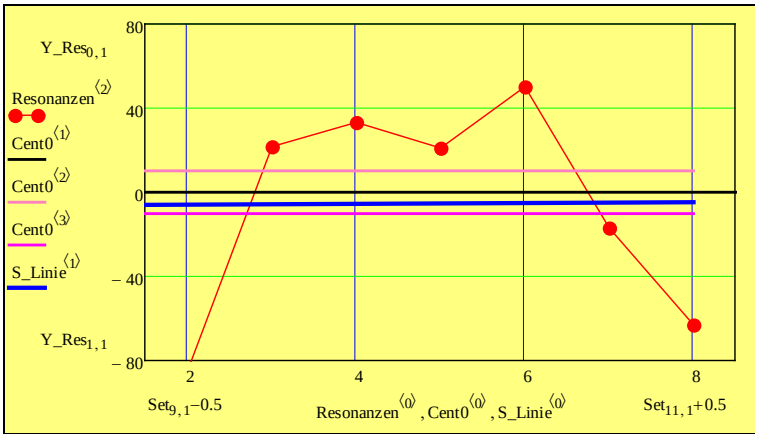
Measurement No.9

Instrument with 1st valve plus 3rd key

1st Harmonic: E	-42 cents		
2nd Harmonic: Bb	+12 cents	Bb1/20tone	
3rd Harmonic: F	+109 cents	F 1/2tone	(F# +9 cents)
4th Harmonic: Bb	+130 cents	Bb2/3tone	(B +30 cents)
5th Harmonic: D	+118 cents	D 3/5tone	(Eb +18 cents)
6th Harmonic: F	+148cents	F 3/4tone	(F# +48 cents)
7th Harmonic: Ab	+80 cents	Ab2/5tone	(A -20 cents)
8th Harmonic: Bb	+34 cents	Bb1/6tone	(Bb +34 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	71.99	-739	"D2"	"-42Cent"	634.9
1	2	210.06	-85	"Ab3"	"12Cent"	24.7
2	3	332.74	22	"E4"	"9Cent"	3.3
3	4	449.69	33	"A4"	"30Cent"	6
4	5	562.69	21	"Db5"	"18Cent"	3
5	6	680.65	50	"E5"	"48Cent"	11.3
6	7	778.63	-17	"G5"	"-20Cent"	2.2
7	8	850.67	-63	"Ab5"	"34Cent"	16



Measurements of 1st and 2nd valve combined.

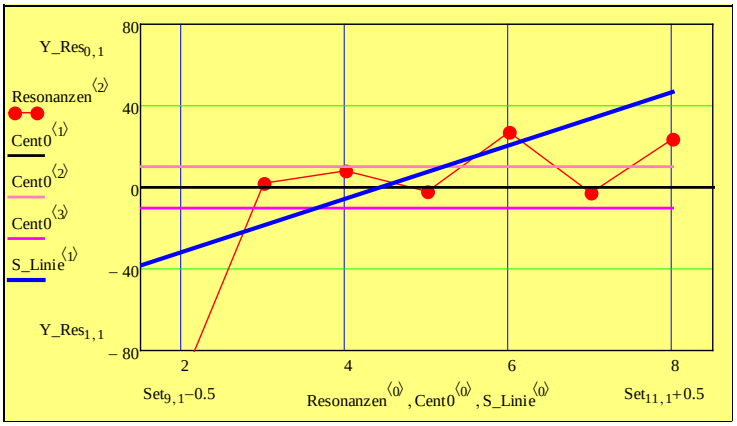
Measurement No.10

Instrument with 1st & 2nd valve plus 1st key

1st Harmonic: D	-5 cents		
2nd Harmonic: A	-47 cents	(Ab1/4tone)	
3rd Harmonic: E	+39 cents	E 1/5tone	
4th Harmonic: A	+56 cents	A 1/4tone	(Bb -44 cents)
5th Harmonic: C#	+46 cents	C#1/4tone	
6th Harmonic: E	+75 cents	E 2/5tone	(F -25 cents)
7th Harmonic: G	+45 cents	G 1/4tone	
8th Harmonic: A	+72 cents	A 1/3tone	(Bb -28 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	65.5	-753	"C2"	"-5Cent"	653.6
1	2	191.62	-95	"G3"	"-47Cent"	29.2
2	3	301.65	2	"D4"	"39Cent"	0.1
3	4	406.66	8	"Ab4"	"-44Cent"	0.7
4	5	509.44	-2	"B4"	"46Cent"	0.1
5	6	616.03	27	"Eb5"	"-25Cent"	4.4
6	7	720.22	-3	"F5"	"45Cent"	0.1
7	8	820.95	24	"Ab5"	"-28Cent"	3.7



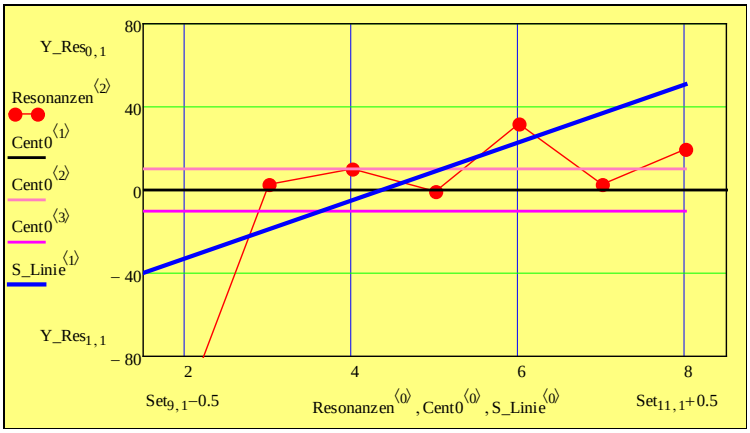
Measurement No.11

Instrument with 1st & 2nd valve plus 2nd key

1st Harmonic: D	+1 cent		
2nd Harmonic: A	-31 cents	Ab1/3tone	
3rd Harmonic: E	+64 cents	E 1/3tone	(F -36 cents)
4th Harmonic: A	+81 cents	A 2/5tone	(Bb -19 cents)
5th Harmonic: C#	+71 cents	C#1/3tone	(D -29 cents)
6th Harmonic: E	+104 cents	E 1/2tone	(F +4 cents)
7th Harmonic: G	+75 cents	G 2/5tone	(Ab -25 cents)
8th Harmonic: A	+98 cents	A 1/2tone	(Bb -8 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	65.75	-770	"C2"	"1Cent"	676.2
1	2	193.33	-103	"G3"	"-31Cent"	33.1
2	3	306.03	3	"Eb4"	"-36Cent"	0.1
3	4	412.7	10	"Ab4"	"-19Cent"	1
4	5	516.84	-1	"C5"	"-29Cent"	0
5	6	626.39	32	"Eb5"	"4Cent"	5.7
6	7	732.49	3	"Gb5"	"-25Cent"	0.1
7	8	830.57	20	"Ab5"	"-8Cent"	2.9



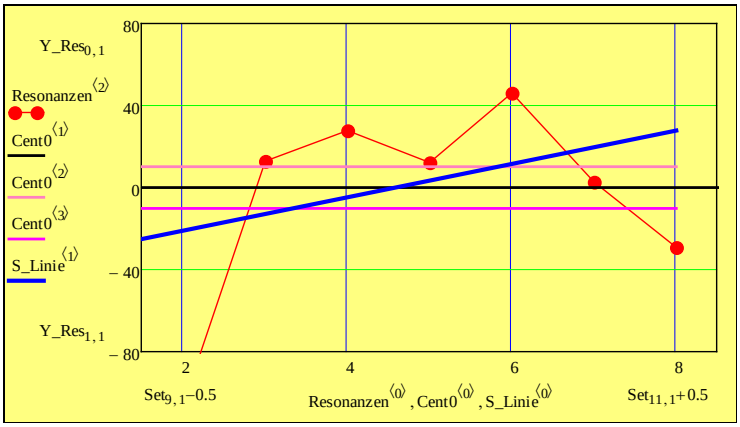
Measurement No.12

Instrument with 1st & 2nd valve plus 3rd key

1st Harmonic: D	+19 cents		
2nd Harmonic: A	-9 cents	A	
3rd Harmonic: E	+100 cents	E 1/2tone	(F 0 cents)
4th Harmonic: A	+125 cents	A 2/3tone	(Bb +25 cents)
5th Harmonic: C#	+109 cents	C#1/2tone	(D +9 cents)
6th Harmonic: E	+143 cents	E 3/4tone	(F +43 cents)
7th Harmonic: G	+100 cents	G 1/2tone	(Ab 0 cents)
8th Harmonic: A	+67 cents	A 1/3tone	(Bb -33 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	66.41	-778	"C2"	"19Cent"	686.5
1	2	195.83	-106	"G3"	"-9Cent"	34.5
2	3	312.43	13	"Eb4"	"0Cent"	1.6
3	4	423.27	28	"Ab4"	"25Cent"	4.8
4	5	528.43	12	"C5"	"9Cent"	1.4
5	6	640.63	46	"Eb5"	"43Cent"	9.7
6	7	743.42	3	"Gb5"	"0Cent"	0.2
7	8	818.76	-29	"Ab5"	"-33Cent"	5.1



Measurements of 3rd valve.

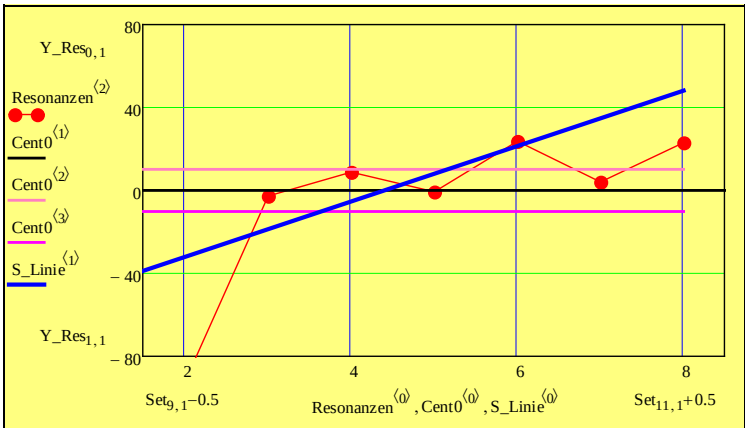
Measurement No.13

Instrument with 3rd valve plus 1st key

1st Harmonic: D	-40 cents		
2nd Harmonic: A	-68 cents	(Ab 1/6tone)	(Ab +32 cents)
3rd Harmonic: E	+10 cents	E	
4th Harmonic: A	+33 cents	A 1/6tone	
5th Harmonic: C#	+23 cents	C#1/8tone	
6th Harmonic: E	+48 cents	E 1/4tone	
7th Harmonic: G	+28 cents	G 1/6tone	
8th Harmonic: A	+47 cents	A 1/4tone	

Resonanzen =

	0	1	2	3	4	5
0	1	64.21	-763	"C2"	"-40Cent"	667.1
1	2	189.26	-92	"Gb3"	"32Cent"	27.9
2	3	296.61	-3	"D4"	"10Cent"	0.2
3	4	401.26	9	"G4"	"33Cent"	0.8
4	5	502.75	-1	"B4"	"23Cent"	0
5	6	606.7	24	"D5"	"48Cent"	3.8
6	7	712.96	4	"F5"	"28Cent"	0.2
7	8	809.25	23	"G5"	"47Cent"	3.6



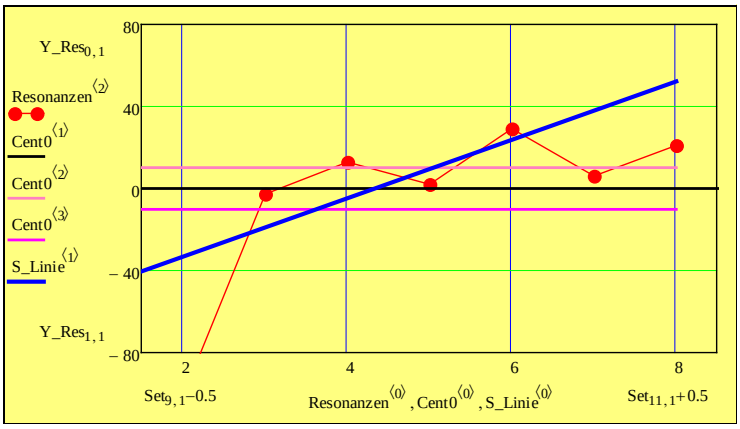
Measurement No.14

Instrument with 3rd valve plus 2nd key

1st Harmonic: D	-28 cents		
2nd Harmonic: A	-53 cents	Ab1/4tone	
3rd Harmonic: E	+34 cents	E 1/6tone	(Ab +47 cents)
4th Harmonic: A	+60 cents	A 1/3tone	(Bb -40 cents)
5th Harmonic: C#	+50 cents	C#1/4tone	
6th Harmonic: E	+78 cents	E 2/5tone	(F -22 cents)
7th Harmonic: G	+54 cents	G 1/4tone	(Ab -46 cents)
8th Harmonic: A	+69 cents	A 1/3tone	(Bb -31 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	64.66	-776	"C2"	"-28Cent"	683
1	2	190.96	-101	"Gb3"	"47Cent"	32
2	3	300.82	-3	"D4"	"34Cent"	0.2
3	4	407.74	13	"Ab4"	"-40Cent"	1.4
4	5	510.59	2	"B4"	"50Cent"	0.1
5	6	617.01	29	"Eb5"	"-22Cent"	5.1
6	7	723.66	6	"Gb5"	"-46Cent"	0.4
7	8	819.58	21	"Ab5"	"-31Cent"	3.1



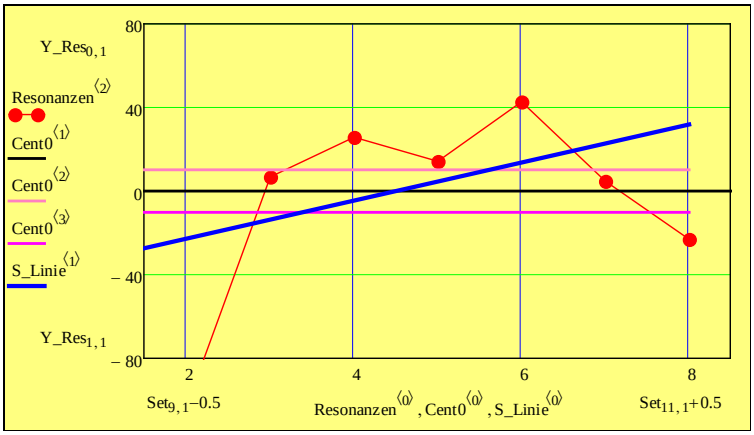
Measurement No.15

Instrument with 3rd valve plus 3rd key

1st Harmonic: D	-14 cents			
2nd Harmonic: A	-29 cents	Ab1/3tone		
3rd Harmonic: E	+70 cents	E 1/3tone	(F	-30 cents)
4th Harmonic: A	+99 cents	A 1/2tone	(Bb	-1 cents)
5th Harmonic: C#	+88 cents	C#2/5tone	(D	-12 cents)
6th Harmonic: E	+117 cents	E 3/5tone	(F	+17 cents)
7th Harmonic: G	+79 cents	G 2/5tone	(Ab	-21 cents)
8th Harmonic: A	+50 cents	A 1/4tone		

Resonanzen =

	0	1	2	3	4	5
0	1	65.17	-787	"C2"	"-14Cent"	698.7
1	2	193.56	-103	"G3"	"-29Cent"	33
2	3	307.11	7	"Eb4"	"-30Cent"	0.6
3	4	416.94	26	"Ab4"	"-1Cent"	4.1
4	5	521.82	14	"C5"	"-12Cent"	1.7
5	6	631.16	43	"Eb5"	"17Cent"	9
6	7	734.23	5	"Gb5"	"-21Cent"	0.4
7	8	810.53	-23	"G5"	"50Cent"	3.6



Measurements of 2nd and 3rd valve combined.

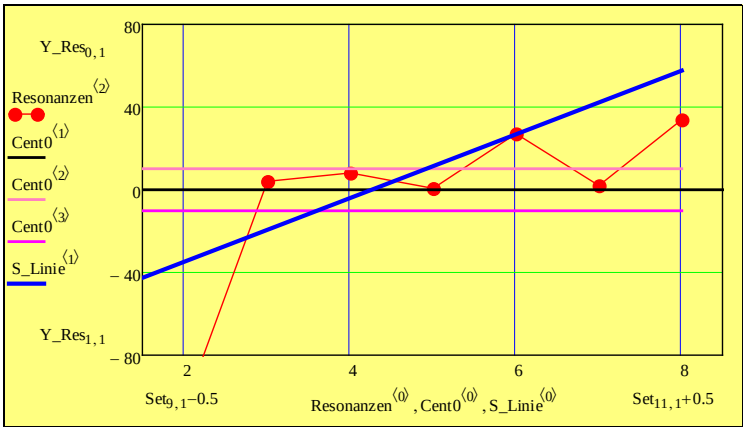
Measurement No.22

Instrument with 2nd & 3rd valve plus 1st key

1st Harmonic: C	+37 cents		
2nd Harmonic: Ab	-83 cents	(G 1/10tone)	(G +17 cents)
3rd Harmonic: Eb	+15 cents	Eb1/10tone	
4th Harmonic: Ab	+30 cents	Ab1/6tone	
5th Harmonic: C	+24 cents	C 1/8tone	
6th Harmonic: Eb	+49 cents	Eb1/4tone	
7th Harmonic: Gb	+24 cents	Gb1/8tone	
8th Harmonic: Ab	+56 cents	Ab1/4tone	(A -44 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	59.79	-785	"Bb1"	"37Cent"	695.7
1	2	177.12	-105	"F3"	"17Cent"	34
2	3	280.83	4	"Db4"	"15Cent"	0.2
3	4	378.15	8	"Gb4"	"30Cent"	0.7
4	5	474.64	1	"Bb4"	"24Cent"	0.1
5	6	572.96	27	"Db5"	"49Cent"	4.5
6	7	671.52	2	"E5"	"24Cent"	0.1
7	8	767.58	34	"G5"	"-44Cent"	6.2



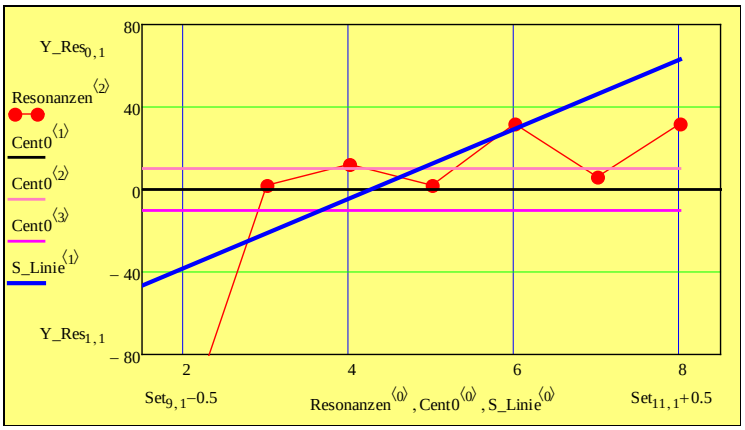
Measurement No.23

Instrument with 2nd & 3rd valve plus 2nd key

1st Harmonic: C	+48 cents		
2nd Harmonic: Ab	-70 cents	G 1/6tone	(G +30 cents)
3rd Harmonic: Eb	+37 cents	Eb1/5tone	
4th Harmonic: Ab	+57 cents	Ab1/4tone	(A -43 cents)
5th Harmonic: C	+48 cents	C 1/4tone	
6th Harmonic: Eb	+78 cents	Eb2/5tone	(E -22 cents)
7th Harmonic: Gb	+52 cents	Gb1/4tone	(G -48 cents)
8th Harmonic: Ab	+78 cents	Ab2/5tone	(A -22 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	60.17	-798	"Bb1"	"48Cent"	712.8
1	2	178.48	-116	"F3"	"30Cent"	39.3
2	3	284.41	2	"Db4"	"37Cent"	0.1
3	4	384.15	12	"G4"	"-43Cent"	1.2
4	5	481.39	2	"Bb4"	"48Cent"	0.1
5	6	582.61	32	"D5"	"-22Cent"	5.8
6	7	682.27	6	"F5"	"-48Cent"	0.4
7	8	777.42	32	"G5"	"-22Cent"	5.7



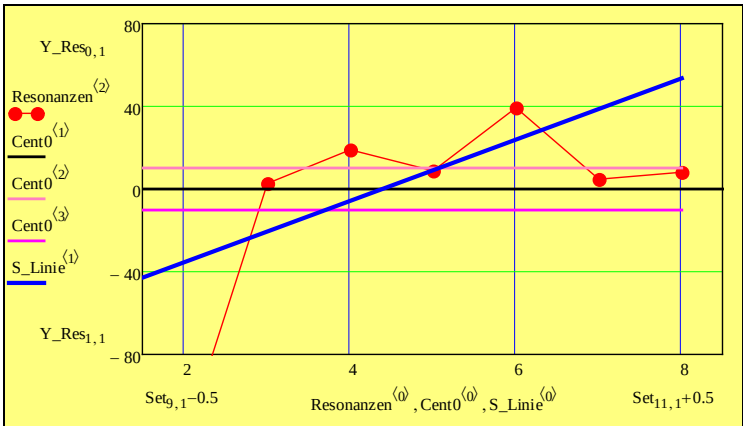
Measurement No.24

Instrument with 2nd & 3rd valve plus 3rd key

1st Harmonic: C	+46 cents		
2nd Harmonic: Ab	-42 cents	G 1/6tone	
3rd Harmonic: Eb	+72 cents	Eb1/3tone	(E -28 cents)
4th Harmonic: Ab	+99 cents	Ab1/2tone	(A -1 cent)
5th Harmonic: C	+89 cents	C 2/5tone	(C# -11 cents)
6th Harmonic: Eb	+119 cents	Eb3/5tone	(E +19 cents)
7th Harmonic: Gb	+85 cents	Gb2/5tone	(G -15 cents)
8th Harmonic: Ab	+88 cents	Ab2/5tone	(A -12 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	60.09	-834	"Bb1"	"46Cent"	762.2
1	2	181.33	-122	"Gb3"	"-42Cent"	42.8
2	3	290.32	3	"D4"	"-28Cent"	0.2
3	4	393.53	19	"G4"	"-1Cent"	2.7
4	5	492.94	9	"B4"	"-11Cent"	0.8
5	6	596.46	39	"D5"	"19Cent"	7.7
6	7	695.53	5	"F5"	"-15Cent"	0.3
7	8	781.97	8	"G5"	"-12Cent"	0.7



Measurements of 1st and 3rd valve combined.

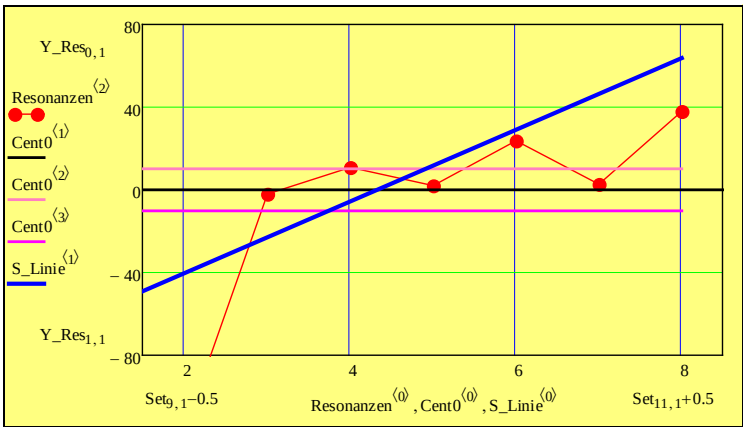
Measurement No.16

Instrument with 1st & 3rd valve plus 1st key

1st Harmonic: B	+36 cents			
2nd Harmonic: G	-69 cents	F#1/6tone	(F#	+31 cents)
3rd Harmonic: D	+34 cents	D 1/6tone		
4th Harmonic: G	+58 cents	G 1/3tone	(Ab	-42 cents)
5th Harmonic: B	+49 cents	B 1/4tone		
6th Harmonic: D	+71 cents	D 1/3tone	(Eb	-29 cents)
7th Harmonic: F	+50 cents	G 1/4tone	(F	+50 cents)
8th Harmonic: G	+85 cents	A 2/5tone	(Ab	-15 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	56.42	-810	"A1"	"36Cent"	729.5
1	2	168.53	-116	"E3"	"31Cent"	39.5
2	3	267.95	-2	"C4"	"34Cent"	0.1
3	4	362.79	11	"Gb4"	"-42Cent"	1.2
4	5	454.7	2	"A4"	"49Cent"	0.1
5	6	547.67	24	"Db5"	"-29Cent"	3.8
6	7	643.17	3	"Eb5"	"50Cent"	0.1
7	8	736.86	38	"Gb5"	"-15Cent"	7.5



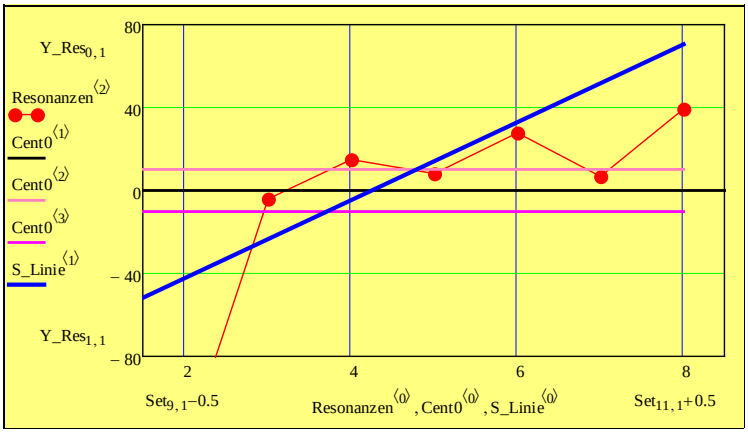
Measurement No.17

Instrument with 1st & 3rd valve plus 2nd key

1st Harmonic: B	+41 cents		
2nd Harmonic: G	-57 cents	F#1/4tone	(F# +43 cents)
3rd Harmonic: D	+53 cents	D 1/4tone	(Eb -47 cents)
4th Harmonic: G	+83 cents	G 2/5tone	(Ab -17 cents)
5th Harmonic: B	+76 cents	B 2/5tone	(C -24 cents)
6th Harmonic: D	+97 cents	D 1/2tone	(Eb -3 cents)
7th Harmonic: F	+75 cents	F 2/5tone	(F# -25 cents)
8th Harmonic: G	+107 cents	G 1/2tone	(Ab +7 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	56.58	-826	"A1"	"41Cent"	751.4
1	2	169.69	-125	"E3"	"43Cent"	44.2
2	3	270.95	-4	"Db4"	"-47Cent"	0.3
3	4	367.93	15	"Gb4"	"-17Cent"	1.8
4	5	461.89	8	"Bb4"	"-24Cent"	0.8
5	6	555.72	28	"Db5"	"-3Cent"	4.8
6	7	652.63	7	"E5"	"-25Cent"	0.6
7	8	746.29	39	"Gb5"	"7Cent"	7.7



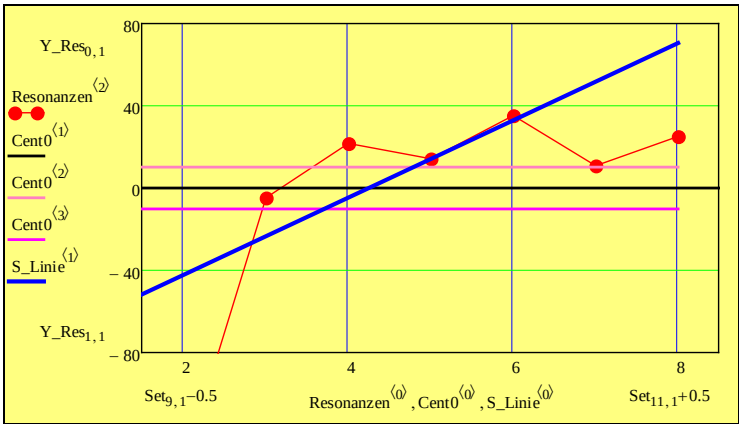
Measurement No.18

Instrument with 1st & 3rd valve plus 3rd key

1st Harmonic: C	-45 cents		
2nd Harmonic: G	-39 cents	F#1/5tone	
3rd Harmonic: D	+80 cents	D 2/5tone	(Eb -20 cents)
4th Harmonic: G	+118cents	G 3/5tone	(Ab +18 cents)
5th Harmonic: B	+110cents	B 3/5tone	(C +10 cents)
6th Harmonic: D	+131 cents	D 2/3tone	(Eb +31 cents)
7th Harmonic: F	+107 cents	F 1/2tone	(F# +7 cents)
8th Harmonic: G	+121 cents	G 3/5tone	(Ab +21 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	57.04	-841	"Bb1"	"-45Cent"	770.9
1	2	171.45	-135	"F3"	"-39Cent"	49.8
2	3	275.19	-5	"Db4"	"-20Cent"	0.4
3	4	375.54	22	"Gb4"	"18Cent"	3.3
4	5	470.9	14	"Bb4"	"10Cent"	1.6
5	6	566.84	35	"Db5"	"31Cent"	6.4
6	7	664.86	11	"E5"	"7Cent"	1.1
7	8	752.53	25	"Gb5"	"21Cent"	4



Measurements of 1st, 2nd and 3rd valve combined.

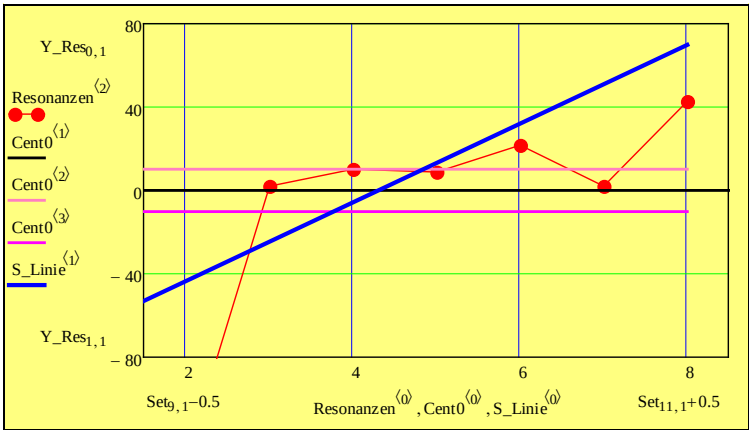
Measurement No.19

Instrument with 1st& 2nd & 3rd valve plus 1st key

1st Harmonic: Bb	+29 cents		
2nd Harmonic: F#	-71 cents	F 1/6tone	(F +29 cents)
3rd Harmonic: C#	+49 cents	C#1/4tone	
4th Harmonic: F#	+68 cents	F#1/3tone	(G -32 cents)
5th Harmonic: A#	+67cents	A#1/3tone	(B -33 cents)
6th Harmonic: C#	+80 cents	C#2/5tone	(D -20 cents)
7th Harmonic: E	+61 cents	E 1/3tone	(F -39 cents)
8th Harmonic: F#	+101 cents	F#1/2tone	(G +1 cent)

Resonanzen =

	0	1	2	3	4	5
0	1	53.03	-829	"Ab1"	"29Cent"	754.8
1	2	158.88	-129	"Eb3"	"29Cent"	46.5
2	3	255.14	2	"B3"	"49Cent"	0.1
3	4	344.36	10	"F4"	"-32Cent"	1
4	5	433.71	9	"A4"	"-33Cent"	0.9
5	6	519.66	22	"C5"	"-20Cent"	3.3
6	7	610.96	2	"Eb5"	"-39Cent"	0.1
7	8	702.06	43	"F5"	"1Cent"	8.9



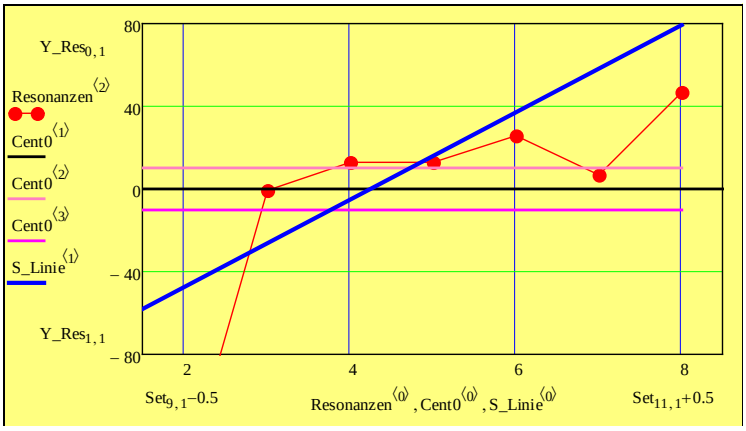
Measurement No.20

Instrument with 1st& 2nd & 3rd valve plus 2nd key

1st Harmonic: Bb	+38 cents		
2nd Harmonic: F#	-61 cents	F 1/5tone	(F +39 cents)
3rd Harmonic: C#	+66 cents	C#1/3tone	(D -34 cents)
4th Harmonic: F#	+91 cents	F#1/2tone	(G -9 cents)
5th Harmonic: A#	+92cents	A#1/2tone	(B -8 cents)
6th Harmonic: C#	+105 cents	C#1/2tone	(D +5 cents)
7th Harmonic: E	+85 cents	E 2/5tone	(F -15 cents)
8th Harmonic: F#	+125 cents	F#2/3tone	(G +25 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	53.29	-841	"Ab1"	"38Cent"	770.7
1	2	159.79	-140	"Eb3"	"39Cent"	52.1
2	3	257.7	-1	"C4"	"-34Cent"	0
3	4	348.92	13	"F4"	"-9Cent"	1.4
4	5	439.87	13	"A4"	"-8Cent"	1.6
5	6	527.02	26	"C5"	"5Cent"	4.3
6	7	619.67	7	"Eb5"	"-15Cent"	0.5
7	8	711.77	47	"F5"	"25Cent"	10.1



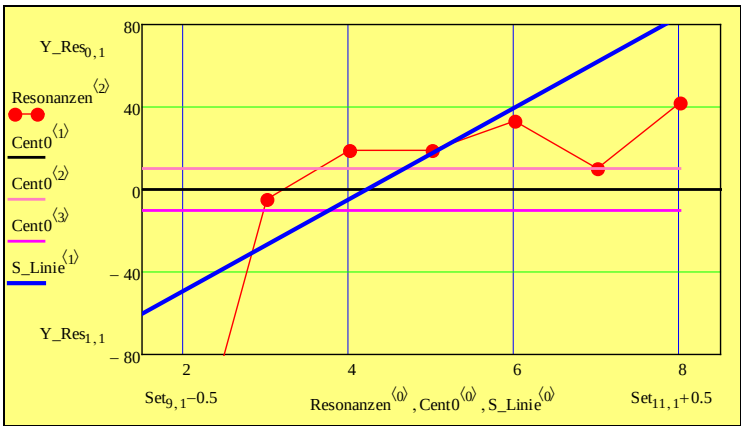
Measurement No.21

Instrument with 1st& 2nd & 3rd valve plus 3rd key

1st Harmonic: Bb	+46 cents		
2nd Harmonic: F#	-45 cents	F 1/4tone	(F# -45 cents)
3rd Harmonic: C#	+90 cents	C#1/2tone	(D -10 cents)
4th Harmonic: F#	+125 cents	F#3/5tone	(G +25 cents)
5th Harmonic: A#	+125cents	A#3/5tone	(B +25 cents)
6th Harmonic: C#	+139 cents	C#2/3tone	(D +39 cents)
7th Harmonic: E	+116 cents	E 3/5tone	(F +16 cents)
8th Harmonic: F#	+148 cents	F#3/4tone	(G +48 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	53.54	-860	"Ab1"	"46Cent"	797.9
1	2	161.29	-151	"E3"	"-45Cent"	58.7
2	3	261.33	-5	"C4"	"-10Cent"	0.3
3	4	355.82	19	"F4"	"25Cent"	2.6
4	5	448.48	19	"A4"	"25Cent"	2.7
5	6	537.7	33	"C5"	"39Cent"	6.1
6	7	630.74	10	"Eb5"	"16Cent"	0.9
7	8	721.16	42	"F5"	"48Cent"	8.5



Extra measurements before proceeding to improvements.

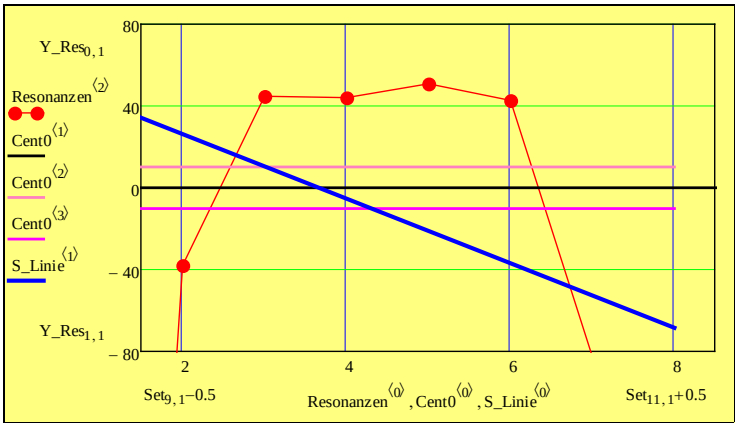
Measurement No.25

Instrument without valve plus 3rd key / ***After correcting intonation by replacing the 10mm hole with a 11mm hole***

1st Harmonic: F#	+48 cents			
2nd Harmonic: C	+61 cents	C 1/3 tone	(C#	-39 cents)
3rd Harmonic: G	+132cents	G 2/3 tone	(Ab	+32 cents)
4th Harmonic: C	+142cents	C ¾ tone	(C#	+42 cents)
5th Harmonic: E	+150cents	E ¾ tone	(F	+50 cents)
6th Harmonic: G	+141cents	G ¾ tone	(Ab	+41 cents)
7th Harmonic: Bb	+15 cents	Bb1/20 tone	(Bb	+15 cents)
8th Harmonic: C	-1 cents	C	(C	-1 cents)

Resonanzen =

	0	1	2	3	4	5
0	1	85.12	-650	"E2"	"48Cent"	524
1	2	242.45	-38	"B3"	"-39Cent"	7.3
2	3	378.63	45	"Gb4"	"32Cent"	9.5
3	4	508.31	44	"B4"	"42Cent"	9.2
4	5	643.19	51	"Eb5"	"50Cent"	11.6
5	6	761.26	43	"Gb5"	"41Cent"	8.9
6	7	841.63	-83	"Ab5"	"15Cent"	24.1
7	8	936	-99	"Bb5"	"-1Cent"	31.2



Measurement No.26

Instrument without valves and keys/ ***measurement of the main bell***

1st Harmonic: F# +3 cents

2nd Harmonic: C -32 cents

3rd Harmonic: G -4 cents

4th Harmonic: C +3 cents

5th Harmonic: E -5 cents

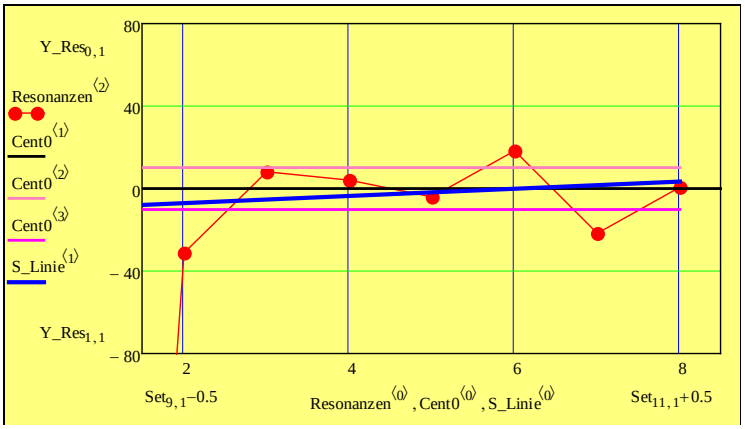
6th Harmonic: G +18cents

7th Harmonic: Bb -23 cents

8th Harmonic: C 0 cents

Resonanzen =

	0	1	2	3	4	5
0	1	82.91	-596	"E2"	"3Cent"	460.4
1	2	229.82	-31	"Bb3"	"-32Cent"	5.5
2	3	350.03	8	"F4"	"-4Cent"	0.7
3	4	469.09	4	"Bb4"	"3Cent"	0.3
4	5	588.22	-4	"D5"	"-5Cent"	0.3
5	6	708.74	18	"F5"	"18Cent"	2.5
6	7	823.31	-22	"Ab5"	"-23Cent"	3.3
7	8	936.63	1	"Bb5"	"0Cent"	0



Measurement No.27

Instrument without valves and keys/ ***measurement of the second bell***

1st Harmonic: F# -21 cents

2nd Harmonic: C -57 cents (B +43 cents)

3rd Harmonic: G -14 cents

4th Harmonic: C -29 cents

5th Harmonic: E -25 cents

6th Harmonic: G -10 cents

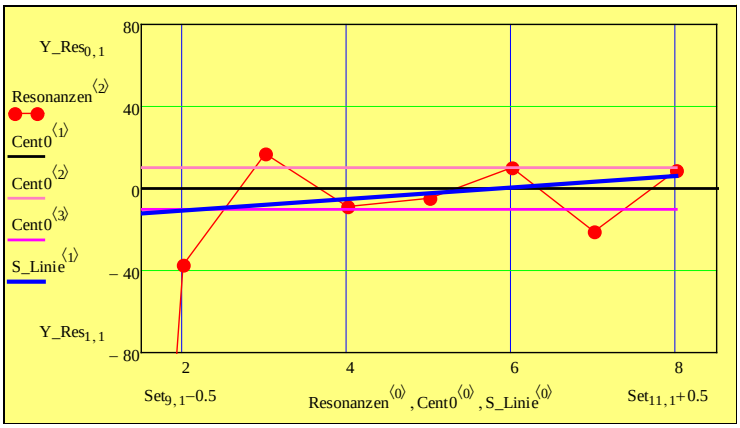
7th Harmonic: Bb -41 cents

8th Harmonic: C -12 cents

Average 1/8 tone lower/ ***<u>solved by reducing the length of the bell.</u>***

Resonanzen =

	0	1	2	3	4	5
0	1	81.79	-600	"E2"	"-21Cent"	465.3
1	2	226.48	-37	"A3"	"43Cent"	7.2
2	3	348.03	17	"F4"	"-14Cent"	2.3
3	4	460.51	-9	"Bb4"	"-29Cent"	0.8
4	5	581.44	-5	"D5"	"-25Cent"	0.4
5	6	697.7	10	"F5"	"-10Cent"	1.1
6	7	814.94	-21	"Ab5"	"-41Cent"	3
7	8	930.17	9	"Bb5"	"-12Cent"	0.8



7.2 Tables of measurements after correcting the dimensions of the holes

Valves without keys

Measurement No.1

Instrument without valves (natural length)

1st Harmonic: F# -6 cents

2nd Harmonic: C -37 cents

3rd Harmonic: G -7 cents

4th Harmonic: C 0 cents

5th Harmonic: E -8 cents

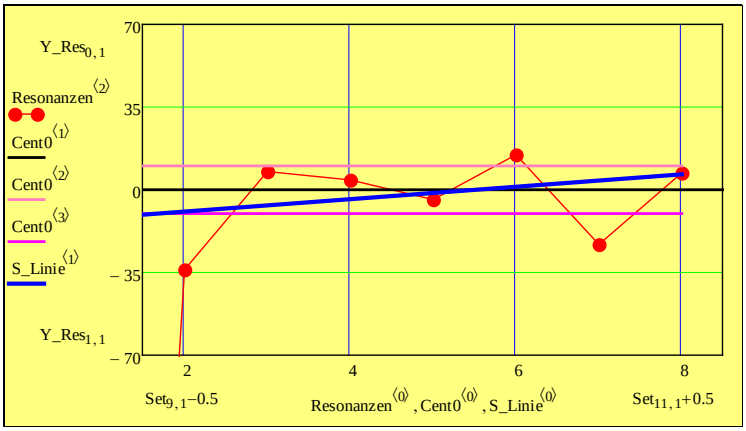
6th Harmonic: G +11cents

7th Harmonic: Bb -27 cents

8th Harmonic: C +3 cents

Resonanzen =

	0	1	2	3	4	5
0	1	82.48	-602	"E2"	"-6Cent"	467.4
1	2	229.12	-34	"Bb3"	"-37Cent"	6.1
2	3	349.41	8	"F4"	"-7Cent"	0.7
3	4	468.36	4	"Bb4"	"0Cent"	0.3
4	5	587.36	-4	"D5"	"-8Cent"	0.2
5	6	706.19	15	"F5"	"11Cent"	1.8
6	7	821.51	-23	"Ab5"	"-27Cent"	3.5
7	8	937.98	7	"Bb5"	"3Cent"	0.5



Measurement No.2

Instrument with 2nd valve

1st Harmonic: E +49 cents

2nd Harmonic: B -59 cents (Bb +41 cents)

3rd Harmonic: F# -14 cents

4th Harmonic: B -9 cents

5th Harmonic: D# -13 cents

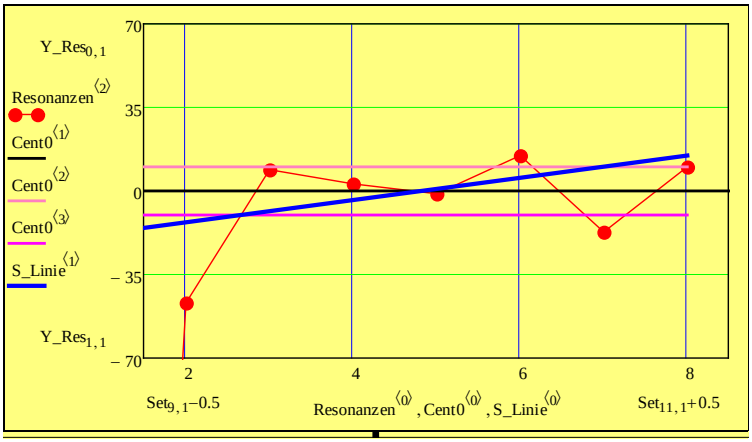
6th Harmonic: F# +2 cents

7th Harmonic: A -29 cents

8th Harmonic: B -3 cents

Resonanzen =

	0	1	2	3	4	5
0	1	75.87	-638	"D2"	"49Cent"	510
1	2	213.53	-47	"Ab3"	"41Cent"	10.2
2	3	328.38	9	"E4"	"-14Cent"	0.8
3	4	439.54	3	"A4"	"-9Cent"	0.2
4	5	552.51	-1	"Db5"	"-13Cent"	0
5	6	663.13	15	"E5"	"2Cent"	1.8
6	7	774.18	-17	"G5"	"-29Cent"	2.3
7	8	882.43	10	"A5"	"-3Cent"	0.9



Measurement No.3

Instrument with 1st valve

1st Harmonic: Eb +16 cents

2nd Harmonic: Bb -58 cents (A +42 cents)

3rd Harmonic: F -3 cents

4th Harmonic: Bb +2 cents

5th Harmonic: D -1 cents

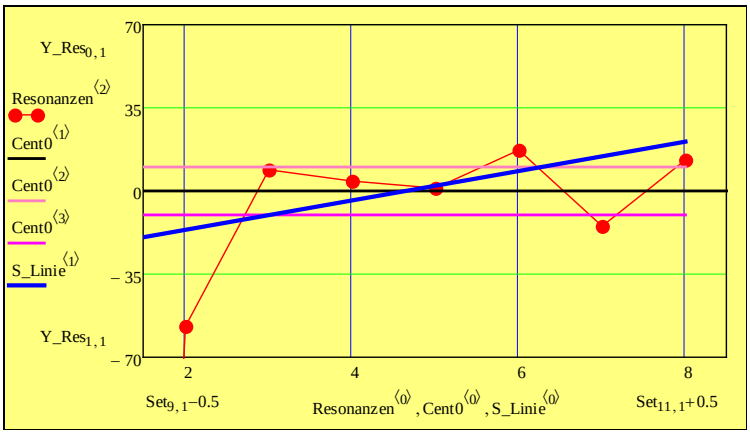
6th Harmonic: F +15cents

7th Harmonic: Ab -17 cents

8th Harmonic: Bb +11cents

Resonanzen =

	0	1	2	3	4	5
0	1	70.25	-683	"Db2"	"16Cent"	563.9
1	2	201.68	-57	"G3"	"42Cent"	13.5
2	3	312	9	"Eb4"	"-3Cent"	0.9
3	4	417.73	4	"Ab4"	"2Cent"	0.2
4	5	525.42	1	"C5"	"-1Cent"	0
5	6	630.57	17	"Eb5"	"15Cent"	2.1
6	7	736.15	-15	"Gb5"	"-17Cent"	1.9
7	8	839.68	13	"Ab5"	"11Cent"	1.4



Measurement No.4

Instrument with 1st and 2nd valve

1st Harmonic: D -14 cents

2nd Harmonic: A -70 cents (Ab +30 cents)

3rd Harmonic: E -2 cents

4th Harmonic: A +6 cents

5th Harmonic: C# -6 cents

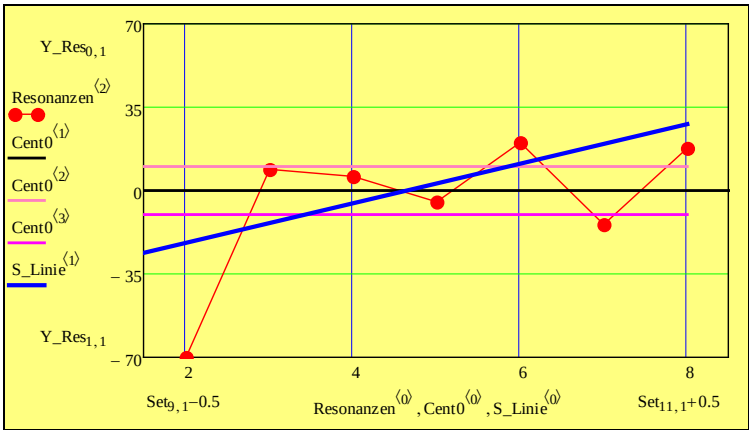
6th Harmonic: E +20cents

7th Harmonic: G -15 cents

8th Harmonic: A +18cents

Resonanzen =

	0	1	2	3	4	5
0	1	65.17	-713	"C2"	"-14Cent"	602.5
1	2	189.04	-70	"Gb3"	"30Cent"	18.4
2	3	294.59	9	"D4"	"-2Cent"	0.9
3	4	395.05	6	"G4"	"6Cent"	0.5
4	5	494.45	-5	"B4"	"-6Cent"	0.4
5	6	596.66	20	"D5"	"20Cent"	2.8
6	7	695.64	-14	"F5"	"-15Cent"	1.7
7	8	795.57	18	"G5"	"18Cent"	2.5



Measurement No.5

Instrument with 3rd valve

1st Harmonic: D -42 cents

2nd Harmonic: A -91 cents (Ab +9 cents)

3rd Harmonic: E -25 cents

4th Harmonic: A -14 cents

5th Harmonic: C# -26 cents

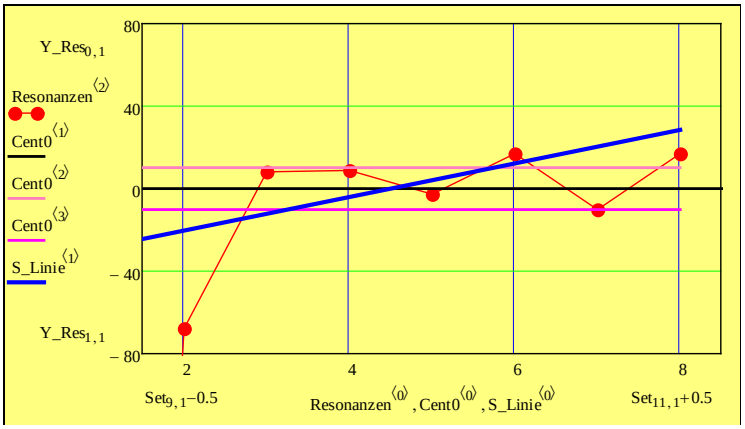
6th Harmonic: E -6 cents

7th Harmonic: G -33 cents

8th Harmonic: A -6 cents

Resonanzen =

	0	1	2	3	4	5
0	1	63.83	-719	"C2"	"-42Cent"	609.8
1	2	185.98	-68	"Gb3"	"9Cent"	17.6
2	3	289.38	8	"D4"	"-25Cent"	0.8
3	4	388.71	9	"G4"	"-14Cent"	0.8
4	5	486.54	-3	"B4"	"-26Cent"	0.2
5	6	585.31	17	"D5"	"-6Cent"	2.2
6	7	685.34	-10	"F5"	"-33Cent"	1
7	8	781.31	17	"G5"	"-6Cent"	2.2



Measurement No.6

Instrument with 2nd and 3rd valve

1st Harmonic: Bb -14 cents

2nd Harmonic: Ab -99 cents (G +1 cents)

3rd Harmonic: Eb -19 cents

4th Harmonic: Ab -9 cents

5th Harmonic: C -19 cents

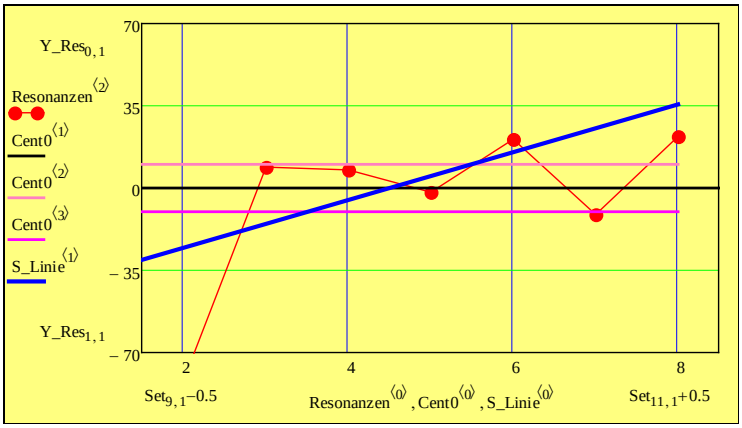
6th Harmonic: Eb +5 cents

7th Harmonic: Gb -28 cents (F# -28 cents)

8th Harmonic: Ab +5 cents

Resonanzen =

	0	1	2	3	4	5
0	1	59.54	-753	"Bb1"	"30Cent"	653.9
1	2	175.53	-82	"F3"	"1Cent"	23.3
2	3	275.38	9	"Db4"	"-19Cent"	0.8
3	4	369.73	8	"Gb4"	"-9Cent"	0.7
4	5	463.1	-2	"Bb4"	"-19Cent"	0.1
5	6	558.32	21	"Db5"	"5Cent"	3.1
6	7	651.5	-11	"E5"	"-28Cent"	1.2
7	8	745.6	22	"Gb5"	"5Cent"	3.4



Measurement No.7

Instrument with 1st and 3rd valve

1st Harmonic: B +29 cents

2nd Harmonic: G -85 cents (F# +15 cents)

3rd Harmonic: D +3 cents

4th Harmonic: G +17 cents

5th Harmonic: B +4 cents

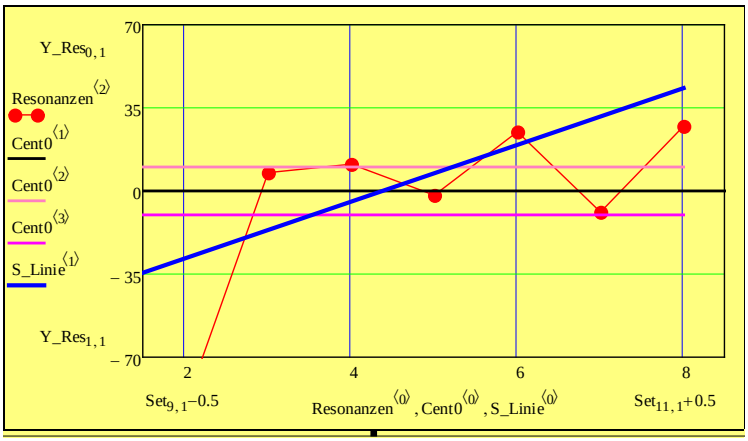
6th Harmonic: D +31 cents

7th Harmonic: F -3 cents

8th Harmonic: G +33 cents

Resonanzen =

	0	1	2	3	4	5
0	1	56.17	-777	"A1"	"29Cent"	685.2
1	2	166.97	-91	"E3"	"15Cent"	27.5
2	3	263.22	8	"C4"	"3Cent"	0.7
3	4	354.21	11	"F4"	"17Cent"	1.1
4	5	443.09	-2	"A4"	"4Cent"	0.1
5	6	535.02	25	"C5"	"31Cent"	3.9
6	7	624.04	-9	"Eb5"	"-3Cent"	0.8
7	8	715.08	27	"F5"	"33Cent"	4.4



Measurement No.8

Instrument with 1st, 2nd and 3rd valve

1st Harmonic: Bb +29 cents

2nd Harmonic: F# -86 cents (F +14 cents)

3rd Harmonic: C# +20 cents

4th Harmonic: F# +29 cents

5th Harmonic: A# +26 cents

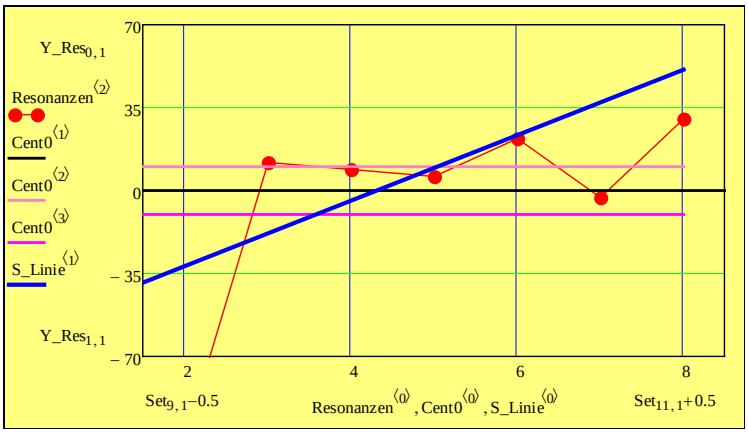
6th Harmonic: C# +42 cents

7th Harmonic: E +16 cents

8th Harmonic: F# +49 cents

Resonanzen =

	0	1	2	3	4	5
0	1	52.55	-806	"Ab1"	"13Cent"	723.4
1	2	157.55	-105	"Eb3"	"14Cent"	34
2	3	250.96	12	"B3"	"20Cent"	1.3
3	4	336.64	9	"E4"	"29Cent"	0.9
4	5	423.4	6	"Ab4"	"26Cent"	0.5
5	6	508.15	22	"B4"	"42Cent"	3.3
6	7	595.58	-3	"D5"	"16Cent"	0.2
7	8	681.12	30	"E5"	"49Cent"	5.1



1st key

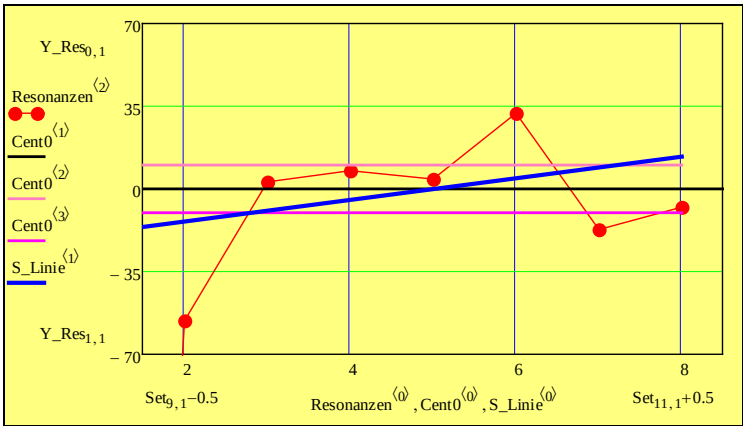
Measurement No.9

Instrument without valves, 1st key

1st Harmonic: F#	+29 cents		
2nd Harmonic: C	+8 cents		
3rd Harmonic: G	+56 cents	(Ab -44 cents)	G1/4tone
4th Harmonic: C	+72 cents	(C# -28 cents)	C1/3tone
5th Harmonic: E	+69 cents	(F -31 cents)	E1/3tone
6th Harmonic: G	+97 cents	(Ab -3 cents)	G1/2tone
7th Harmonic: Bb	+48 cents		Bb1/4tone
8th Harmonic: C	+57 cents	(C# -43 cents)	C1/4tone

Resonanzen =

	0	1	2	3	4	5
0	1	83.5	-649	"E2"	"15Cent"	523.2
1	2	235.2	-56	"Bb3"	"8Cent"	13.4
2	3	362.37	3	"Gb4"	"-44Cent"	0.1
3	4	488.11	8	"B4"	"-28Cent"	0.6
4	5	613.94	4	"Eb5"	"-31Cent"	0.3
5	6	741.91	32	"Gb5"	"-3Cent"	5.8
6	7	857.62	-17	"Ab5"	"48Cent"	2.2
7	8	967.64	-8	"B5"	"-43Cent"	0.7



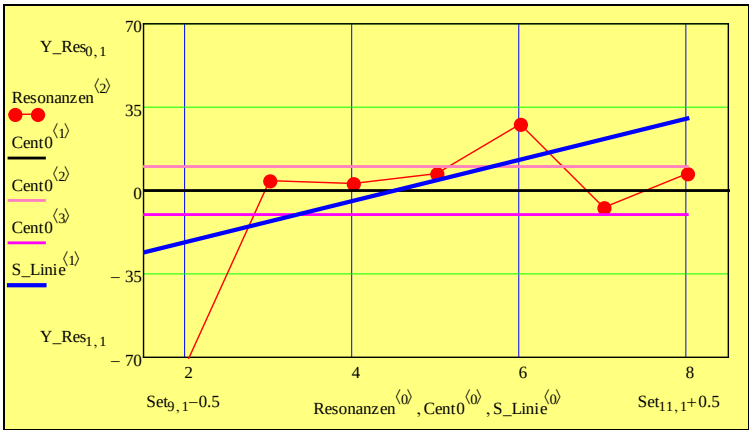
Measurement No.10

Instrument with 2nd valve, 1st key

1st Harmonic: F	-40 cents		
2nd Harmonic: B	-22 cents		
3rd Harmonic: F#	+44 cents		F#1/4tone
4th Harmonic: B	+54 cents	(C -46 cents)	B1/4tone
5th Harmonic: D#	+58 cents	(E -42 cents)	D#1/3tone
6th Harmonic: F#	+79 cents	(G -21 cents)	F#2/5tone
7th Harmonic: A	+44 cents		A1/4tone
8th Harmonic: B	+58 cents	(C -42 cents)	B1/3tone

Resonanzen =

	0	1	2	3	4	5
0	1	76.33	-691	"Eb2"	"-40Cent"	574.9
1	2	218.18	-73	"A3"	"-22Cent"	19.8
2	3	339.61	4	"E4"	"44Cent"	0.2
3	4	456.05	3	"Bb4"	"-46Cent"	0.2
4	5	575.73	7	"D5"	"-42Cent"	0.5
5	6	693.06	28	"F5"	"-21Cent"	4.6
6	7	807.83	-7	"G5"	"44Cent"	0.6
7	8	914.1	7	"Bb5"	"-42Cent"	0.6



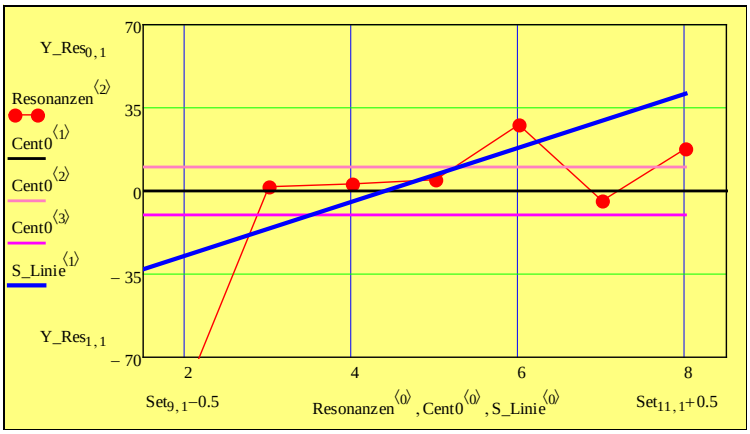
Measurement No.11

Instrument with 1st valve, 1st key

1st Harmonic: Eb	+39 cents		
2nd Harmonic: Bb	-25 cents		
3rd Harmonic: F	+50 cents		F1/4tone
4th Harmonic: Bb	+62 cents	(B -38 cents)	Bb1/3tone
5th Harmonic: D	+64 cents	(Eb -36 cents)	D1/3tone
6th Harmonic: F	+87 cents	(F# -13 cents)	F2/5tone
7th Harmonic: Ab	+56 cents	(A -44 cents)	Ab1/4tone
8th Harmonic: Bb	+86 cents	(B -24 cents)	Bb2/5tone

Resonanzen =

	0	1	2	3	4	5
0	1	71.17	-720	"Db2"	"39Cent"	611.5
1	2	205.57	-84	"Ab3"	"-25Cent"	24.4
2	3	321.68	2	"Eb4"	"50Cent"	0.1
3	4	432.46	3	"A4"	"-38Cent"	0.2
4	5	545.52	5	"Db5"	"-36Cent"	0.4
5	6	657.39	28	"E5"	"-13Cent"	4.7
6	7	767.51	-4	"G5"	"-44Cent"	0.2
7	8	871.98	18	"A5"	"-24Cent"	2.3



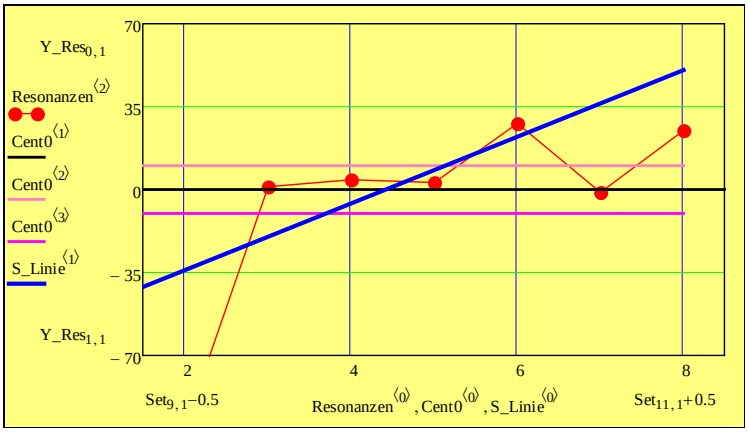
Measurement No.12

Instrument with 1st and 2nd valve, 1st key

1st Harmonic: D	-1 cents		
2nd Harmonic: A	-42 cents		
3rd Harmonic: E	+48 cents		E1/4tone
4th Harmonic: A	+62 cents	(Bb -38 cents)	A1/3tone
5th Harmonic: C#	+61 cents	(D -39 cents)	C#1/3tone
6th Harmonic: E	+86 cents	(F -14 cents)	E2/5tone
7th Harmonic: G	+57 cents	(Ab -43 cents)	G1/4tone
8th Harmonic: A	+83 cents	(Bb -17 cents)	A2/5tone

Resonanzen =

	0	1	2	3	4	5
0	1	65.67	-759	"C2"	"-1Cent"	661.1
1	2	192.19	-100	"G3"	"-42Cent"	31.5
2	3	303.26	1	"D4"	"48Cent"	0
3	4	408.16	4	"Ab4"	"-38Cent"	0.3
4	5	513.89	3	"C5"	"-39Cent"	0.1
5	6	620.14	28	"Eb5"	"-14Cent"	4.7
6	7	725.21	-1	"Gb5"	"-43Cent"	0
7	8	826.37	25	"Ab5"	"-17Cent"	4



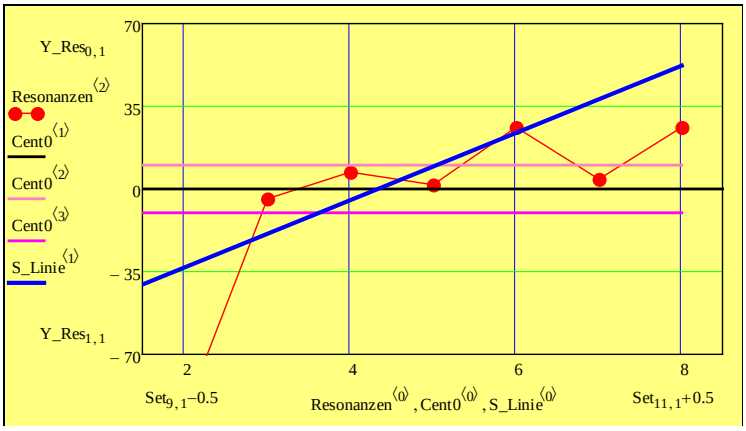
Measurement No.13

Instrument with 3rd valve, 1st key

1st Harmonic: D	-35 cents		
2nd Harmonic: A	-62 cents	(Ab +38 cents)	
3rd Harmonic: E	+17 cents		E1/10tone
4th Harmonic: A	+40 cents		A1/5tone
5th Harmonic: C#	+34 cents		C#1/5tone
6th Harmonic: E	+59 cents	(F -41 cents)	E1/3tone
7th Harmonic: G	+36 cents		G1/5tone
8th Harmonic: A	+58 cents	(Bb -42 cents)	A1/3tone

Resonanzen =

	0	1	2	3	4	5
0	1	64.38	-768	"C2"	"-35Cent"	672.5
1	2	189.92	-95	"Gb3"	"38Cent"	29.1
2	3	297.92	-4	"D4"	"17Cent"	0.3
3	4	402.93	7	"G4"	"40Cent"	0.6
4	5	505.96	2	"B4"	"34Cent"	0.1
5	6	610.3	26	"Eb5"	"-41Cent"	4.2
6	7	716.5	4	"F5"	"36Cent"	0.2
7	8	814.36	26	"Ab5"	"-42Cent"	4.1



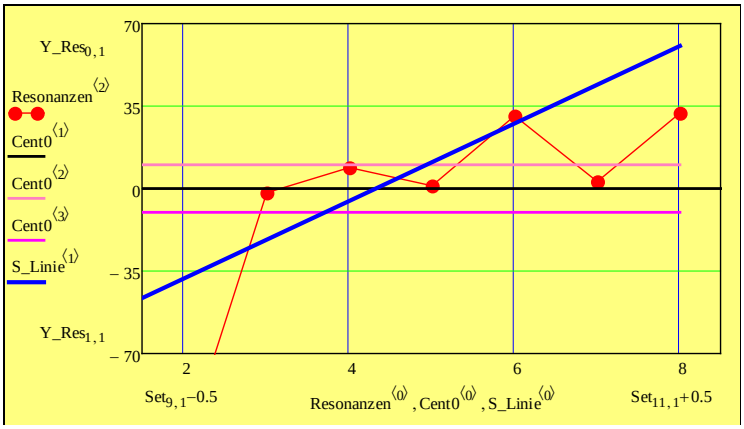
Measurement No.14

Instrument with 2nd and 3rd valve, 1st key

1st Harmonic: C	-35 cents		
2nd Harmonic: Ab	-76 cents	(G +24 cents)	
3rd Harmonic: Eb	+22 cents		Eb1/10tone
4th Harmonic: Ab	+44 cents		Ab1/5tone
5th Harmonic: C	+36 cents		C1/5tone
6th Harmonic: Eb	+66 cents	(E -34 cents)	Eb1/3tone
7th Harmonic: Gb	+38 cents	(F# +38 cents)	Gb1/5tone
8th Harmonic: Ab	+67 cents	(A -33 cents)	Ab1/3tone

Resonanzen =

	0	1	2	3	4	5
0	1	60.06	-790	"Bb1"	"45Cent"	702.4
1	2	177.87	-111	"F3"	"24Cent"	36.8
2	3	282.01	-2	"Db4"	"22Cent"	0.1
3	4	381.15	9	"Gb4"	"44Cent"	0.8
4	5	477.94	1	"Bb4"	"36Cent"	0
5	6	578.52	31	"D5"	"-34Cent"	5.5
6	7	677.04	3	"E5"	"38Cent"	0.2
7	8	772.61	32	"G5"	"-33Cent"	5.8



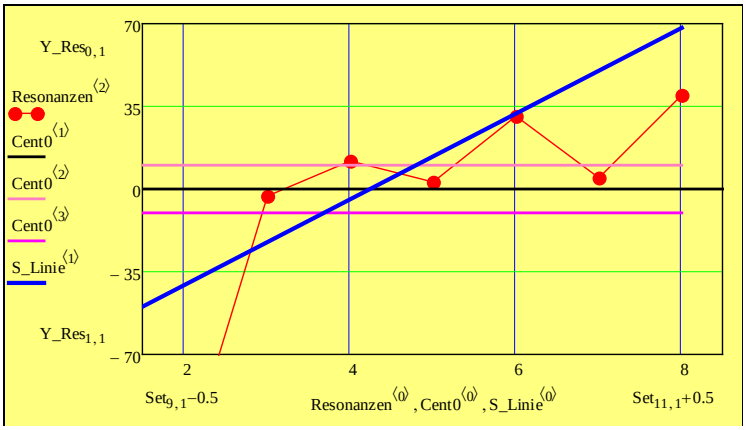
Measurement No.15

Instrument with 1st and 3rd valve, 1st key

1st Harmonic: B	-35 cents		
2nd Harmonic: G	-64 cents	(F# +36 cents)	
3rd Harmonic: D	+41 cents		D1/5tone
4th Harmonic: G	+66 cents	(Ab -34 cents)	G1/3tone
5th Harmonic: B	+58 cents	(C -42 cents)	B1/3tone
6th Harmonic: D	+86 cents	(Eb -14 cents)	D2/5tone
7th Harmonic: F	+60 cents	(F# -40 cents)	F1/3tone
8th Harmonic: G	+94 cents	(Ab -6 cents)	G1/2tone

Resonanzen =

	0	1	2	3	4	5
0	1	56.54	-814	"A1"	"40Cent"	734.9
1	2	169.04	-118	"E3"	"36Cent"	40.7
2	3	269.08	-3	"C4"	"41Cent"	0.1
3	4	364.49	12	"Gb4"	"-34Cent"	1.3
4	5	457.02	3	"Bb4"	"-42Cent"	0.2
5	6	552.41	31	"Db5"	"-14Cent"	5.6
6	7	647.05	5	"E5"	"-40Cent"	0.4
7	8	740.71	40	"Gb5"	"-6Cent"	7.9



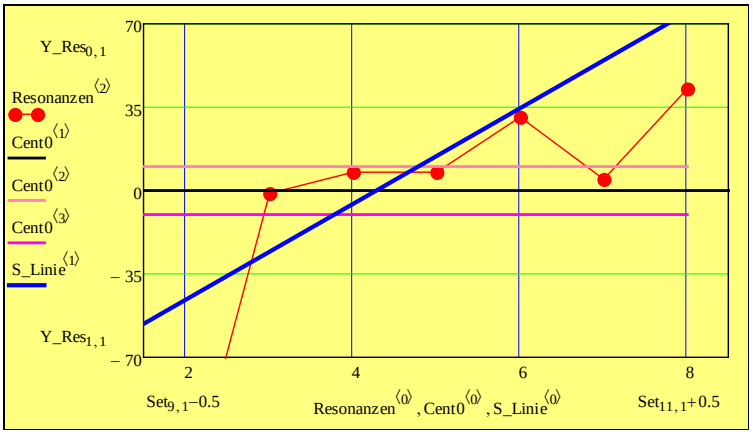
Measurement No.16

Instrument with 1st, 2nd and 3rd valve, 1st key

1st Harmonic: Bb	-35 cents		
2nd Harmonic: F#	-67 cents	(F +33 cents)	
3rd Harmonic: C#	+54 cents	(D -46 cents)	C#1/4tone
4th Harmonic: F#	+74 cents	(G -26 cents)	F#2/5tone
5th Harmonic: A#	+74 cents	(B -26 cents)	A#2/5tone
6th Harmonic: C#	+97 cents	(D -3 cents)	C#1/2tone
7th Harmonic: E	+71 cents	(F -29 cents)	E1/3tone
8th Harmonic: F#	+91 cents	(G +9 cents)	F#1/2tone

Resonanzen =

	0	1	2	3	4	5
0	1	53.12	-834	"Ab1"	"32Cent"	761.8
1	2	159.26	-133	"Eb3"	"33Cent"	48.6
2	3	255.96	-1	"C4"	"-46Cent"	0
3	4	345.5	8	"F4"	"-26Cent"	0.7
4	5	435.49	8	"A4"	"-26Cent"	0.7
5	6	524.76	31	"C5"	"-3Cent"	5.4
6	7	614.72	5	"Eb5"	"-29Cent"	0.3
7	8	705.37	43	"F5"	"9Cent"	9



2nd key

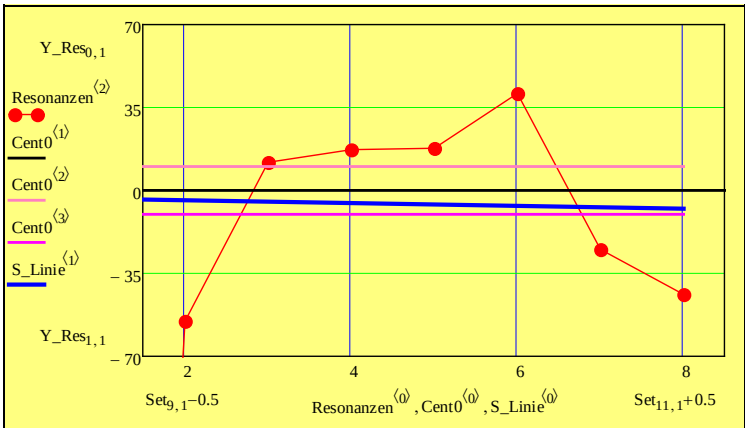
Measurement No.17

Instrument without valve, 2nd key

1st Harmonic: F#	-35 cents		
2nd Harmonic: C	+33 cents		C1/6tone
3rd Harmonic: G	+90 cents	(Ab -10 cents)	G1/2tone
4th Harmonic: C	+106cents	(C# +6 cents)	C1/2tone
5th Harmonic: E	+107cents	(F +7 cents)	E1/2tone
6th Harmonic: G	+129cents	(Ab +29 cents)	G2/3tone
7th Harmonic: Bb	+64 cents	(B -36 cents)	Bb1/3tone
8th Harmonic: C	+45 cents		C1/4tone

Resonanzen =

	0	1	2	3	4	5
0	1	84.26	-658	"E2"	"31Cent"	533.4
1	2	238.64	-55	"Bb3"	"33Cent"	13
2	3	369.48	12	"Gb4"	"-10Cent"	1.3
3	4	497.78	17	"B4"	"6Cent"	2.3
4	5	627.59	18	"Eb5"	"7Cent"	2.5
5	6	756.03	41	"Gb5"	"29Cent"	8.2
6	7	865.79	-25	"A5"	"-36Cent"	3.9
7	8	961.05	-44	"Bb5"	"45Cent"	9.1



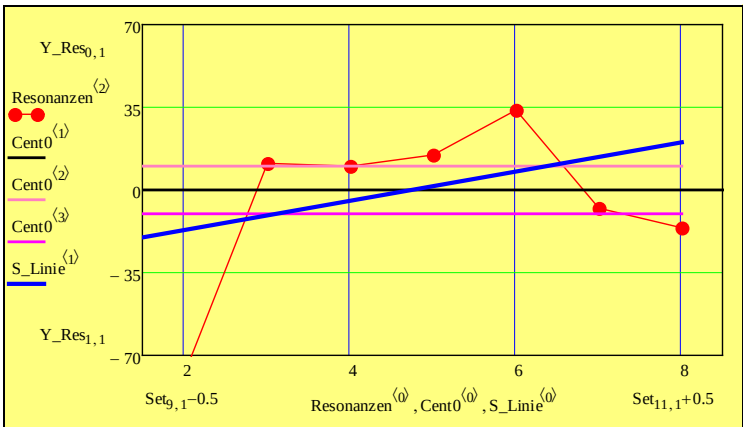
Measurement No.18

Instrument with 2nd valve, 2nd key

1st Harmonic: F	-25 cents		
2nd Harmonic: B	-1 cents		
3rd Harmonic: F#	+77 cents	(G -23 cents)	F#2/5tone
4th Harmonic: B	+87cents	(C -13 cents)	B2/5tone
5th Harmonic: D#	+91cents	(E -9 cents)	D#1/2tone
6th Harmonic: F#	+111cents	(G +11 cents)	F#1/2tone
7th Harmonic: A	+69 cents	(Bb -31 cents)	A1/3tone
8th Harmonic: B	+61 cents	(C -39 cents)	B1/3tone

Resonanzen =

	0	1	2	3	4	5
0	1	77.02	-702	"Eb2"	"-25Cent"	587.6
1	2	220.88	-78	"A3"	"-1Cent"	21.6
2	3	346.1	11	"F4"	"-23Cent"	1.1
3	4	464.67	10	"Bb4"	"-13Cent"	1
4	5	587.05	15	"D5"	"-9Cent"	1.8
5	6	706.19	34	"F5"	"11Cent"	6.4
6	7	819.32	-8	"Ab5"	"-31Cent"	0.8
7	8	915.55	-16	"Bb5"	"-39Cent"	2



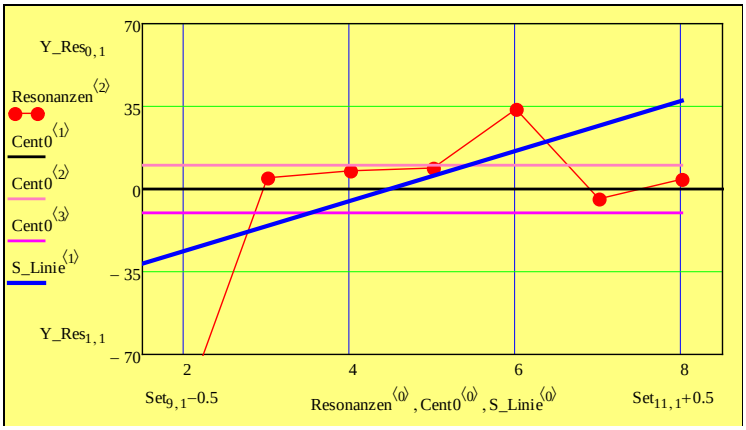
Measurement No.19

Instrument with 1st valve, 2nd key

1st Harmonic: Eb	-25 cents		
2nd Harmonic: Bb	-6 cents		
3rd Harmonic: F	+80 cents	(F# -20 cents)	F2/5tone
4th Harmonic: Bb	+94cents	(B -6 cents)	Bb1/2tone
5th Harmonic: D	+95cents	(Eb -5 cents)	D1/2tone
6th Harmonic: F	+120cents	(F# +20 cents)	F3/5tone
7th Harmonic: Ab	+82 cents	(A -18 cents)	A2/5tone
8th Harmonic: Bb	+90 cents	(B -10 cents)	B1/2tone

Resonanzen =

	0	1	2	3	4	5
0	1	71.58	-738	"Db2"	"48Cent"	633.4
1	2	207.83	-92	"Ab3"	"-6Cent"	28
2	3	327.27	5	"E4"	"-20Cent"	0.3
3	4	440.42	8	"A4"	"-6Cent"	0.7
4	5	555.27	9	"Db5"	"-5Cent"	0.9
5	6	669.9	34	"E5"	"20Cent"	6.2
6	7	779.44	-4	"G5"	"-18Cent"	0.3
7	8	878.68	4	"A5"	"-10Cent"	0.2



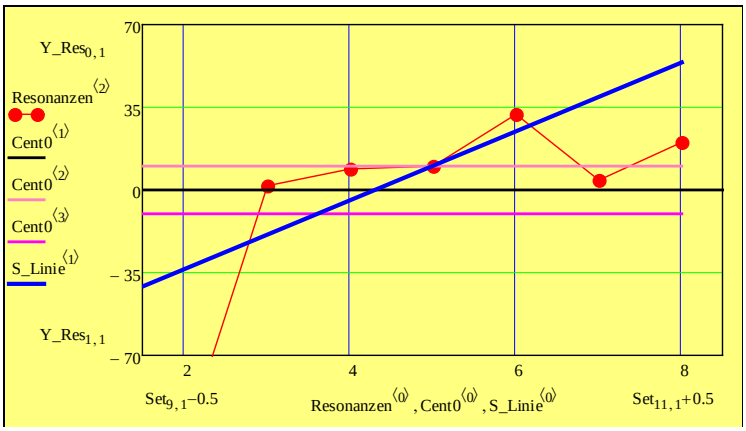
Measurement No.20

Instrument with 1st and 2nd valve, 2nd key

1st Harmonic: D	+9 cents		
2nd Harmonic: A	-25 cents		
3rd Harmonic: E	+73 cents	(F -27 cents)	E1/3tone
4th Harmonic: A	+91cents	(Bb -9 cents)	A1/2tone
5th Harmonic: C#	+92cents	(D -8 cents)	C#1/2tone
6th Harmonic: E	+114cents	(F +14 cents)	E1/2tone
7th Harmonic: G	+86 cents	(Ab -14 cents)	G2/5tone
8th Harmonic: A	+98 cents	(B +2 cents)	A1/2tone

Resonanzen =

	0	1	2	3	4	5
0	1	66.04	-773	"C2"	"9Cent"	679.4
1	2	194.04	-107	"G3"	"-25Cent"	35
2	3	307.7	2	"Eb4"	"-27Cent"	0.1
3	4	415.01	9	"Ab4"	"-9Cent"	0.9
4	5	523.03	10	"C5"	"-8Cent"	0.9
5	6	630.22	32	"Eb5"	"14Cent"	5.8
6	7	737.29	4	"Gb5"	"-14Cent"	0.2
7	8	835.09	20	"Ab5"	"2Cent"	2.8



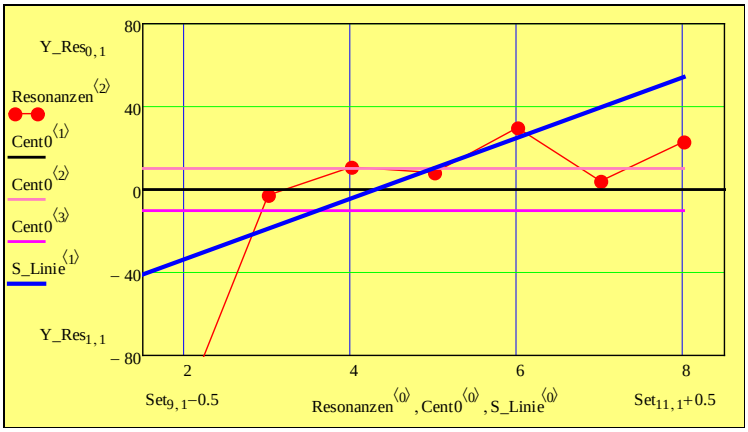
Measurement No.21

Instrument with 3rd valve, 2nd key

1st Harmonic: D	-25 cents		
2nd Harmonic: A	-45 cents		
3rd Harmonic: E	+44 cents		E1/5tone
4th Harmonic: A	+70 cents	(Bb -30 cents)	A1/3tone
5th Harmonic: C#	+66 cents	(D -34 cents)	C#1/3tone
6th Harmonic: E	+88 cents	(F -12 cents)	E2/5tone
7th Harmonic: G	+62 cents	(Ab -38 cents)	G1/3tone
8th Harmonic: A	+81 cents	(Bb -19 cents)	A2/5tone

Resonanzen =

	0	1	2	3	4	5
0	1	64.74	-784	"C2"	"-25Cent"	693.7
1	2	191.84	-103	"G3"	"-45Cent"	33.1
2	3	302.61	-3	"D4"	"44Cent"	0.2
3	4	409.88	11	"Ab4"	"-30Cent"	1.2
4	5	515.46	8	"C5"	"-34Cent"	0.7
5	6	620.72	30	"Eb5"	"-12Cent"	5.1
6	7	727.13	4	"Gb5"	"-38Cent"	0.2
7	8	825.25	23	"Ab5"	"-19Cent"	3.5



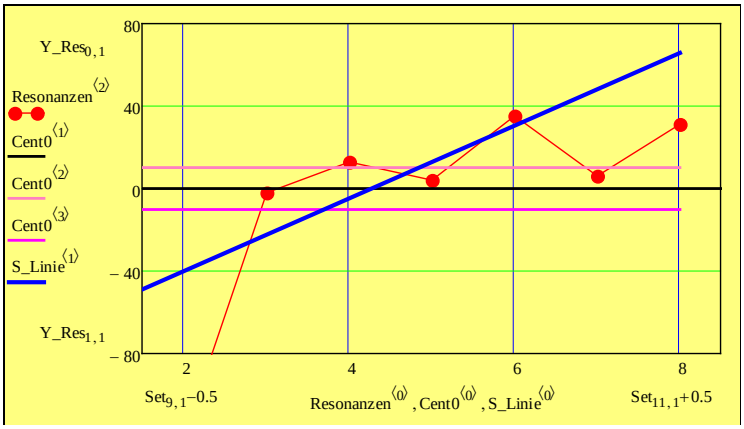
Measurement No.22

Instrument with 2nd and 3rd valve, 2nd key

1st Harmonic: C	+50 cents		
2nd Harmonic: Ab	-61 cents	(G +39 cents)	
3rd Harmonic: Eb	+46 cents		Eb1/4tone
4th Harmonic: Ab	+72 cents	(A -28 cents)	Ab1/3tone
5th Harmonic: C	+62 cents	(C# -38 cents)	C1/3tone
6th Harmonic: Eb	+94 cents	(E -6 cents)	Eb1/2tone
7th Harmonic: Gb	+65 cents	(G -35 cents)	Gb1/3tone
8th Harmonic: Ab	+90 cents	(A -10 cents)	Ab1/2tone

Resonanzen =

	0	1	2	3	4	5
0	1	60.25	-808	"Bb1"	"50Cent"	726.7
1	2	179.38	-120	"F3"	"39Cent"	41.3
2	3	285.92	-2	"Db4"	"46Cent"	0.1
3	4	387.37	13	"G4"	"-28Cent"	1.5
4	5	485.44	4	"B4"	"-38Cent"	0.2
5	6	587.79	35	"D5"	"-6Cent"	6.6
6	7	687.48	6	"F5"	"-35Cent"	0.5
7	8	782.9	31	"G5"	"-10Cent"	5.6



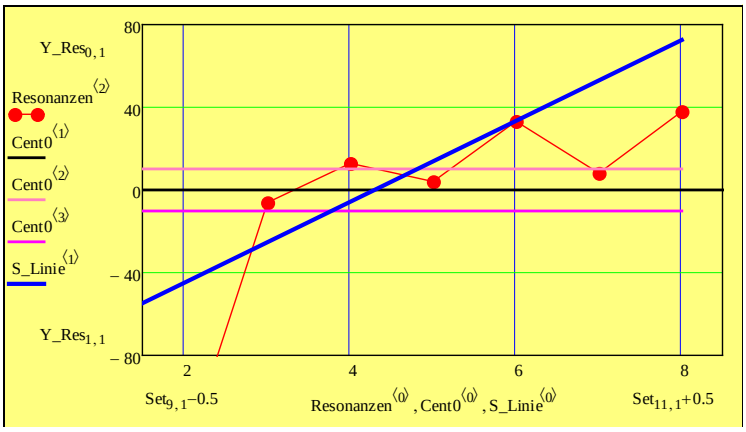
Measurement No.23

Instrument with 1st and 3rd valve, 2nd key

1st Harmonic: B	+47 cents		
2nd Harmonic: G	-50 cents	(F# +50 cents)	
3rd Harmonic: D	+62 cents	(Eb -38 cents)	D1/3tone
4th Harmonic: G	+92 cents	(Ab -8 cents)	G1/2tone
5th Harmonic: B	+84 cents	(C -16 cents)	B2/5tone
6th Harmonic: D	+113 cents	(Eb +13 cents)	D1/2tone
7th Harmonic: F	+87 cents	(F# -13 cents)	F2/5tone
8th Harmonic: G	+117 cents	(Ab +17 cents)	G1/2tone

Resonanzen =

	0	1	2	3	4	5
0	1	56.75	-833	"A1"	"47Cent"	759.8
1	2	170.38	-129	"E3"	"50Cent"	46.5
2	3	272.42	-6	"Db4"	"-38Cent"	0.5
3	4	370.01	13	"Gb4"	"-8Cent"	1.5
4	5	463.86	4	"Bb4"	"-16Cent"	0.3
5	6	560.9	33	"Db5"	"13Cent"	6
6	7	657.21	8	"E5"	"-13Cent"	0.7
7	8	750.5	38	"Gb5"	"17Cent"	7.3



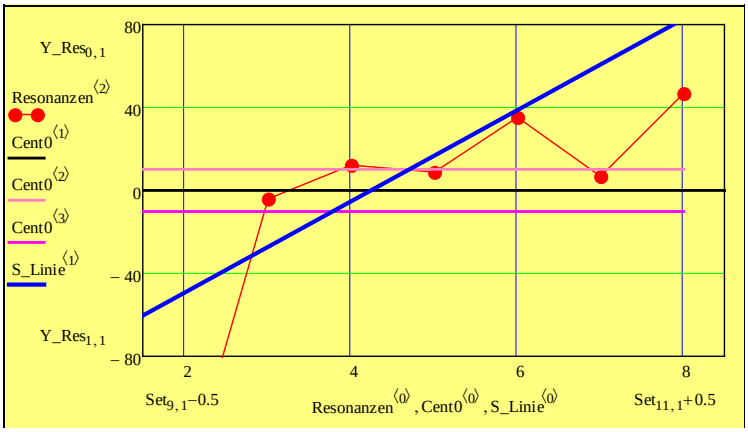
Measurement No.24

Instrument with 1st, 2nd and 3rd valve, 2nd key

1st Harmonic:	Bb	+43 cents	
2nd Harmonic:	F#	-55 cents	(F +45 cents)
3rd Harmonic:	C#	+73 cents	(D -27 cents) C#1/3tone
4th Harmonic:	F#	+100 cents	(G 0 cents) F#1/2tone
5th Harmonic:	A#	+98 cents	(B -2 cents) A#1/2tone
6th Harmonic:	C#	+124 cents	(D +24 cents) C#3/5tone
7th Harmonic:	E	+96 cents	(F -4 cents) E1/2tone
8th Harmonic:	F#	+135 cents	(G +35 cents) F#2/3tone

Resonanzen =

	0	1	2	3	4	5
0	1	53.46	-845	"Ab1"	"43Cent"	776.8
1	2	160.38	-143	"Eb3"	"45Cent"	54.1
2	3	258.73	-4	"C4"	"-27Cent"	0.3
3	4	350.74	12	"F4"	"0Cent"	1.2
4	5	441.36	9	"A4"	"-2Cent"	0.9
5	6	532.86	35	"C5"	"24Cent"	6.7
6	7	623.52	7	"Eb5"	"-4Cent"	0.6
7	8	716.02	47	"F5"	"35Cent"	10.2



3rd key

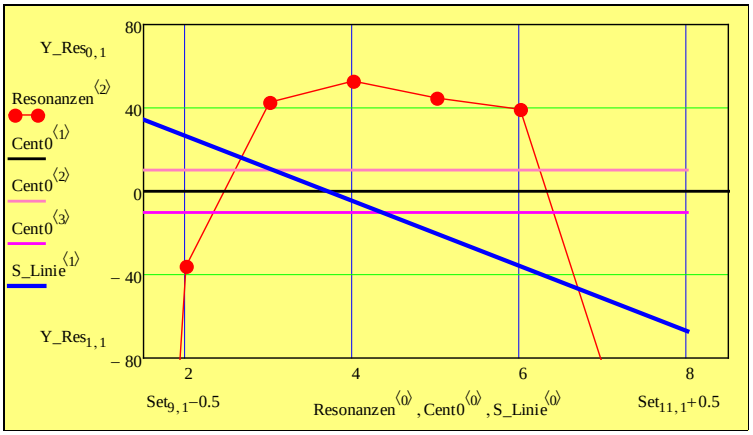
Measurement No.25

Instrument without valve, 3rd key

1st Harmonic: F#	+48 cents		
2nd Harmonic: C	+68 cents	(C# -32 cents)	
3rd Harmonic: G	+136 cents	(Ab +36 cents)	G2/3tone
4th Harmonic: C	+157 cents	(D -43 cents)	C3/4tone
5th Harmonic: E	+149 cents	(F +49 cents)	E3/4tone
6th Harmonic: G	+143 cents	(Ab +43 cents)	G3/4tone
7th Harmonic: Bb	+19 cents		Bb1/10tone
8th Harmonic: C	+12 cents		C1/20tone

Resonanzen =

	0	1	2	3	4	5
0	1	85.08	-656	"E2"	"48Cent"	531.7
1	2	243.5	-36	"B3"	"-32Cent"	6.8
2	3	379.54	43	"Gb4"	"36Cent"	9
3	4	512.79	53	"C5"	"-43Cent"	12.4
4	5	642.89	45	"Eb5"	"49Cent"	9.5
5	6	761.96	39	"Gb5"	"43Cent"	7.7
6	7	843.33	-85	"Ab5"	"19Cent"	25
7	8	943.07	-92	"Bb5"	"12Cent"	27.8



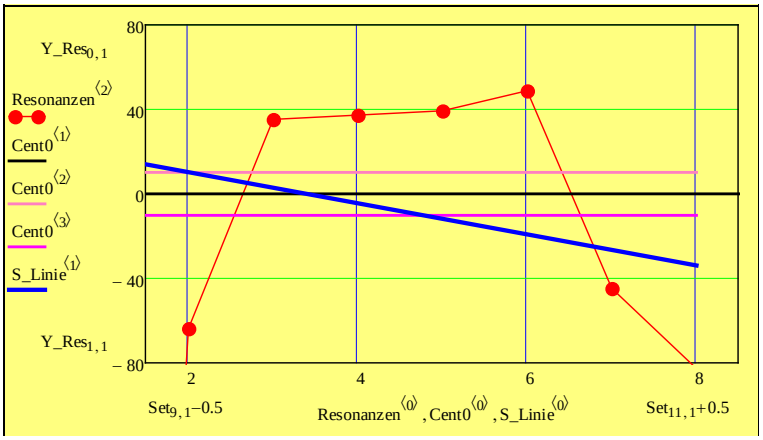
Measurement No.26

Instrument with 2nd valve, 3rd key

1st Harmonic: F	-10 cents	
2nd Harmonic: B	+30 cents	
3rd Harmonic: F#	+118 cents (G +18 cents)	F#3/5tone
4th Harmonic: B	+130 cents (C +30 cents)	B2/3tone
5th Harmonic: D#	+132 cents (E +32 cents)	D#2/3tone
6th Harmonic: F#	+143 cents (G +43 cents)	F#3/4tone
7th Harmonic: A	+48 cents	A1/4tone
8th Harmonic: B	+10 cents	B1/20tone

Resonanzen =

	0	1	2	3	4	5
0	1	77.67	-703	"Eb2"	"-10Cent"	589.9
1	2	224.78	-64	"A3"	"30Cent"	16.1
2	3	354.38	35	"F4"	"18Cent"	6.6
3	4	476.38	37	"Bb4"	"30Cent"	7
4	5	601.01	39	"D5"	"32Cent"	7.7
5	6	719.02	49	"F5"	"43Cent"	10.9
6	7	809.62	-45	"G5"	"48Cent"	9.7
7	8	888.9	-83	"A5"	"10Cent"	24.1



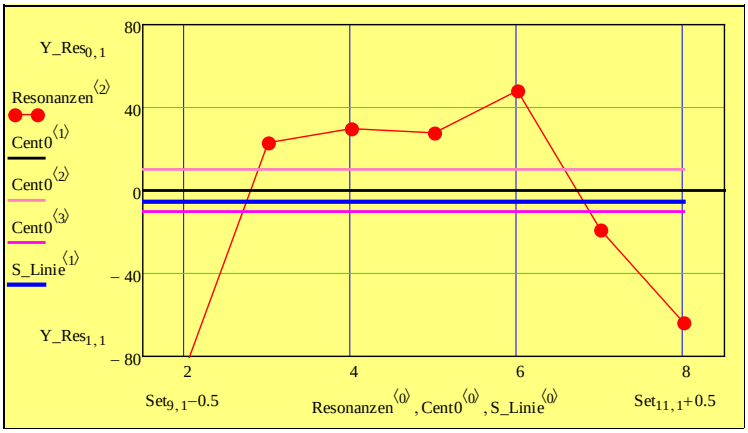
Measurement No.27

Instrument with 1st valve, 3rd key

1st Harmonic: E	-36 cents		
2nd Harmonic: Bb	+21 cents		
3rd Harmonic: F	+118 cents	(F# +18 cents)	F3/5tone
4th Harmonic: Bb	+136 cents	(B +36 cents)	Bb2/3tone
5th Harmonic: D	+135 cents	(Eb +35 cents)	D2/3tone
6th Harmonic: F	+155 cents	(G -45 cents)	F3/4tone
7th Harmonic: Ab	+88 cents	(A -12 cents)	Ab2/5tone
8th Harmonic: Bb	+42 cents	(Bb +42 cents)	Bb1/5tone

Resonanzen =

	0	1	2	3	4	5
0	1	72.24	-742	"D2"	"-36Cent"	639.2
1	2	211.08	-86	"Ab3"	"21Cent"	25.1
2	3	334.59	23	"E4"	"18Cent"	3.4
3	4	451.33	30	"A4"	"36Cent"	5.2
4	5	568.16	28	"Db5"	"35Cent"	4.8
5	6	683.45	48	"F5"	"-45Cent"	10.5
6	7	781.88	-19	"G5"	"-12Cent"	2.6
7	8	854.9	-64	"Ab5"	"42Cent"	16.3



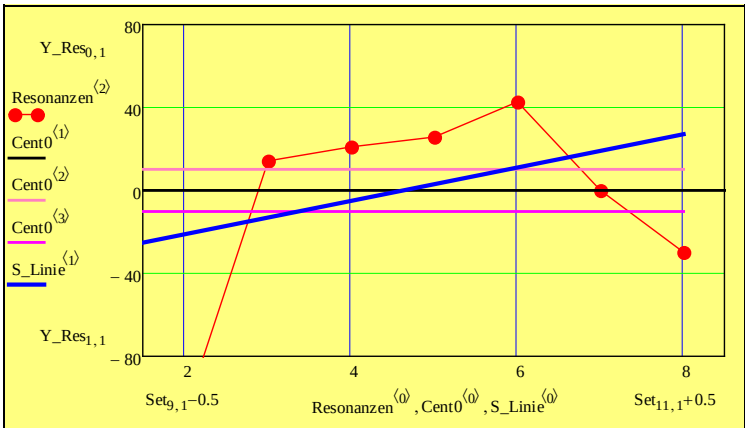
Measurement No.28

Instrument with 1st and 2nd valve, 3rd key

1st Harmonic: D	+29 cents		
2nd Harmonic: A	-1 cents		
3rd Harmonic: E	+109 cents	(F +9 cents)	E1/2tone
4th Harmonic: A	+126 cents	(Bb +26 cents)	A3/5tone
5th Harmonic: C#	+132 cents	(D +32 cents)	C#2/3tone
6th Harmonic: E	+148 cents	(F +48 cents)	E3/4tone
7th Harmonic: G	+106 cents	(Ab +6 cents)	G1/2tone
8th Harmonic: A	+76 cents	(Bb -24 cents)	A2/5tone

Resonanzen =

	0	1	2	3	4	5
0	1	66.79	-777	"C2"	"29Cent"	684.4
1	2	196.7	-107	"G3"	"-1Cent"	34.8
2	3	314.11	14	"Eb4"	"9Cent"	1.7
3	4	423.57	21	"Ab4"	"26Cent"	3.1
4	5	535.25	26	"C5"	"32Cent"	4.3
5	6	642.77	43	"Eb5"	"48Cent"	8.9
6	7	745.77	0	"Gb5"	"6Cent"	0
7	8	822.63	-30	"Ab5"	"-24Cent"	5.1



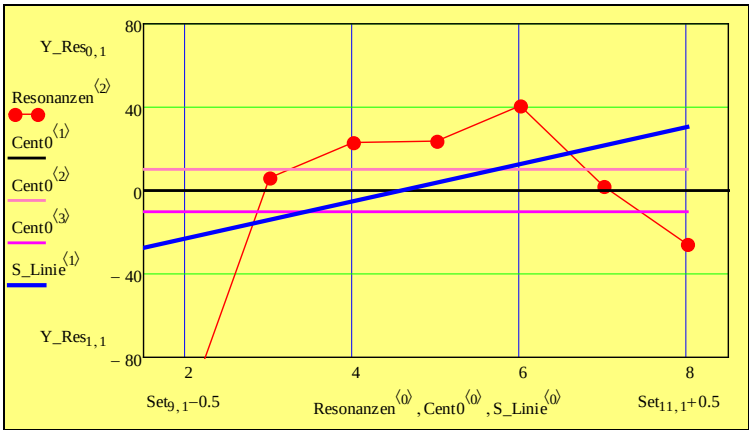
Measurement No.29

Instrument with 3rd valve, 3rd key

1st Harmonic: D	-11 cents		
2nd Harmonic: A	-24 cents		
3rd Harmonic: E	+77 cents	(F -23 cents)	E2/5tone
4th Harmonic: A	+105 cents	(Bb +5 cents)	A1/2tone
5th Harmonic: C#	+106 cents	(D +6 cents)	C#1/2tone
6th Harmonic: E	+123 cents	(F +23 cents)	E3/5tone
7th Harmonic: G	+84 cents	(Ab -16 cents)	G2/5tone
8th Harmonic: A	+56 cents	(Bb -44 cents)	A1/4tone

Resonanzen =

	0	1	2	3	4	5
0	1	65.29	-793	"C2"	"-11Cent"	705.7
1	2	194.18	-106	"G3"	"-24Cent"	34.3
2	3	308.32	6	"Eb4"	"-23Cent"	0.4
3	4	418.31	23	"Ab4"	"5Cent"	3.5
4	5	527.38	24	"C5"	"6Cent"	3.7
5	6	633.25	41	"Eb5"	"23Cent"	8.2
6	7	736.41	2	"Gb5"	"-16Cent"	0.1
7	8	813.39	-26	"Ab5"	"-44Cent"	4.1



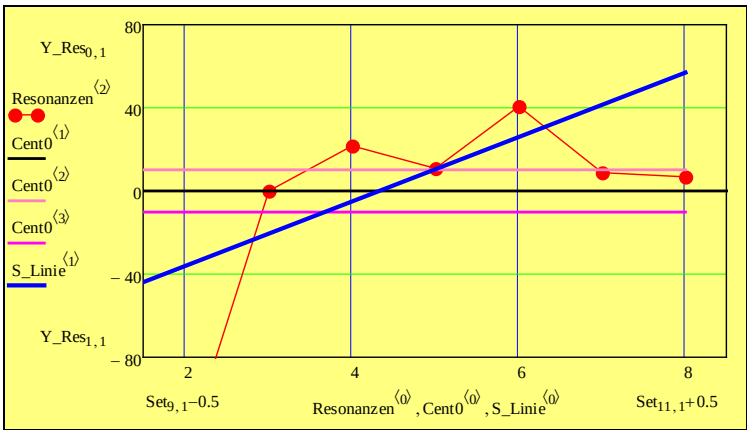
Measurement No.30

Instrument with 2nd and 3rd valve, 3rd key

1st Harmonic: C#	-33 cents		
2nd Harmonic: Ab	-41 cents		
3rd Harmonic: Eb	+75 cents	(E -25 cents)	Eb2/5tone
4th Harmonic: Ab	+107 cents	(A +7 cents)	Ab1/2tone
5th Harmonic: C	+96 cents	(C# -4 cents)	C1/2tone
6th Harmonic: Eb	+127 cents	(E +27 cents)	Eb2/3tone
7th Harmonic: Gb	+95 cents	(G -5 cents)	Gb1/2tone
8th Harmonic: Ab	+92 cents	(A -8 cents)	Ab1/2tone

Resonanzen =

	0	1	2	3	4	5
0	1	60.83	-819	"B1"	"-33Cent"	740.5
1	2	181.48	-126	"Gb3"	"-41Cent"	44.8
2	3	290.7	0	"D4"	"-25Cent"	0
3	4	395.33	22	"G4"	"7Cent"	3.2
4	5	494.93	11	"B4"	"-4Cent"	1.1
5	6	599.19	41	"D5"	"27Cent"	8.4
6	7	699.43	9	"F5"	"-5Cent"	0.9
7	8	783.91	7	"G5"	"-8Cent"	0.6



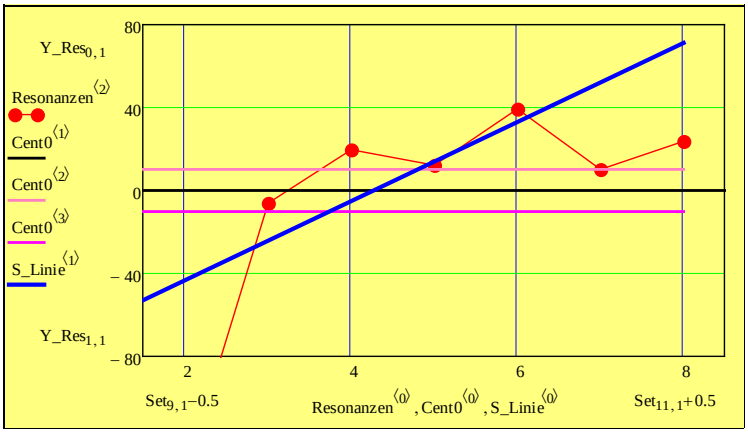
Measurement No.31

Instrument with 1st and 3rd valve, 3rd key

1st Harmonic: C	-38 cents		
2nd Harmonic: G	-32 cents		
3rd Harmonic: D	+88 cents	(Eb -12 cents)	D2/5tone
4th Harmonic: G	+126 cents	(Ab +26 cents)	G3/5tone
5th Harmonic: B	+117 cents	(C +17 cents)	B3/5tone
6th Harmonic: D	+145 cents	(Eb +45 cents)	D3/4tone
7th Harmonic: F	+116 cents	(F# +16 cents)	F3/5tone
8th Harmonic: G	+129 cents	(Ab +29 cents)	G3/4tone

Resonanzen =

	0	1	2	3	4	5
0	1	57.25	-844	"Bb1"	"-38Cent"	774.9
1	2	172.17	-137	"F3"	"-32Cent"	51
2	3	276.57	-6	"Db4"	"-12Cent"	0.5
3	4	377.16	20	"Gb4"	"26Cent"	2.9
4	5	472.86	12	"Bb4"	"17Cent"	1.2
5	6	571.37	39	"Db5"	"45Cent"	7.7
6	7	668.27	10	"E5"	"16Cent"	1
7	8	755.98	24	"Gb5"	"29Cent"	3.7



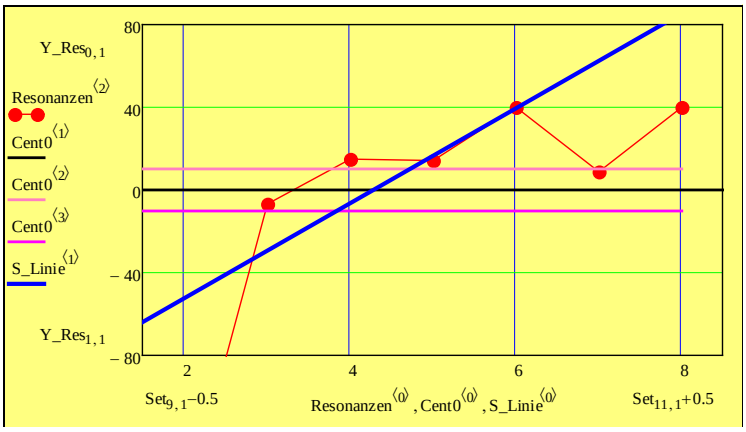
Measurement No.32

Instrument with 1st, 2nd and 3rd valve, 3rd key

1st Harmonic: Bb	+48 cents		
2nd Harmonic: F#	-39 cents		
3rd Harmonic: C#	+98 cents	(D -2 cents)	C#1/2tone
4th Harmonic: F#	+131 cents	(G +31 cents)	F#2/3tone
5th Harmonic: A#	+130 cents	(B +30 cents)	A#2/3tone
6th Harmonic: C#	+156 cents	(Eb -44 cents)	C#3/4tone
7th Harmonic: E	+125 cents	(F +25 cents)	E3/5tone
8th Harmonic: F#	+156 cents	(Ab -44 cents)	F#3/4tone

Resonanzen =

	0	1	2	3	4	5
0	1	53.62	-867	"Ab1"	"48Cent"	808
1	2	161.88	-155	"E3"	"-39Cent"	60.8
2	3	262.52	-7	"C4"	"-2Cent"	0.6
3	4	357.09	15	"F4"	"31Cent"	1.8
4	5	449.61	14	"A4"	"30Cent"	1.6
5	6	542.94	40	"Db5"	"-44Cent"	8.1
6	7	633.95	9	"Eb5"	"25Cent"	0.8
7	8	724.59	40	"Gb5"	"-44Cent"	8



Extra measurements.

Measurement No.33

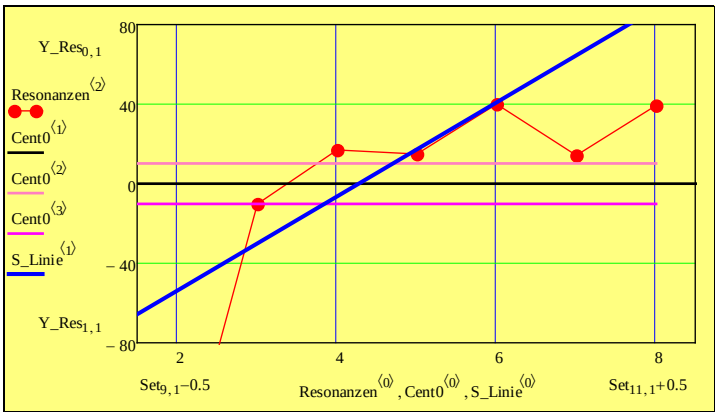
Instrument with 1st, 2nd and 3rd valve, 3rd key

*3rd slide open as it is required at least for the 3rd harmonic by normal use of the instrument with classical technique

1st Harmonic: Bb	0 cents		
2nd Harmonic: F#	-86 cents	(F +14 cents)	
3rd Harmonic: C#	+52 cents	(D -48 cents)	C#1/4tone
4th Harmonic: F#	+89 cents	(G -11 cents)	F#2/5tone
5th Harmonic: A#	+87 cents	(B -13 cents)	A#2/5tone
6th Harmonic: C#	+113 cents	(D +13 cents)	C#3/5tone
7th Harmonic: E	+87 cents	(F -13 cents)	E2/5tone
8th Harmonic: F#	+111 cents	(G +11 cents)	F#3/5tone

Resonanzen =

	0	1	2	3	4	5
0	1	52.13	-873	"Ab1"	"0Cent"	815.3
1	2	157.54	-158	"Eb3"	"14Cent"	62.8
2	3	255.59	-10	"C4"	"-48Cent"	0.9
3	4	348.55	17	"F4"	"-11Cent"	2.2
4	5	438.7	15	"A4"	"-13Cent"	1.8
5	6	529.41	40	"C5"	"13Cent"	8
6	7	620.19	14	"Eb5"	"-13Cent"	1.7
7	8	706.21	39	"F5"	"11Cent"	7.8



Measurement No.34

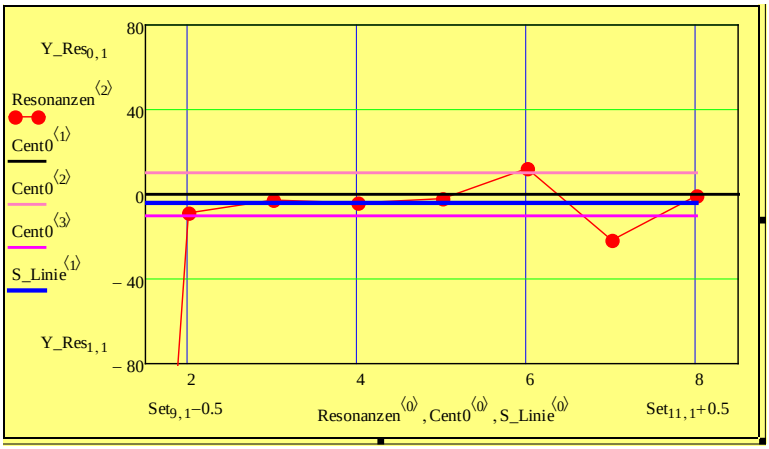
Measurement from another Bach Stradivarius with bell No72.

Instrument in natural length (no valves) and closed tuning slide (expected to have high intonation in all harmonics)

1st Harmonic: F# +45 cents
2nd Harmonic: C +18 cents
3rd Harmonic: G +13 cents
4th Harmonic: C +22 cents
5th Harmonic: E +24 cents
6th Harmonic: G +39 cents
7th Harmonic: Bb +4 cents
8th Harmonic: C +25 cents

Resonanzen =

	0	1	2	3	4	5
0	1	84.56	-581	"E2"	"45Cent"	443.2
1	2	235.43	-9	"Bb3"	"18Cent"	0.8
2	3	351.73	-3	"F4"	"13Cent"	0.1
3	4	472.02	-4	"Bb4"	"22Cent"	0.3
4	5	595.4	-2	"D5"	"24Cent"	0.1
5	6	714.2	12	"F5"	"39Cent"	1.4
6	7	832.63	-22	"Ab5"	"4Cent"	3.2
7	8	945.92	-1	"Bb5"	"25Cent"	0



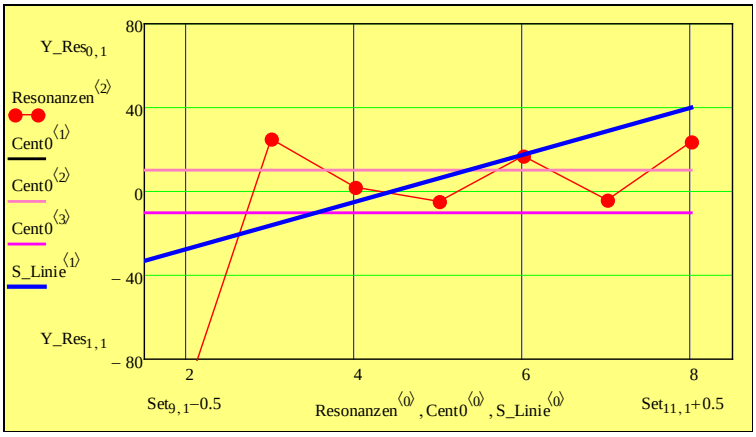
Measurement No.35

Measurement from the same Bach Stradivarius with bell No72.
Instrument with 1st, 2nd and 3rd valve and closed tuning slide (expected to have high intonation in all harmonics)

1st Harmonic: Bb +35 cents
2nd Harmonic: F# -72 cents
3rd Harmonic: C# +38 cents
4th Harmonic: F# +26 cents
5th Harmonic: A# +19 cents
6th Harmonic: C# +41 cents
7th Harmonic: E +20 cents
8th Harmonic: F# +47 cents

Resonanzen =

	0	1	2	3	4	5
0	1	53.29	-788	"Ab1"	"35Cent"	699.3
1	2	159.04	-95	"Eb3"	"28Cent"	29.2
2	3	253.82	25	"B3"	"38Cent"	4
3	4	336.44	2	"E4"	"26Cent"	0.1
4	5	422.16	-5	"Ab4"	"19Cent"	0.3
5	6	508.57	17	"B4"	"41Cent"	2.3
6	7	597.53	-4	"D5"	"20Cent"	0.2
7	8	681.36	24	"E5"	"47Cent"	3.7



7.3 Gallery

3D model by Kostas Tataroglou, 04.01.2017

Gerd Friedel working on the keys

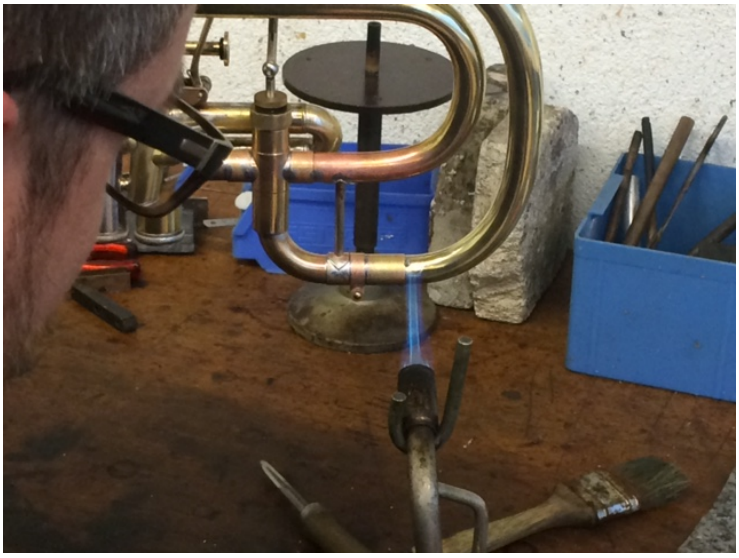
The M - D next to a keyed trumpet

The keys installed

Preparing to install the switch valve

The tube of the valve installed/no valve

Preparing the second bell for bending.



Installing the second bell.

Gerd Friedel, Tassos Tataroglou and Janine Meier when the Microtone – Duplex was finished, 8th of February 2017 at Egger's workshop.

Selbständigkeitserklärung

Hiermit erkläre ich, dass ich die vorliegende Arbeit selbständig und ohne die Mithilfe anderer Personen verfasst habe, dass ich keine anderen als die angegebenen Hilfsmittel verwendet sowie alle wörtlich oder dem Sinn nach aus der Literatur zitierten Stellen entsprechend gekennzeichnet habe.

Anastasios Tataroglou, April 2017