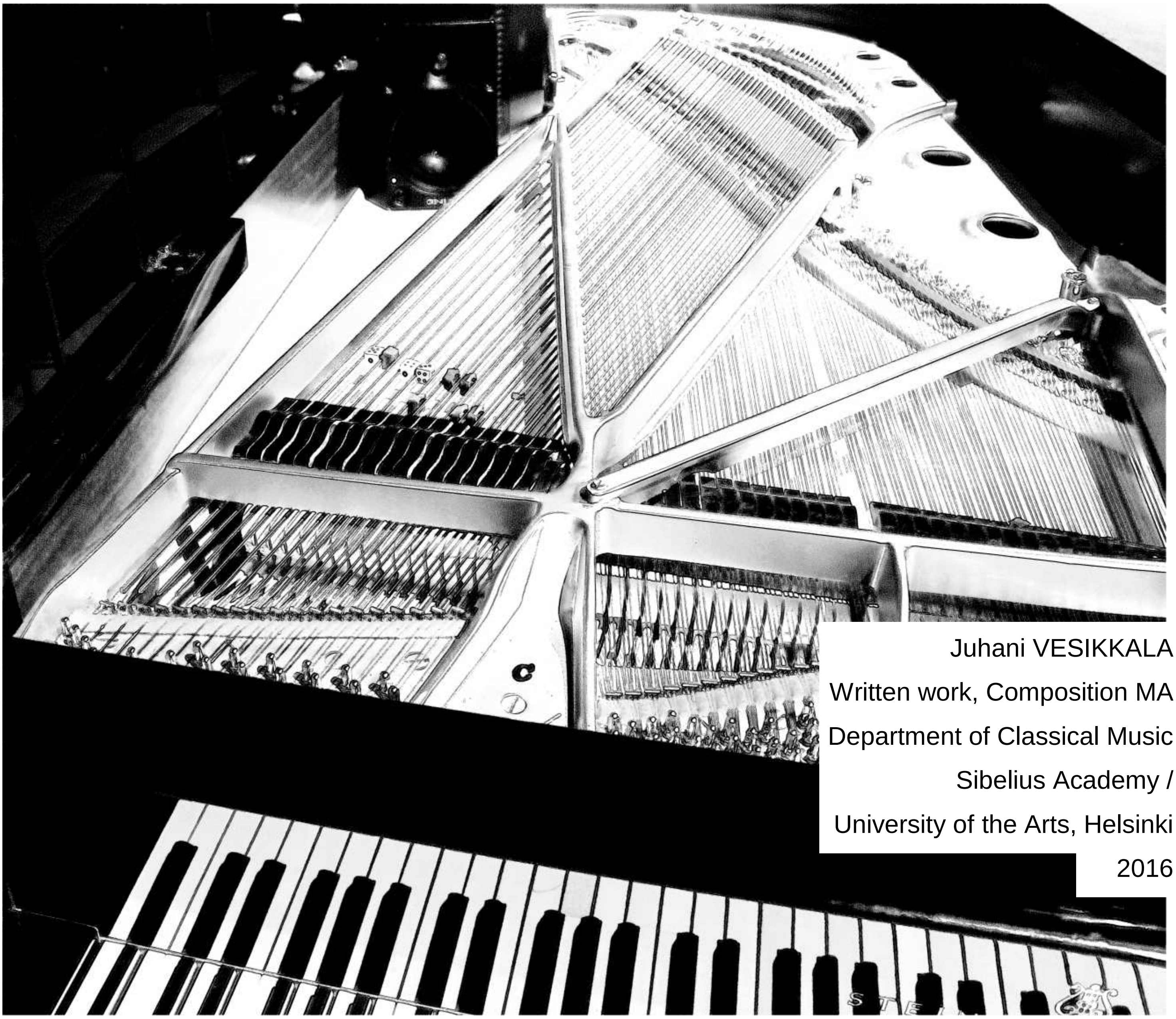
Multiphonics of the Grand Piano – Timbral Composition and Performance with Flageolets



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Abstract — Kirjallinen työ

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Abstract

The aim of my study is to enable a broader knowledge and compositional use of the piano multiphonics in current music. This corpus of text will benefit pianists and composers alike, and it provides the answers to the questions "what is a piano multiphonic", "what does a multiphonic sound like," and "how to notate a multiphonic sound".

New terminology will be defined and inaccuracies in existing terminology will be dealt with. The multiphonic "mode of playing" will be separated from "playing technique" and from flageolets.
Moreover, multiphonics in the repertoire are compared from the aspects of composition and notation, and the portability of multiphonics to the sounds of other instruments or to other mobile playing modes of the manipulated grand piano are examined.

Composers tend to use multiphonics in a different manner, making for differing notational choices. This study examines notational choices and proposes a notation suitable for most situations, and notates the most commonly produceable multiphonic chords.

The existence of piano multiphonics will be verified mathematically, supported by acoustic recordings and camera measurements. In my work, the correspondence of FFT analysis and hearing will be touched on, and by virtue of audio excerpts I offer ways to improve as a listener of multiphonics.

It is observed that to produce of multiphonics the musician needs to have specialized knowledge, a small amount of technique and detailed instructions from the composer. Multiphonics are not impossible to produce, contrary to what a lack of prior literature would suggest.

Keywords

piano, multiphonic, composition, timbre, notation, microtonality

Other Information

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Abstract

Meine Studie soll ein breiteres Wissen über die Klaviermehrklänge und dessen kompositionelle Verwendbarkeit in der Musik unserer Zeit ermöglichen. Von der vorliegenden Texteinheit werden Pianisten und Komponisten gleichermaßen profitieren, und er bietet die Antworten auf die Fragen: "was ist ein Klaviermehrklang", "wie klingt ein Mehrklang" und "wie soll man einen Mehrklang notieren".

Neue Vokabulär wird definiert und Ungenauigkeiten in der bisherigen Terminologie werden abgeschafft. Die multiphonische Spielart (mode of playing) wird von der Spieltechnik (playing technique) und den Flageolets getrennt. Darüber hinaus werden Mehrklänge im Repertoire anhand Aspekten der Komposition und der Notation verglichen, und kompositorische Übertragbarkeit in ähnlichen Klängen auf anderen Instrumenten oder auf den mobilen Spielarten (mobile modes of manipulated playing) des manipulierten Klaviers (manipulated grand piano) werden ausgelotet.

Mehrklänge werden von Komponisten in verschiedensten Weisen benutzt, wodurch die notationellen Lösungen sich auch unterscheiden. Diese Studie untersucht Notationsweisen und wird eine für die meisten Fällen geeignete Notation vorschlagen ebenso wie die am häufigsten vorkommenden Mehrklänge in Notation eintragen.

Das Bestehen der Klaviermehrklänge wird mathematisch nachgewiesen, sowie mit Tonaufzeichnungen und Kameramessungen. In meiner Arbeit berühre ich an der Übereinstimmung der FFT-Analyse und des Gehörten und biete durch Klangbeispielen Mittel dafür, sich as Zuhörer der Mehrklänge zu verbessern.

Es wird festgestellt, dass Mehrklänge zu produzieren vom Pianisten kognitive Besonderfähigkeiten und einiges technisches Können, und vom Komponisten detaillierte Anweisungen erfordert. Es ist nicht unmöglich, Mehrklänge zu erzeugen, obwohl die Mangel an vorhandener Literatur darauf hinweisen würde.

Suchwörter

Klavier, Mehrklang, Komposition, Klang, Notation, Mikrotonalität

Weitere Information

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Tiivistelmä

Tutkimukseni tarkoituksena on mahdollistaa pianon multifonien nykyistä laajempi tuntemus ja sävellyksellinen käyttö aikamme musiikissa. Tekstikokonaisuudesta on yhtäläistä hyötyä pianistille ja säveltäjälle, ja se tarjoaa vastauksen kysymyksiin "mikä on pianon multifoni", "miltä multifoni kuulostaa" ja "miten multifoni nuotinnetaan".

Uutta sanastoa määritellään ja aiemman terminologian epätarkkuuksia karsitaan. Multifonien soittotapa (mode of playing) erotetaan soittotekniikasta (playing technique) ja huiluäänistä (flageolets).
Lisäksi vertaillaan multifoneja sisältävää ohjelmistoa sävellyksellisistä ja nuotinnuksen näkökulmista sekä tutkitaan multifonien sävellyksellistä siirrettävyyttä muiden soittimien samankaltaisiin ääniin tai muokatun pianon (manipulated grand piano) muihin liikkuviin soittotapoihin (mobile modes of manipulated playing).

Säveltäjät käyttävät multifoneja eri tavoin, joten myös nuotinnusratkaisut eroavat. Työssä tarkastellaan notaatiotapoja ja tehdään ehdotus useimpiin tilanteisiin sopivasta notaatiosta sekä nuotinnetaan yleisimmin tuotettavat multifonisoinnut.

Pianon multifonien olemassaolo todennetaan paitsi matemaattisesti, myös akustisten äänitysten ja kameramittausten avulla. Työssäni sivuan FFT-analyysin ja kuulokuvan vastaavuutta ja ääniesimerkein tarjoan keinoja harjaantua multifonien kuulijana.

Todetaan, että multifonien tuottaminen vaatii soittajaltaan tiedollista erikoisosaamista ja hieman tekniikkaa sekä säveltäjältä tarkkaa ohjeistusta. Multifoneja ei ole mahdotonta tuottaa, kuten aiemman kirjallisuuden vähyydestä voisi päätellä.

Hakusanat

piano, multifoni, säveltäminen, sointiväri, notaatio, mikrotonaalisuus

Muita tietoja

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1. Introduction

1.1 Preliminaries and Aim of the Work

In this study on multiphonics of the grand piano I have aimed to present a broad approach to the many different compositional solutions in using multiphonics to unravel the many yet uncharted ways of playing and, especially, of composing for these sounds.

My motives for the research were those of a composer-pianist who wants to use multiphonic sounds and to convince pianists of these sounds' validity as performable musical substance. As more and more pioneering composers and pianists employ and push forward multiphonic sounds with local musicians, it becomes increasingly an everyday experience for later generations.

Multiphonics are a valuable timbral and instrumental resource that composers have to master since they provide a gateway between noise and pitch and open the conventional piano to visual-spatial dimensions and multiphonic sounds on other instruments. All of this is illustrated in the recent tendencies in repertoire and acoustic research that have found more noisy sound substances to be used in composition.

I intend this study as an appreciation and empowerment of the multiphonic realm of sounds on the piano. Certainly, multiphonic sounds deserve recognition as they are distinguishable from the conventional music played on the piano keys only. Yet awareness is not nearly in line with the conventional portrayal of the grand piano. Multiphonics will take on this new meaning with this study, since the phenomenon is to be proven by acoustic measurements, accurate descriptions of the multiphonic sound will be formulated, and notation is to be developed considerably to transfer the musical ideas to pianists.

I hold that multiphonic sounds could become more widely acknowledged by and familiar to pianists and composers alike. This study can be read by both kinds of professionals as a guidebook in different ways according to the reader's viewpoint. As a result, a notation for the multiphonic mode of playing is proposed that caters to both composers and pianists.

Alongside the text, sound examples of multiphonics will gradually introduce the corresponding way of listening. Several materials thematically near to the piano multiphonics are presented along the way and referred in the appendices. Audio materials that are deemed central to understanding the point in question have been referred to with the symbol  . In the concluding chapter 6, the results are examined and additional directions for future research are proposed.

The composer who settles for no less accurate results than the intended multiphonic sounds should have comprehensive theoretical knowledge on the topic, for instance when reacting to pianists' and string instrumentalists' comments such as "but couldn't you just say flageolet?". On the piano, multiphonics have to be separated as a subcategory from the concept of **flageolets** as they sound different. The difference to the tempered pitches conventionally played on the keys is even more evident. Multiphonics present minute grades of interval steps with complex microtonal frequency proportions and most cannot be accurately presented on the tempered 12-tuned instrument. Throughout this study, the term **multiphonic** will be predominantly used to denote a sound that is made of some but not all the **harmonic components** from an overtone series. The wider meaning of the term could mean any sound with many discernible frequency components – friction multiphonics are included in both as they additionally have inharmonic components. [1]

Using a contemporary way of attentive listening, one starts to identify the previously unnoticed or "subsidiary" pitches in almost any flageolet. This refinedness is in keeping with many recent developments in composition, where one tendency in music now is to consist less of densely performed events and more of bare acoustic details that, while also dense, are given by the composer enough time and space to be perceived.

1.2 Terminology and Definitions

1.2.1 Essential Terminology

A complete terminology for the contemporary piano does not yet exist. Besides the word multiphonic itself, neither has a standard terminology evolved around it to describe phenomena specific to multiphonics. Here I will present historical precedents and also seize the opportunity by proposing terminology that portrays the essential concepts discussed in the study.

Multiphonics on the piano have been consciously used by composers since the 1970's at latest, after separate non-establishing attempts since the 1930's. As will be seen, there are many differences, even advantages of piano multiphonics over similar instrumental and electronic sounds which leads to terminology specific to the piano. Depending on the type and use of multiphonics, a composer could do with or without a **notational** reform; for instance in a score that was acquired, *Serynade* by Helmut Lachenmann, the multiphonic mode of playing is marked with the **flageolet circle** above the stem, familiar from many other instruments (see Fig. 1.2-1). Lachenmann has called it a "Flag.Reservoir", alluding to a notated collection of six flageolet pitches below it that are supposed to sound by playing the notated key, which in turn is notated a "Flageolett-Berührung", a **flageolet touch**.

The type of touch needed for flageolets and multiphonics is light and does not shorten the acoustical sounding length of the string. As we will see, different compositional goals require different terminology and notation and such double terminology is not always necessary. Lachenmann's composition will be dealt with in more detail in chapter 4, along with scores by other composers.

[1] For a detailed explanation see Appendix 1.

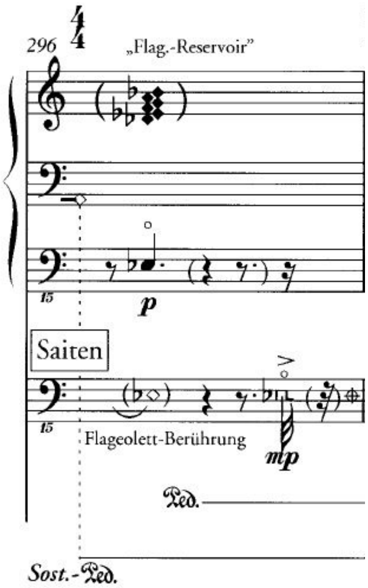

Fig.1.2-1. Piano multiphonic in H.Lachenmann: Serynade*, b. 296. Edition Breitkopf.*

For **conventional playing**, using the piano keys by pressing them with the fingers is the only definitive prerequisite. The majority of existing keyboard repertoire is written with this concept in mind. With the historical introduction of pedals, they were, with the exception of short-lived pedals for external percussive sounds, gradually absorbed to the convention of piano playing.

When speaking of conventional playing repertoire, the manner of playing is considered highly dependent on the performer. This individual choice is often called the pianist's **technique**. In this study the same type of choice of **playing technique** can be considered in **non-conventional playing** as well. If the music instructs to hit the side of the grand piano, the pianist could choose for example to either hit it with the thumb recoiling rapidly, or with entire the palm of the hand in an angle that lets the knuckles hit slightly sooner than the rest of the hand. In conventional repertoire, a performer's playing technique can only start where notation ends – and this happens quite soon as composers' notation has historically been much less specific than the present average. Any type of audible contact other than fingers pressing keys of the piano counts as non-conventional playing.

The choice of playing technique is thus more about granting convenience, adjustment to the particular instrument, or accuracy to the performer in those cases when the choices pose a narrow range of aesthetic variation anyway. In too many a current music text, the term playing technique has been used misleadingly and disrespecting of this performer viewpoint. In music that concerns itself with an unconventional location on the instrument, a new direction or contact of playing or a fresh combination of conventional technical elements, the term **mode of playing** should be used instead[2]. In short, *technique* is an ergonomic or habitual choice best left to the performer's physique, whereas the *mode* of playing is a choice yielding audibly different results and should be left to the composer.

We can also distinguish between piano sounds that are played with hands only, and all the rest that could include any amount of **external objects** either held by the performer or attached to the piano. Both of these cases with external objects constitute playing **a**

[2] This usage of the term has been acquired from Robert (1995).

manipulated piano, though the first case can be defined as **mobile playing**[3], and the latter as **prepared playing** – a term familiar to the public since H.Cowell and J.Cage at latest. In the case of prepared playing, the instrument itself has been transformed which might even require conscious adjustments to the performer's playing technique on the keys.

None of the modes of manipulated playing should seriously be called **"extended playing"**. Neither are "extended techniques" a display of a skilful pianist's technique as opposed to that of another pianist. Any "extension" done by the performer's hand is only cosmetic while the grand piano and its wide possibilities remain, and the term rather is symptomatic of a limited knowledge of all the historical facets of keyboard repertoire or consistent ignorance thereof.[4] The term "extended" is also criticised as having an ethical connotation and lacking definition (Vaes 2009, 5-6) in Vaes's comprehensive study that fails to mention the multiphonics, though. Piano multiphonics should not be defined as an extended mode of playing, as the strings have always been of similar construction and within the performer's reach. The earliest pianos were designed and optimised, however short-sightedly, for playing on the keys that transmits impulses to the strings and dampers via an intricate mechanism. This is the original intention of the piano – any other functionality can be seen as a manipulation and not as an extension since this core mechanism is only being interacted with and not being continued from either direction. By using the term *mode of playing* equally for sound production of any kind on the piano, one can avoid this ethical discussion.

The multiphonics are always a form of non-conventional playing on a manipulated piano, as the piano cannot produce these sounds without **modifications**. Then, whether prepared playing or a mobile mode of playing is involved depends on the composition. If fixed external objects, i.e. **preparations**, have been attached on the strings at multiphonic locations, the keyboard is indispensable but hands-only playing is possible for both hands. Objects are attached above, under, or around strings at a desired distance and the corresponding keys are played. The object often cannot be removed while the string is vibrating.

If, using the other option, no preparations have been made but objects are held temporarily and used for instant results, multiphonics would be a mobile mode of playing a non-prepared piano for one moving hand inside the piano while the second hand makes use of the keyboard. The strings are left as they are but one hand has to hold a plectrum or another object on the string at the desired distance, an acoustic **node**, whenever the key is pressed by the other hand. For a cleaner sound, the object can be released shortly afterwards.

In both cases, the distance of the object is crucial to the resulting pitch complex – use of the pedals is optional, though it is preferred in many compositions. There are several placements inside the piano where objects can be applied. For a description of the piano inner parts and a more categorising discussion about the possibilities of the manipulated piano, see Appendix 1. In this study, the mobile mode of playing multiphonics will prove itself more versatile and somewhat unpredictable, whereas the prepared multiphonics

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[3] A term influenced by Luk Vaes's "mobile preparation" (Vaes 2009, 711)

[4] Similar concerns as to differentiating "extensions" and "global technique" on the cello have been expressed by Fallowfield (2009).

will have a reliable though short-sounding and more limited choice of what can be woven together to form equally interesting music. More attention is given to the former.

The **degree of inharmonicity** should not be used as an indicator of whether a flageolet be classified as a multiphonic or not. When the words are taken apart, a multiphonic means any sound coming from one source that has at least two discernible frequency peaks. Friction multiphonics are also included and will be discussed later on. Some multiphonics consist of exceedingly harmonic partials that also lie at almost tempered frequencies. One possible perceptual requirement is that more frequencies than the fundament and one partial are audible simultaneously. The sole acoustical requirement is that these audible partials also form the highest three peaks in an FFT analysis, with some exceptions[5].

Practically, any attempt at producing a flageolet higher than the 5th harmonic will result in a multiphonic. The perception even at the 5th is not exact – in cases where a high spectral peak is almost as loud as a lower spectral peak, the loudness difference at which the perception changes from simply a flageolet to a multiphonic is probably individual.

Employing individual partials higher than partial 5 can be seen as theoretical only, because of the comparably short length of the strings and human inaccuracies in locating the mathematically best suitable slot. The absolute distance between adjacent mathematically best suitable slots becomes smaller while the winding itself remains similar in construction and thus hard to estimate. Each node of a partial has a **range of influence** along a string relative to its vibration period. The range of influence for a partial's node point on the string is the range where that partial can still be heard when the external object progresses to other nodes away from the theoretical node point. It has been empirically found out to be around 15% to 20% of the partial's cycle to both directions from the theoretical node point.

Higher partials' nodes are distributed nearer to all kinds of other partials but also have smaller ranges of influence. The relative distance to the next audible partial becomes too small to prevent them from blending with other partials. For example:

The location of node 1/5 is 20% of string length, with nearest neighbour nodes 3/19 and 3/16 (see Figure 1.2-2).[6]

> 20 – 18.75 = 2.25 and results in 11.25% of a 5th partial cycle, which is 20% of string length.
> 21.05 – 20 = 1.05 and results in 5.25% of a 5th partial cycle.
>
> The location of node 2/7 is 28.57% of string length, with nearest neighbour nodes 5/17 and 5/18.
> 28.57 – 27.78 = 0.79 and results in 2.77% of a 7th partial cycle, which is 14.29% of string length.
> 29.41 – 28.57 = 0.84 and results in 2.94% of a 7th partial cycle.

The neighbours of 2/7, the higher partial node, has neighbours relatively nearer to it than 1/5, the lower partial node, has. This makes the higher partials neighbours of any partial node more difficult to play independently without interference from a lower partial neighbour. The 11.25% distance of 3/19 from 1/5 makes that node of the 19th partial the most independent and pure of these examples. The other neighbour of 3/19, the 3/14, also has a small enough range of influence. Their distance is 21.43 – 21.05 = 0.38 and results in 5.32% of a 14th partial cycle, which is 7.14% of string length. On the inverse,

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5 The hearing curve and noise levels tend to progress with frequency and have to be accounted for.

6 There are more partial nodes more near yet they are of a higher number and cannot be realistically heard on most instruments.

0.38 is 7.22% of a 19th partial cycle, so the partial 19 will be less audible when playing the 3/14 node.

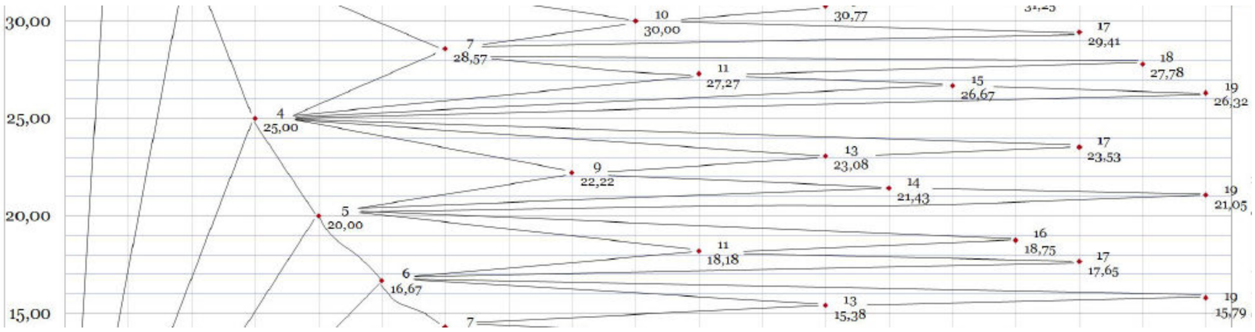


Fig. 1.2-2. The region of the string around 15% and 30% of string length from the keyboard side (on the vertical axis). When the string is affected by an external object at a node, certain partials will sound (shown as a percentage and the number of the resulting partial). Also see Appendix 5.

Generally, the higher the partial, the less dominant and the more blurred it will be. The extremes of this rule are the 2nd partial, and pressing a node within about 5% of string length from the start of the string, as in T02. Another exceptionally clear-sounding possibility produces pure partials, made of the fundament and one harmonic sound, by using a wide object that steadily covers many slots in and only in the range of influence for the desired partial. Once the hammer hits, some other partials will be present but as soon as the pianist presses the object down forcefully the other partials will cease. Pressing the object has the disadvantage of notably shortening the decay time. This technical adjustment to the multiphonic mode of playing functions on partials from the 5th upwards, and on the long strings of a Steinway D.

1.2.2 Playing Multiphonics – Mechanics, Precision, and Timing

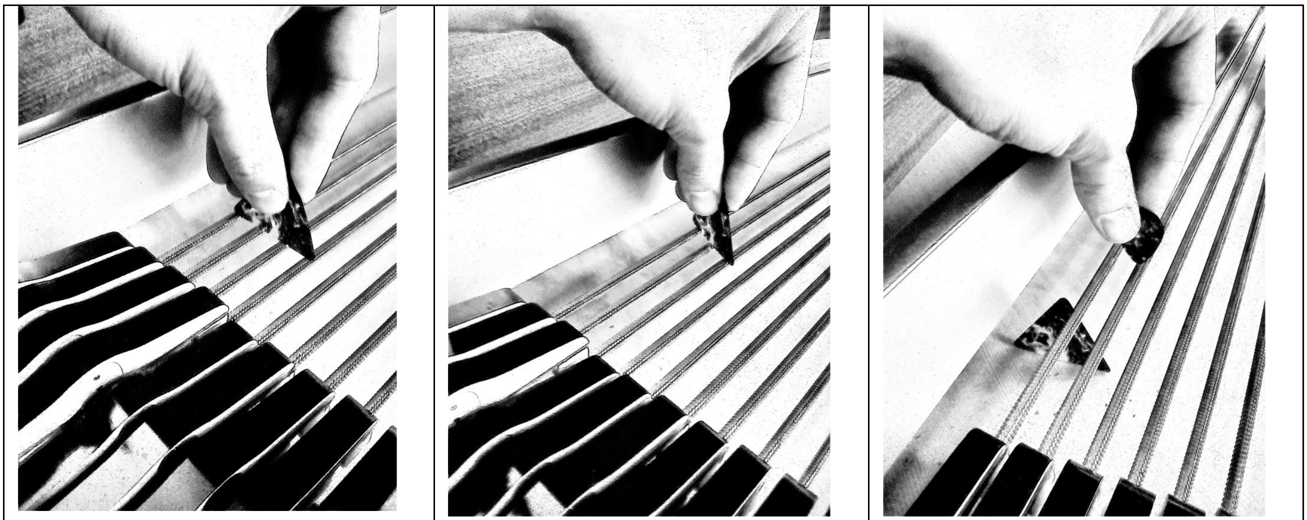
In its simplest and most reliable form, a multiphonic can be played in the following way:

1) a light and small object (a **node-obstacle**) such as a plectrum is put on a **monochord** string, to rest on a slot of the copper winding. (kept in the right hand)
2) the corresponding key is hit quite loudly and held pressed. (left hand)
3) the plectrum is soon released upwards away from the string (right hand)
4) the key is released at latest after the sound has faded completely, or earlier (left hand). Also, the pedal can used, in which case the decay can be regulated more.

As long as this mechanical procedure is accepted, the most commonly held conception of the resulting piano multiphonic is that the sound is made of a clean and "filtered-out" compound of partial frequencies. These partials' frequencies are not quite harmonic and can be attributed to the piano's inherent inharmonicity. The perhaps most common misconception is that the multiphonic sound is stable. Neither can it be generalised that a key and a hammer must be controlled by one of the pianist's hands, regulating time, and the string by the other hand, regulating frequency content. To each of these strictly defined statements, exceptions will be found from the technical and acoustic domain, especially in chapter 2.4 and Appendix 1.

There are numerous multiphonics available on any grand piano. The exact number depends on the length of the string, as longer strings have more slots and less blending or neighbouring partials. Illustrations can be seen in Appendices 3 and 5.

As easy alterations to this method, the multiphonic onset can be achieved with the hammer, the hand, or external objects. Several multiphonics can be played simultaneously if there are enough node-obstacles or they are shared between nearby strings. In the case of Erik Oña's *Jodeln*, a second player responsible for pressing the nodes enables numerous simultaneous multiphonic combinations. There are also differences in **plectrum size and shape**, which can be taken advantage of (see Figure 1.2.2-1).



a. b. c.

Fig. 1.2.2-1 a, b & c. Ways of producing sounds with a plectrum. a) A large thin plectrum that has even sides (in the picture, a Fender Thin 355 Shell*) can be used to play up to four simultaneous multiphonics on adjacent strings. The nodes will not be similar because of the different length and starting points of the strings. b) When aiming at similar nodes, the plectrum has to be slanted slightly and will most probably hit two or three strings. More pressure is needed to prevent buzzing. c) Comparison of the plectrum sizes. A big enough plectrum can also rest on the soundboard with support from the winding. It will not produce enough pressure on the node to result in a multiphonic though a device can be built on the soundboard to control the string from underneath (see Chapter 4.5). A more secure way to indicate multiphonic nodes is to use push pins sticking upwards from a steady surface next to the string. A small thin round plectrum (in the picture, a* Fender Thin 351 Shell*) is practical for playing multiphonics on two neighbouring strings. Large, triangular or sharp plectrums are rather unsuitable for smooth releases from the string. A large plectrum should only be used in the special cases such as a and b. Thin plectrums, however, will be damaged by scratching the winding, and a comb or a credit card is preferable. When playing on one string, the plectrum cannot always rest on other strings. Placing any kind of plectrum between the strings of a dichord pich demands slightly more force against stiffness at either end of the string.*

More challenges arise once the performer has become accustomed to holding and releasing the plectrum silently and coordinating with the keys. For a pianist, becoming microscopically aware of the inner parts of the piano constitutes beginning to learn an entirely new versatile instrument. Near to the strings, there are a hardly any **landmarks** to help find the right slots.

The limited number of keys available might prove problematic as well. Many grand pianos have around 8 or 9 monochord strings. The **dichord strings** are playable yet demand more attention. More sideward pressure is required with dichord string grips at both ends of the string than near the centre. Once successful, the multiphonic's quality might surpass that of a monochord. Visually associating the correct string with the relevant key to press can seem daunting and especially irritating in the many cases when there is no time or room for safety muting. The number of keys is however advantageous from the viewpoint of the number of fingers. The entirety of monochord strings can be controlled by one hand and the *prolonger* pedal, which quickly manages to "remember" all of the strings. Instead of traveling between the inner parts and the keys, both hands can be used exclusively around the inner parts if the prolonger pedal is fixed to stay down, an appropriate mallet is used and the strings can be damped manually with a glove for instance.

To improve **precision** in rapid passages, the pianist can mark the score in advance with all the intervals between the fundamentals in terms of half-tones. The half-tones will then correspond to the number of strings to cross. For ease of orientation, the central string among the monochord strings could be temporarily coloured at its agraffe and intervals can be memorised relative to it, or all black keys could be marked at their agraffes. Each concert instrument tends to be different to the practising one so no distances can be memorised. A particular node is located at a different distance from the performer on each string, making for yet different angles for such "**node glissandi"** where the strings are played one by one at the similar node. These distances have to be practiced and memorised from scratch on an unfamiliar instrument to retain that node percentage. For finding a precise slot on any string, there seems to be no easy solution unless several tries are allowed or external devices are used. Some suggestions are given in chapter 4.5.

Pianists beginning to study multiphonics should not be discouraged by fatigue and extended times of **practicing** that might undermine precision. Concentration may not suffice to distinguish small distances between neighbouring slots or strings easily, or the hand holding the plectrum might cramp. Whenever possible, practice hitting the pitches on the keys and add the inner elements only when minimal attention has to be paid to the keyboard and there is enough lighting for locating the nodes.

When multiphonics are juxtaposed with more multiphonics or other loud sounds, **timing** becomes essential. Since the dynamic range where all partials can fully project is limited, the situation becomes rather analogous to playing traditional repertoire on the harpsichord, in which lacking dynamics can be compensated with timing. In metred music, in order for the multiphonic be perceived it is necessary to avoid onsets at bar lines or beats– whenever this fits the intention of the composer. On the other hand, some music requires the onset to be obscured or crowded in which case the body of the multiphonic sound can readily be perceived.

1.2.3 Microtonal Implications

Multiphonics are a source of **microtones** – a fact often ignored in notation, for instance by the Lachenmann score. The term *microtone* is always a relative connotation. In this case, it means any pitch detectably differing from 12-TET pitches in 440Hz tuning – those pitches most used in contemporary music practice. That **just noticeable difference** or **difference limen**[7] could constitute non-simultaneously sounding sine tone frequencies even as near as 7¢ apart in the frequency region of 1 ... 5 kHz, and about 10¢ in the region of 500 Hz. [8] Detectability depends on register and the **critical band of hearing** in that register.

Tonality in the wide sense is a pitch referentiality. *Microtonality* is a misnomer when non-12-TET music uses no intervals smaller than 100¢, and in those cases where no pitch referentiality is implied – such is the case of many compositions with piano multiphonics. However, as the term enjoys firmly established status it will be used throughout this study.

Many of the partials are somewhat lower than the tempered 12-tone equivalent pitch. One restriction for the versatile use of multiphonics can be seen easily: in an overtone series of a tempered pitch there are no partials that are notably higher than a tempered pitch and a few early partials in the series such as the fifth are so slightly out of pitch, flat, that approximating them as their tempered neighbour above may seem tempting. The inflections to the temperament brought about by the partials 1...19 are, seen from a lower tempered pitch, +2¢, +4¢, +5¢, +41¢, +51¢, +69¢, +86¢, +88¢, and +98¢. There is an unfortunate lack of partials between +5¢ and +41¢ that could fill a tempered minor second evenly and thus smoothly bridge the microtonal and tempered realms.

Microtonal notation will be dealt with in chapter 5. Microtonal notation and methods for composition can be found in the Appendix 2.

1.3. Literature Review and Refinements of Terminology

1.3.1 Multiphonics Source Literature

In the following, research literature is discussed in regard to the present study. Many limitations in studying the phenomenon will also be encountered and these dead ends will be dealt with. The remaining core concepts in and around multiphonics will be defined alongside the corresponding literature.
While the multiphonic sound does not possess a long and glorious artistic history to discuss, analogies from historical use of other modes of playing the piano will be drawn from the literature. Recent turns in compositional aesthetics leading to the wider use of multiphonics will only be touched upon where relevant. As is often the case with recent musical findings, experiential accounts are few and far between. For this reason, subsequent elaboration on the literature of performative aspects will have to be kept to a minimum.

[7] Values calculated from charts in Moore (2012; 77, 86, 205). Sources agree only qualitatively, not quantitatively. Low frequencies can be discerned more accurately and listeners' hair cells differ in their values for motile response.
[8] In acoustics, the tempered semitone is made of 100 cents, marked 100¢.

All existing research into the subject of piano multiphonics is rather recent, from the years 2014 and 2015 – it has surfaced during the process of my research. Even within such a limited corpus, the works by Hirvelä (2013), Onofre & Bragagnolo (2014), and Walter (2014) might unfortunately be perceived as inaccessible by the greater public as they have not been translated into English.

As to the piano multiphonic repertoire, no research before 2014 exists if treatises on George Crumb's works are excluded on basis of their rather general approach to multiphonics. Apparently no list portraying the piano works with multiphonics has been compiled and the first one can be found appended in this study.

Relevant examples of the multiphonic repertoire, such as Walter's, have been included in Onofre & Bragagnolo (2014). Even they do not provide a lengthy analysis of a work in the multiphonic repertoire. Walter (2014) does not draw on the composer's own or any other multiphonic compositions for examples. Robert (1995), Fallowfield (2009), Thelin (2011), and Tsao & Josel (2014) have written about multiphonics on some **other stringed instruments** in such mathematical detail that the results are readily transferrable to the piano. The piano repertoire has been examined with a minor focus on flageolets in Ishii (2005) which is a valuable resource for listing the US-American repertoire and including flageolets in discussions of selected works.

This far the most compact source explaining in overview all relevant facets[9] can be attributed to Onofre & Bragagnolo (2014). Theoretical and mathematical insights are brought by Walter (2014) as the first to deeply address the peculiarities of the piano multiphonics. Walter's mathematical principle of calculating multiphonic nodes will be discussed later on. At a wider scope, Walter aims at explaining microtonal composition. Similar ground-breaking theory of the unique sounds of long strings has been laid out in Robert (1995) and Thelin (2011), both for the **double bass** and can function as a reference for the pitch content of piano multiphonics. Perhaps acoustically the nearest instrument to piano multiphonics, the **double bass** had its "first to be published on the subject [of multiphonic sounds]" book in Pierre Robert's *Modes of playing the double bass* (Robert 1995, 21). It still is the prevailing and definitive guide in terms of practical instructions on playability and notation and introduces a vast range of different playing modes for the double bass. Thelin (2011), studying the same phenomenon on the same instrument, builds on even more mathematical knowledge. Although the multiphonics are less applicable on shorter instruments, Fallowfield (2009) also provides strikingly similar and confirming audio documentation for the violoncello and Tsao & Josel (2014) for the acoustic guitar. In both studies, charts are given showing the placement of the flageolet nodes on the respective instrument. Tsao & Josel have researched a vast realm of guitar modes of playing whereas Fallowfield concentrates on the violoncello multiphonics mode. **Non-stringed instruments** have multiphonics that are not produced in the same manner as on hammered, plucked, or bowed strings. That literature has developed a few decades earlier than that of the string multiphonics and will be mentioned in chapter 2.2. The technical limitations for playing selected manipulated sounds and flageolets – not multiphonics – and differences between various piano models have been undertaken in detail by Hirvelä (2013). This technical point will not be discussed thor-

[9] Repertoire, notation, spectral analysis, comparison of technical limitations on different pianos, multiphonics on other instruments.

oughly here and for that Hirvelä's work should be preferred. Within an investigation of the restrictions set on "extended" playing, excluding multiphonics, by different models of grand pianos and their interiors, Hirvelä (2013, 24-30) also covers flageolets on the **Steinway model D** in astute detail. According to Hirvelä (2013, 24), this particular model enjoys a standard and widespread usage in concert halls and has the longest strings of all Steinway models, which solves some problems for flageolet playability. The study is written for composers and performers who previously were irritated by the lack of standardized piano inner construction to rely on (Hirvelä 2013, 1). Hirvelä (2013, 25) goes on to list the node positions of partials 1...11 on the lowest C string as fractions, as partials and as pitches with cent deviations from the tempered scale. The listing of node points has been considerably expanded in the present study.

Vaes (2009) is the by far most extensive source on almost any mode of playing on the piano but does not explain much about multiphonics. A fleeting passage labels multiphonic sounds with the term "polyphonic harmonics" without fully defining it (Vaes 2009, 21). Yet another term used, on the guitar, has been "complex harmonic partials" (Josel & Tsao 2014, 123). The term multiphonic seems however to have attracted the widest following in the literature.

Hudicek (2002) and Proulx (2009) both provide a general overview to the realm of the manipulated piano. Proulx defines the harmonic [flageolet] as "a variant of the mute" (Proulx 2009,67). The technical content of the only mentioned composition with multiphonics, *Sinister Resonance* by Cowell, is described as "mute, harmonic" by Proulx (2009, 3). [10] Both texts include remarkably little about a conception of timbre and the sounding result, however. Instead, both have a rather practical approach, giving **precautions and ergonomical suggestions** to pianists (Proulx 2009, 28-31 and Hudicek 2002; 123, 170, 190). Apart from Hudicek (2002, 183ff.) not much has been written to a high degree to guide the pianist about safety with mobile and fixed modes of playing. The findings by Hudicek that can be most easily expanded to the multiphonics are those of the bass strings and dampers. Hudicek makes the reader aware that the compositions pose **threats and risks** to the instrument as well as to the pianist playing and preparing it. **Muting** and the **prepared piano**, relevant to some multiphonic sounds, is addressed by Hudicek (2002, 166) and Vaes (2009, 76-80). Those topics deal with intricacies of external object materials and have been mostly left outside this study.

The study at hand is a culmination of a **research project** that intends to combine existing strands of knowledge and previously dispersed compositional expertise. The project has started in January of 2014 and is firmly established on acoustic measurements to prove the existence of piano multiphonics. I have conducted and published acoustic measurements at the Aalto University Department of Signal Processing and Acoustics (Kubilay, Vesikkala, Pàmies-Vilà, Kuusi & Välimäki 2015a). Such measurements are necessary to prove not only the validity of the aural perception but also an analogously applicable physioacoustic basis of multiphonics on the piano. To my knowledge, studies to this effect were not to be found elsewhere. Nor were there studies verifying the existence of multiphonic vibration on the piano, the nearest field being Välimäki's ongoing research

[10] Even conventional playing on the keyboard constitutes harmonic sounds, thus the technical method of muting is of importance here. Proulx declines to go into explaining neither the basic mathematics of harmonics, and there is no mention about the term or existence of multiphonics.

focus on peculiarities of the piano sound. No previous projects exist with the same method of measuring any instrument's multiphonics both by ear, audio recording, and a specific mechanism called line-camera recording. Selected results of the project paper Kubilay, Vesikkala, Pàmies-Vilà, Kuusi & Välimäki (2015b) will be referenced here.

During my process of the measurements and writing, two other studies were published. The first one is by Walter (2014) in a publication on microtonality. The reason for Walter to publish the study was to facilitate performance of the repertoire. Walter especially mentions the writer's own compositions intended for and easily performable on an unspecified Bechstein concert instrument thanks to node locations that lie intuitively next to the inner structures of that piano model (Walter 2014, 25). Walter envisioned that the music by all means should become approachable on other types of instruments as well, which has happened with the help of a specifically developed technical device on Bösendorfer 200 and Steinway D instruments and the collaboration with students (Walter 2014, 25-26). The device is not sufficiently described by Walter, and the possibility of such a device will be discussed later on in chapter 4.5.

The second similar work was published in December 2014 by Onofre & Bragagnolo, which I came across in June 2015. Their work, available in Portuguese only, is of a smaller scale than Walter's and introduces multiphonics as an "extended technique" (técnica expandida) to the general public of composers. Their unique viewpoint is to generalise multiphonics on two different instruments and, in so doing, importantly prove the general applicability of this mode of playing and to put an end on any claims of arbitrariness. Again, many of the results by them are replicated in my research.

For the literature review, I have examined several publications on **contemporary instrumentation** and **notation**, extending from old esteemed to the brand new from year 2013. It is theoretical reference books like these that have had a share in inspiring composers, and to some extent even today. None of those studied has a mention of piano multiphonics. Interestingly, one of the earliest, Read (1976), gets closest. Read lists some early compositions known for their piano multiphonics, such as *Duet I* by Christian Wolff, in another context but fails to mention them having the most typical of multiphonics – Read does allude at attackless multiphonics and buzz multiphonics though (Read 1976, 198). Read describes the almost typical multiphonic by "raise a low, wound string with two fingers, let it twang audibly, then touch the still-vibrating string with a fingernail or a plectrum" (ibid., 199); in its simplest form, raising the strings and releasing them is of course not required and would result only in an extremely faint sound at the start already, and operating the keys and hammer is the now prevalent option. At no point does Read describe the resulting sound as being a flageolet or a multiphonic or having several pitch components.

All the studies encountered are lacking in **audio examples** – the lack of an open source collection is lamented by Walter (2014, 40). Audio samples are a definitive feature of the recent Bärenreiter instrument guide series, for example.

I have not encountered viewpoints denying the existence of multiphonics. The use of multiphonics on the piano was considered rather utopistic compositionally by Marco Stroppa, having composed one work with piano multiphonics (Stroppa 2015). Positive practical multiphonic experiences of composers and pianists will be decisive in speeding up formation of repertoire and creating a need for more research. As most statements made in the literature this far are merely qualitative, I have found no results conflicting with mine.

1.3.2 The Flageolet vs. Multiphonic Distinction

Vaes (2009), although an extensive resource on the modes of playing the piano, does not mention multiphonics except for in a catalogue-like footnote, and even flageolets are mentioned as part of particular compositions, in passing contexts only (ibid., 7 & 85; 184ff.). [11]

Vaes (2009, 74) defines and comments on the flageolets thus

> "A flageolet – the sound and technique of manually pressing on a string's nodal point and then triggering that string's vibrations to produce the partial relative to the nodal point" – "Ligeti's calling the latter *touches blocquées* (blocked keys) was more accurate and to the point. This study will therefore distinguish between *flageolet* on the one hand (directly manipulating the string's length) and *silently depressed keys* or *open strings* on the other hand."

No statement distinguishing piano multiphonics from flageolets can be found other than a contextual and perceptual one by Walter (2014), where a "Flageolett-Mehrklang" is described as "Flageolet multiphonics are only with difficulty transferable to notation and are often used as an object that lies between a chord, timbre [Klang], and noise, that arises from the musical context." (Walter 2014, 14) From this intermediary compositional identity, Walter also alludes towards an aim to rid the piano multiphonics of their exotic flavour to let them communicate freely with other pitched elements (Walter 2014, 14). Such exoticism may be understood by the fact that flageolets simply point at one pitch in addition to the faint fundament sound whereas multiphonics might get reduced in auditory perception to a wide category of noise.

After first defining a flageolet, Walter however does not give a binding definition to the multiphonic flageolet, instead describing it as having the similar manner of playing as a flageolet but choosing such a place on the contacted string on which "no clear flageolet responds" (Walter 2014, 16). A strict definition for such degrees of clarity of response is not provided by Walter although numerical considerations about node points between the flageolet nodes are being presented.

Contrary to flageolets, many partials can be heard in the case of multiphonics because the position of the node-obstacle does not even nearly correspond to a small integer number of small waves. The string divides into small waves of several different lengths simultaneously, each wave with less energy than that of a comparable flageolet impulse.

A further definition could be formulated that nodes where a multiphonic is heard cannot be replaced by any other node except its symmetrical counterpoint. Small-number flageolets can be replaced by other nodes without causing detectable differences and are often notated without a particular node in mind. The "synonymous" nodes 1/5 and 2/5 sound to some degree similar yet to some degree different and thus constitute a grey area be-

[11] Also, Vaes (2009, 7; 74) seems to give disproportionate importance to the nowadays obsolete usage of the term "Klavierflageolett" by Schoenberg to denote silently depressed keys. Vaes does not mention the composition in question. Schoenberg apparently had an early spectral method, the sympathetic resonance brought about by the "selective" activation of open strings (Vaes 2009, 73) in mind.

tween flageolets and multiphonics. With higher-number partials' nodes, comparisons such as with nodes 2/11 and 3/11, multiphonic sounds are unavoidable – unless both nodes are being pressed simultaneously. This would reduce spectral content and pinpoint to one of the shared partials even amid the pitch complexes: "touching two nodes of the same partial simultaneously can bring about timbral variation, more than when partials at those nodes are pressed separately" (Fallowfield 2009, 143-144 & 150). Around the nodes of low partials such as 0/1 (0%), 1/2 (50%), and 1/3 (33%), bitone-sounding multiphonics prevail since there are concentrations of higher and higher partials as one approaches the low partial's node. The partials 11, 13, 15, 17, and 19 of any grand piano can be found here in their cleanest form, if at all.[12] The same applies to the partials 10, 14, and 16 around the 1/3 node.

What no source explicitly notes or differentiates is that an "unclear" and extremely complex multiphonic includes many of the same frequencies as a more clear one almost next to it, though in different loudness proportions. The pitch only changes seamlessly on some instruments near to the agraffe where even the lowest partial (excluding the fundament) of a multiphonic is so high that higher components are extremely difficult to hear – the complex is heard reductively as though simply a flageolet[13]. In all cases, including these front multiphonics, the difference between a flageolet and a multiphonic would have to do with the amount of frequency peaks and their loudness relations. To define an ultimate loudness proportion between the strongest and the second-strongest partial that still qualifies as a multiphonic, as opposed to a flageolet, is after all impossible.

1.3.3 Availability of the Nodes

Not all of the theoretically possible multiphonic and flageolet nodes are always available. The composer has to consider the size of the instrument among other properties.[14]

Having studied only flageolet nodes, string glissandi, damping, and one of the transverse playing modes, Hirvelä (2013, 26) deems partials 1...11 as sufficient for the flageolet approach. [15] Hirvelä's judgement might rely on the fact that a clean 11th partial is already extremely difficult to produce. As also non-copper strings have been included and the practicality of reaching the node by hand is a concern, multiphonics become less relevant for Hirvelä's scope. Hirvelä also mentions that playing the 1/5 node is possible up until d# (D#3 in North American usage) and becomes covered by the dampers following that. Hirvelä (2013, 28) claims that the node 3/8 does not respond even on the lower strings and suggests a possible explanation in the filter effect since the hammer consistently was placed at exactly the 1/8 proportion. Hirvelä (ibid., 27-28) has examined strings up to c3

[12] "Indeed, many of these higher harmonics, when executed in the central area of the string, begin to sound as multiphonics. Thus, there are timbral differences between each location of the same harmonic on the same string." (for the guitar, Josel & Tsao 2014, 102)

[13] On the double bass Robert (1995, 22) notes that the "simplest sounds encountered – – are the non-harmonic multiphonics produced with a pluck near the bridge".

[14] Fallowfield (2009, 73 & 148) charts partials up to the 13th on the cello and presents four multiphonics which happen to be also available on all grand pianos – see Chapter 2.3.

[15] The grand piano interiors examined by Hirvelä are the typical concert instruments – Steinway models D, C, and B, as well as several and less prevalent Baldwin, Bechstein, Bösendorfer, Fazioli, Kawai, Seiler, and Yamaha models. Hirvelä's chart of flageolet nodes, however, applies to the Steinway D model.

[16] explaining with a graph which of the nodes between 1/11 and 4/5 remain reachable and audible when approaching the upper strings. Hirvelä (ibid., 27) also mentions that node points further than 4/5 are either too far from the performer's reach or on strings too high to respond well. The former limitation can be steered clear of in repertoire with preparations in the region or another player accessing the region from the other end of the grand piano, as in Erik Oña's *Jodeln*.

Walter (2014, 20) does mention limitations in the availability of multiphonic caused by the length of the string among other factors. Also the obstruction by the dampers and the filtering effect by the hammer position most commonly at about 1/9, which differs from Hirvelä's (2013, 28) finding, is observed, resulting in almost no 9th partial ever audible on a piano string [17] (Walter 2014, 24, footnote). Walter's notion might base on either a Bösendorfer 200 or a Steinway D instrument, whereas Hirvelä (2013) explicitly refers to a Steinway D. Nowhere is an upper limit given as to how high partials are still audible T01, T02. In a theoretical observation (Walter 2014, 18), the **highest partial** mentioned is the 55th. In a more concluding figure, the highest mentioned partial in a multiphonic is the 21st. [18] The symmetric positioning principle of the multiphonic nodes is mentioned by Walter (2014, 20). More about Walter's mathematical method of locating the multiphonics is mentioned in chapter 2.3.

Hardly will all the nodes be within the reach of one performer standing at the keyboard. It is useful for the multiphonic pianist to reach at least until the midpoint of the string, an almost impossible distance on the largest grand pianos – a total length of 274 cm on a Steinway D. Such ranges can only be achieved if the note stand is removed and perhaps replaced by a separate note stand lying on another region of the piano. Hirvelä's (2013, 3rd attachment) chart proposes 4/11 as the furthest reachable point on all monochord strings of a Steinway D.

Depending on the music crosswise bars can be a memory aid or an obstacle for fingers thicker than ca. 1 cm (Hirvelä 2013, 26). If the instrument model cannot be specified and nodes are not memorisable or cannot be marked the probability of substitution in performance should be somewhat taken into account by composers writing multiphonics for the piano. Instructions for substitution or customisation for a grand piano model to have the multiphonics in a composition performed are seldom provided by composers and lit-

[16] C6 in North American convention . The European convention of pitch names will be used throughout this study.

[17] The second partial of the 9th, the 18th, is also affected. The 18th partial is extremely difficult to hear on the piano. There are theoretically three nodes within a string half: 1/18, 5/18, and 7/18. Of these, 1/18 is the cleanest. Similarly on the guitar even without a hammer, "for producing the 18th harmonic, this area [5/18 at 27,8%] is extremely volatile since several stronger harmonics are present in the immediate vicinity. In fact, it is more likely that a multiphonic consisting of several local harmonics will sound there" (Josel & Tsao 2014, 100).

[18] A likewise extreme case presents itself with Torres & Ferreira-Lopes (2012) which examines the guitar's partial nodes up to the 39th partial. Studies seldom refer to any auditory or technical scientific grounding as to where to set the upper limit for feasibility of partials. In my own compositions with piano and bowed string multiphonics and in the graphs I have used notation up to the 19th partial. On the nodes nearest to the pianist, even higher partials are available, whereas in the middle region, partial components from around the 14th upwards tend to be unintelligible. To set a rather optimistic limit around the 19th leaves some space for individual variance between grand piano playing conditions and demonstrating the numeric patterns of multiphonics.

erature has ignored these sensitive issues, to the detriment of relations between composers and pianists willing to perform the repertoire.

1.4. Structure of the Guidebook & Suggested Chapters

The chapters can be ordered by reading preference as follows:

For pianists, especially chapters 3., 5.3, Appendix 5, Appendix 4, 1.2.1, Appendix 6.

For composers, especially chapters 4., 5., 3., Appendices 2, 3, 5, Appendix 6.

For musicians on other instruments, especially chapters 2.2, 4.4, 3.3, and Appendix 6.

For the reader only concerned with the resulting multiphonic sounds of the piano, there is a description (2.2) alongside audio examples (Appendix 6) and analyses (5.1).

In keeping with the reading suggestions above, the chapters are as follows:

Chapter 2 delves deeper into the essence of the multiphonic sound, with initiatives from mathematics and acoustics.

Chapter 3 explains the visual and sound measurements conducted by the author (Kubilay et al. 2015) and suggest ways to listen to the details inherent in multiphonics.

Chapter 4 examines how multiphonics have been used in past compositions and what can still be discovered compositionally.

Chapter 5 weighs the notational choices made in the existing scores received and proposes a standard notation for piano multiphonics to help future composers and pianists.

Chapter 6 discusses the relevant topics together, leading to a conclusion.

There are 6 Appendices with charts, audio, and information on related topics.

1.5 Researcher Position

As a pianist and composer I am familiar with, firstly the expressive timbral range of the piano and, secondly the repertoire of current art music. That enables me to pinpoint what is unique to compositions with piano multiphonics and what can still be achieved technically and compositionally.

During the research in Finland, I have conducted both acoustic measurements in collaboration with the Aalto University since 2014, studied and charted the differences of grand pianos in the Sibelius Academy since ca. 2013, now included in the audio appendix, as well as maintained multiphonics as a possibility in my compositional work. As I had no funding for any material investments, further help has come from my contacts to composers who are acquainted with this mode of playing, though less helpful has the situation proven with piano tuners or acousticians.

My initially restricted knowledge of string acoustics did not pose an obstacle to the acoustic measurements. Knowing more about string mathematics than the average composer, and, more about pitch than the average acoustician helped me to see the topic in a wider context.

I have had good access to academic music libraries in Helsinki and abroad, in addition to online resources, verifying that not enough written material has been published on the topic. The web has allowed me to actively inform myself with the simultaneous surge of related research especially in late 2014 and up to the present, January 2016.

2. Acoustic Foundations of Piano Multiphonics

2.1 How and Why Does a Multiphonic Sound?

> Harmonics [flageolets] have a silvery, transparent and husky tone, like the ghost of a regular note. Composers use them in slow and quiet passages since they are delicate and difficult to produce. In this context, they can be mysterious and magical. It is generally desirable to make them reverberate as much as possible so the audience can hear them. (Proulx 2009, 69.)

The multiphonic mode of playing, even more than that of a conventional flageolet, produces a sound roughly reminiscent of a bell. Other allusions can hardly be verbalised. Walter (2014) gives a compact technical description of flageolets:

> On a vibrating string a feasible point is touched lightly, e.g. with the tip of the finger. The relaxed finger on the string does not [acoustically] shorten it, and instead lets the string vibrate on both sides of the finger. The position of the finger gives rise to a vibrational node, the position of which on the string is decisive for the new timbral constellation [klangliche Struktur]. Instead of vibrating in a single wave the string now vibrates in several small waves of equal length. The fundament of the string no more sounds, instead a partial from the harmonic overtone series – – The frequency of the partial is in a directly reciprocal relationship to the length of the smaller wave. Walter (2014, 15.)

Amidst their seeming simplicity, there is endless complexity in multiphonics. The subtle sound is in many ways the seed of its own demise:

a) it blends well with almost any other instrumental or electronic sound that has a stable frequency element, thanks to shared morphologies.
b) it has weak localisation because of the large resonating surface and strong acoustic diffusion or projection
c) its sound contour consists of a relatively loud, short-lived and spectrally unstable onset that will acoustically mask part of the following, of a soft distinct spectrally semi-stable sound body, and of an ambivalent but initially dramatic decay
d) once played, the soft part of the sound remains as it is and can be stopped or patiently waited to decay. Attempts at modifying, partially damping, or additionally resonating the sound are only somewhat effective and audible.

Considerations such as the one in point a) could easily lead a composer to orchestration or instrumentation with piano multiphonics in chamber musical or orchestral contexts. Points b) and d) can be made use of in music when combining it with electronics or visual-theatrical dimensions. Point c) could be of special interest in a type of music that concerns itself mainly with audibility and addressing the peculiarities of human perception.

Additional observations about natural harmonics on the guitar are applicable here, with small modifications of terminology:

> “ (a) Harmonics lower in the series have greater amplitude and sustain than harmonics higher in the series.
>
> (b) Amplitude and sustain of all harmonics decrease as one moves across strings, from [the lowest string to the highest].
>
> (c) Harmonics higher than the 5th harmonic of the series have greater amplitude and sustain as one approaches either the [hitch pin] or the [agraffe]. Harmonics beginning with the 7th harmonic are weaker

as one approaches the middle of the string since harmonics lower in the series begin to interfere. Very high harmonics are best obtained in the area closest to the [agraffe].

(d) The amplitude and sustain of any harmonic is greater when [exciting] close to the [agraffe], especially when using a plectrum or the fingernail as [an exciter]". (Josel & Tsao 2014, 102.)

Note that by "harmonics", the source ignores inharmonicity on the guitar and probably means partials.

The friction multiphonics with a wire drawn on the piano string can be compared to those on the bowed string instruments. Robert (1995, 21) speaks of the multiphonic "aggregate": "The mastery of pressure, speed and precision in placing the bow, of great importance in playing harmonics, are essential to the realization of multiphonic sounds." Also in the case of bowed string instruments, such small precise coordination of hands is not encountered in conventional playing.

Robert (1995, 22) also presents the possibility of **artificial multiphonics** on the double bass. Transferrable to the piano, two fingers or other node-objects are required on two nodes on the same string T03, T04. The one of them nearer to the hammer (or to any exciter) has a reduced pressure as in any multiphonic. The other node is pressed heavily, stopped, and will acoustically define a new fundament. The result of the multiphonic node is calculated as a percentage from this remainder of the string. By this method, an intentionally microtonal fundament can be achieved. The stopping node may also be fixed as a damping preparation to lend more freedom for the hand choosing the multiphonic. The hammer may strike a point between the two node-objects but not a part of string unaffected by the multiphonic pressure. Regardless of how well and non-absorbingly the stopping is achieved, the resulting sounds will be somewhat or much more faint than "natural" multiphonics, as the new string length is not optimal for its diameter and hammer placement. With reduced length, less high-partial nodes can be achieved. This mode of playing has to be distinguished from **double multiphonics** where both strings of a dichord fundament (typically from the lowest F key upwards) are assigned two different nodes, resulting in two multiphonics sounding with one hammer attack. [19] T05, T06.

Questions of individual amplitude contours and phases of (in)harmonic components of a multiphonic are almost impossible to answer by listening, by FFT analysis, or by the type of line-camera recording described in chapter 3. Many of the characteristics of multiphonics might be determined by these spectromorphological properties. One cause of phase differences, the possibly present phenomenon of tension modulation, has been left out of calculations.

Many rather musical parameters still remain hypothetical or uncharted, such as the **amplitude ranges** for each multiphonic, or even for each individual partial. There might be psychoacoustic and perceived effects such as "mask effects – some notes hide others – as well as the very different tone-colours proper to each partial, give the agregates [sic!] very specific sound colours" (Robert 1995, 22) and other ways in which some facets of the multiphonic sound are filtered out in perception.

[19] One of these nodes could be a multiphonic and the other a simple harmonic, as Onofre and Bragagnolo (2014, 97) propose without labeling or categorising this method: "um harmônico natural mais um multifônico a partir de uma mesma fundamental tocada." Since simple flageolets tend to overshadow partials in multiphonic compounds, the advantages of this imbalanced sound can be questioned.

2.2. Associations with Other Instruments and Sound Sources

As we can derive from the previous chapter, the availability of multiphonic sounds on the double bass and guitar bears great resemblance to that on the piano. Multiphonics are available to various degrees on historical keyboard instruments such as the harpsichord as well. For the guitar, multiphonic study has seen recent concentration in the works by John Schneider (1985) as the first instance where guitar multiphonics were discussed (Josel & Tsao 2014, 118), and by Seth Josel & Ming Tsao (2014). The relevant works for the violoncello and double bass have been presented in the introduction.

As mentioned above, the properties of multiphonics have been previously studied in several musical instrument families, for example in all of the orchestral woodwinds, but also in bowed stringed instruments and in the guitar. For the bowed string instruments, the desired multiphonic is obtained by touching the string with the finger on a specific point while bowing or playing a pizzicato. In the case of bowed multiphonics, using the finger is itself familiar to the musician but the pressure is in fact less than normally required. Also, there are slight differences in bowing speed and location. In plucked strings such as the guitar, the multiphonic playing technique is quite similar to the piano multiphonic mode of playing, because both instruments have their strings vibrate freely after the excitation.

On most if not all **wind instruments**, multiphonics also exist, though the principle of air vibration is essentially different. These divide further into overblown multiphonics, intentionally fingered multiphonics, and whistle tones. On brass instruments, overblown multiphonics can be achieved only between two adjacent partials and are called "lip multiphonics", whereas valved brasses additionally produce inharmonic yet multi-pitched sounds by half-valving. Research on the multiphonic mode of playing has surfaced in recent decades for the flutes, oboes, clarinets, saxophones, and the bassoon. [20] Sounds of various machines also typically consist of pronounced partial content. Individual partials' loudness and fine tuning may fluctuate quite independently, though.

2.3. Numerics of Multiphonics

Notable branches of literature have been written about the mathematical basis of harmonics and the energies of different types of transverse and rotational vibrations, but not in the context of several simultaneous partials. Thelin (2011) and Guettler (2012) both write about the more complex sound production context of the double bass and bowed string instruments, the basics of which are applicable to the piano as long as the specific many inharmonic properties of copper-plated steel strings are also taken into account. Guettler (2012) and Fiedler (2013) also give instructions for playing and mathematic reasoning about multiphonics on the orchestral string instruments. The mathematics of flageolets are likewise directly applicable to the multiphonics yet a mathematical model would become exceedingly complex if it is to predict loudness proportions of partials. The present models can predict the numbers of the partials that will sound in a multiphonic,

[20] See works by authors Bartolozzi (1982/1st ed. 1967), Kientzy (1982), Veale & Mahnkopf (1998), Levine & Mitropoulos-Bott (2002), Gallois (2009), Bok (2010), Weiss & Netti (2010), Richards (2015). Multiphonics on orchestral instruments have enjoyed a surge of recognition in literature and among composers since Heinz Holliger's 1969 premiere of Luciano Berio's *Sequenza VII* for oboe in Darmstadt.

but not how they are tempered or what their relative loudness is or how it will deviate with time.

Walter (2014) seems to have studied the numerics of multiphonic nodes most thoroughly and takes the mathematical viewpoint of fractions ("Bruch") to explain the locations of partial nodes on a string. When comparing nearby partial nodes there is an algorithm of **iteration**, a continuity of integer fractions that build on each other. Walter points out that the fractions proceed according to the Fibonacci number series. The principles of addition of Fibonacci numbers and iteration are central to the flageolet and multiphonic fractions. Though the number 0 differs from the Fibonacci series, the calculations start at 0/1 (performer side of the string) and 1/1 (end of string). Starting at ½, any new node point found forms two ranges, or branches, on the string; one towards the keyboard, one further away from it. Only one of these two branches (called "Standartaddition" and "Mutation", respectively) is selected for further observation and this procedure is repeated many times. Selecting the smaller-number branch is always possible but whether it lies toward the keyboard or away from it depends on the location on the branch of flageolets in question. [21] Thus, a visual map of the **flageolet node branching** is necessary, only provided in sketch by Walter (2014), and is provided in further elaborated form in Appendix 5.

The figures in Fallowfield & Resch (2013) and in Fallowfield (2009, 73 & 148) chart partials up to the 13th and mention the available multiphonics on a string half as 6_7_13, 5_6_11, 4_5_9_13, 3_4_7_11, 3_7_10_13, 3_8_11, 3_5_8_13, and 5_7_12, [22] although, in Fallowfield's chart, the partial components in the multiphonics have been ordered not by their number or relative audibility but by their practical location on the string. Fallowfield (2009, 131) lists partials even up to the 16th in terms of their synonymous node occurrences and their pitch compared to equal temperament yet does not present the greater amount of multiphonic complexes available.

Each partial number always adds up with a nearby pair of partials, for instance 6 + 7 = 13 in a multiphonic found at the location 15,4 % of string length. The distance of that node, however cannot be calculated as an average of the distances of the nodes 6 and 7 and neither generally. Instead, Walter (2014, 17ff.) shows that nearby nodes by addition are governed not just by the proportions associated with the Fibonacci series but also the midpoint ½ and several consecutive flageolet nodes are even constructed with Fibonacci numbers – an effect that strengthens as higher partials are approached. [23] Non-Fibonacci fractions can be arrived at by using at some point of the iteration or several times a similar method called "Mutation" by Walter, where at any point of the iteration the smaller number instead of the bigger one (the previous) is chosen to be the new divider. The small number divided by the big number typically fluctuates between 0.3 and 0.7. Walter (2014, 23) has developed a code for naming each specific flageolet location. A code consists of the binary numbers 0 and 1, showing at each branch whether the smaller or bigger

[21] The Fibonacci series forms by alternatingly selecting the branch nearer to and further from the keyboard.
[22] In other words, the chart excludes the rather biphonic corridors of 1 around 0%...15.4% and 41.7%...50%, and all multiphonics that have partials higher than 13. In those cases where four component pitches were given, the node misleadingly nearby with nearly the same highest partial, such as 4_5_9_**14** should have been listed as a possibility and point of caution if it weren't for the higher limit.
[23] It has to be noted that most high fractions are not part of the series and only the gradually more consistent region 1/2, 1/3, 2/5, 3/8, 5/13, 8/21, etc. is.

number was chosen, and the amount of binaries indicates how many branches were passed.

Torres and Ferreira-Lopes (2012, 64) defines an apparently empirical **distance rule** as to how far away from its theoretical node point a partial can still be heard. This distance is to both directions a maximum 10 % of the vibrational cycle of that partial, viewed from the partial node. Thus small-number partials have a larger sphere of influence which explains that the low partials 2, 3 and 4 are to some degree present in many multiphonics. Similar results have been verified in our auditive and FFT research for all the partial components examined. All node placements can be defined as being a certain percentage away from the theoretical node point and, once known, these values can be readily calculated with a simple formulas and considered for all partial components between 1..19 for example.[24] Whenever this percentage lies between -10% and +10% of that partial's theoretical node, the partial is likely to be heard. Consider the following

GripDistance × PartialNumber = WhichSynonymousMultiple

where GripDistance, between 0 ... 1, is the gripped point's distance on the string.

The value before the comma tells how many **synonymous nodes** of that partial have been passed. If there are no digits, a node point has been reached exactly and the number indicates of the multiple's "order of synonymity" [25]. In other cases the proportional **proximity to the node** can be calculated; any digits after the comma can be redefined to have a zero and the comma before them. In the calculation

| 0.5 - ZeroAndDigits | × 2 = GripAccuracy

a GripAccuracy result between 0.9 ... 1 would indicate that the point lies near enough to a node of the desired partial for its partial to be heard in the multiphonic, as cursorily hinted at by Torres & Ferreira-Lopes' (ibid.) distance rule.

The flageolet nodes also align according to a further, puzzling numerical series. Taking for example the 2/5 and its "upper" neighbour 3/7 and lower neighbour 3/8, proceeding in each direction will have only odd numerators that add 2 each and denominators that after an initial value increase by 5 each time. Thus the upper side: 2/5, 5/12, 7/17, 9/22 etc. and the lower side: 2/5, 5/13, 7/18, 9/23 etc.

One could call this group of nodes near to 2/5 that approach more complex fractions **the second 5 corridor**. Along a string half, there are for instance two corridors of 5, only one corridor of 3, and five corridors of 11. The node 2/5 by itself is an early member of **the 3 corridor** that starts with 1/3, 2/5, 3/8, 4/11 etc. as its upper side.

A corridor of flageolet nodes constitutes the nodes bordering it – which, on each side start with a different denominator and increase by the number of the corridor's name. In this terminology, upper means nodes nearer to the string midpoint and when corridors are numbered they progress towards the upper corridors. Even-numbered corridors only have odd-numbered denominators (after the initial node) on both sides whereas in odd-numbered corridors the denominators will alternate between even and odd.

[24] These components can be integers presenting the partials, though the calculations become even more accurate if the amounts of spectral warping are known and applied for that string.
[25] Synonymity such as between 2 leading to 2/7 and 3 leading to 3/7 when PartialNumber = 7.

Each side of a corridor is made of members either on the keyboard side branches or the back-of-the-piano side branches, apart from the first member. For example, the performer side of the 3 corridor built on 1/3 takes the performer side 2/7 branch and from there onwards only back-of-the-piano side branches (3/10, 4/13, 5/16 etc.) in relation to the previous member. As seen from of 1/3, each of these members is on the performer side, though (see Appendix 5).The last member of such a series infinitely approaches a limit value that is a highly complex[26] multiphonic node point.

There are changes in partial components' amplitudes during the body of the sound, as observed in guitar string recordings (Josel & Tsao 2014, 211ff.). The mathematical basis of amplitude phenomena in string multiphonic vibrations is highly complex and mostly uncharted. For the purpose of this study, results by listening and FFT analysis will suffice.

Many "multiphonics composers" such as Oña, Ferneyhough, Furrer, and Walter are inclined towards mathematics and the quantitative sciences in their interests[27] or as evidenced by their usage of relatively complex rhythmic patterns.

2.4 Difference Tones and Extraneous Frequencies

Continuing along the numerical and mathematical viewpoint, multiphonics are theoretically related to the acoustic phenomenon of **difference tones**, and summation tones, as well as to the electronic concept of ring modulation. All partials of a multiphonic have integer proportions to each other, meaning that each summation and difference tone will also be a partial of one and the same fundament. Difference and summation tones, occasionally called combination tones, will be jointly called difference tones here, as their mathematic basis is similar. Difference tones are a subjective perception of the inner ear and cannot be technically verified by recordings (Geller 2012, 33). The difference tone sounds the stronger, the louder, and the higher, the less overtones they have, and the more tuned according to the overtone series the real pitches are (ibid.).

As is commented by Walter (2014, 20) and similarly by Maurer (2014, 27), in good circumstances a multiphonic has up to four audible component pitches; two of them form a core or foundation interval for the two others which are the first-order summation and difference tones of the foundation interval. This principle is in keeping with Walter's flageolet branching method. A further link from piano multiphonics and difference tones to functional harmonies of tonal music is pointed out (Walter 2014, 31). T07. Difference tones tend to sound more faintly than the core interval, even more faintly if a partial in the core interval is high and thus faint by default.

One should bear in mind that multiphonics need not consist of exclusively frequencies at harmonic relations. Walter (2014, 22, footnote) explains a phenomenon of frequencies foreign to the multiphonic position and the string's partial series. The same phenomenon has been introduced on the cello in Fallowfield (2009, 106). Fallowfield mentions such a "**grip tone**" phenomenon as belonging to "the upper [lighter] end of harmonic finger

[26] Both the sound of such a multiphonic is complex, as it falls within many partials' range of influence by the distance rule, and its mathematical presentation as a fraction calls for high primes or several prime factors.
[27] For Oña, see Michaels (2011, 10).

pressure"[28] where "the pitch of the harmonic (probably slightly sharp) and the tone at the stopping point [node point] are both present in the sound" and goes on to clarify that one can always find "one node for which these pitches are equal, that is the touch point [node point] nearest to the bridge." (Fallowfield 2009, 106.)

According to Walter (ibid.), even when using a loose (flageolet) pressure on the node, the grip position on the node can also become audible as the pitch corresponding to the distance, as if it was a strong grip, a vibrational stop. Walter gives a rule that involves reviewing the highest partial of the node as the fundament of a new undertone series. As members of this series, the "grip tones" can be found at the numeric relation of the node. The example given by Walter (ibid.), however, seems to make a mistake of octave positioning or oversimplification, as no C_0 is available as a monochord string on any piano model. The correct pitch would be C_1. Consequently, also the remaining pitches have been shifted upwards by an octave.

The relationship of a **gripping distance** and the resulting pitch has however been mathematically covered in Yang et al. (2014). Some of the early measurements in the present study have used an empirical logarithmic formula to approximately transfer a node grip percentage (between 0 and 1) to a stopped pitch in thousands of cents:

$$\textit{stopped pitch} = 4 * \log_{10}(-1 / (\textit{percentage} - 1)) ,$$

a logarithmic rising curve which indicates 1000 cents above the fundament on the Y axis as a function of the amount of string length percentage stopped (0 to 1) on the X axis. The grip tone phenomenon has not been possible to prove relevant in any of the present measurements or the cited accounts and there is not sufficient information to that sound. Some key values for approximation are 1200 cents at the 0.5 percentage as well as 2400 cents at the 0.75 percentage. From remaining microtonal stopping points in the graph, possible extraneous gripping pitches can be checked for verification.

One should remember that the partials that make a multiphonic sound are not tempered and seldom even correspond to the theoretical tuning of the harmonics. The pressure inflicted on the string by the node-object might also have a say on individual partials. According to Fallowfield (2009, 108) on the violoncello, finger pressure on the node can make partials sound either in tune or sharp. Fallowfield (2009, 188-192) found that high-number partials tend to be sharper than a theoretical harmonic intonation. The minority of the deviations was flat. Fallowfield also identified individual differences between subsequent takes and even between supposedly synonymous nodes of the same partial, where the even-numbered occurrences such as nodes 2/7, 4/7, and 6/7 deviated notably more and were perceivable to the ear. Measuring such differences, even as they might manifest themselves on the piano as well, however lies beyond the scope of this study.

[28] i.e. depressing the string but not allowing contact between string and fingerboard.

3. Measurement Methods and Refining Perception

3.1. Line Camera Measurement

In this chapter the physical and acoustical basis of piano multiphonics will be looked at in more detail, explaining the particular case of the paper co-written by me (Kubilay et al. 2015a). [29] Measurements are not even necessary or intended for musicians but for anyone interested in proving the differences in individual multiphonics. A wealth of different multiphonics available, moreover, is vital to composers. The auditory sensation is not to be trusted in all circumstances and additional mechanical and visual evidence of different multiphonics was needed.

The acoustic measurements were conducted at the Aalto University Acoustics Lab in several stages between March of 2014 and June of 2015. A small grand piano by Estonia, half-built for use in the acoustics laboratory, was used. The instrument lacked most strings, pedal mechanisms, sides, lid, and coating. It had a movable key and hammer mechanism without recoil. Because of inaccuracies in the measurement methods the process had to be refined and started again on two occasions. The technical details of the final measurement method are available in (Kubilay, Vesikkala, Pàmies-Vilà, Kuusi & Välimäki 2015a) and results of the last measurement can be read more extensively in the forthcoming publication (Kubilay, Vesikkala, Pàmies-Vilà, Kuusi & Välimäki 2015b).

By using special-designed thin copper wire, we aimed at giving identical amplitudes to each impulse. The thin wire was tied around once and drawn against the piano string with both hands and would break when a certain pressure was reached. This method, however, did not result in identical amplitudes for the fundaments and was abandoned.

Another improvement made was the use of a laser beam to pinpoint one slot as a zero point for reference. An identical plectrum was used and, before the introduction of the laser beam, the zero slot was primarily indicated by written markings near the string. Stickers or other adhesives were not used to mark any nodes. Tape was attached below the string on the soundboard, yet any markings on it were inaccurate, caused by the distance from the string. This, however didn't guarantee an identical pressure or angle of the plectrum on the string. The plectrum was held in the hand as most performers would, and as consistently as possible.

A long and straight side of the plectrum contacts the upper part of the string that is opposite to the hammer side. As the winding itself is both vertically and longitudinally slanted, no more appropriate method was found. Some of the slots might also be divided to smaller acoustically differing parts because of some differences on the two slopes of the winding. These possibilities were not taken into account. Calculations were made with the plectrum on the bottom of the slot. Some other plectrums were also experimented with, and a thin evenly triangular plectrum with rounded edges provided the loudest amplitudes for the fundament and partials in my hearing so clearly that no camera evidence

[29] For a more thorough treatise on acoustic features of the piano sound, see Karatsovis (2011).

was required. The plectrum was of a triangular brown-colour “Fender Thin” type. A bit of tape was occasionally added as a handle to make the grip more stable.

Initially, a metronome was used with only a blinking light to indicate both the start of the camera sample operated by the computer assistant and the subsequent onset operated by the performer. As small timing differences persisted, the metronome was later abandoned in favour of manually analysing the files and visually deciding the starting time of vibration.

Originally, there were plans of choosing up to six different pitches, keys, hammers and their corresponding monochord strings, to represent different dampers and frequency areas. Our method of measuring with a medium-sized camera made fitting the device impossible without inflicting damage to the piano parts. The lack of space and the presence of crosswise bars inside the piano also restricted the prospects of aiming the camera. The research thus concerned itself with the lowest monochord string only (see Fig. 3.1-1).

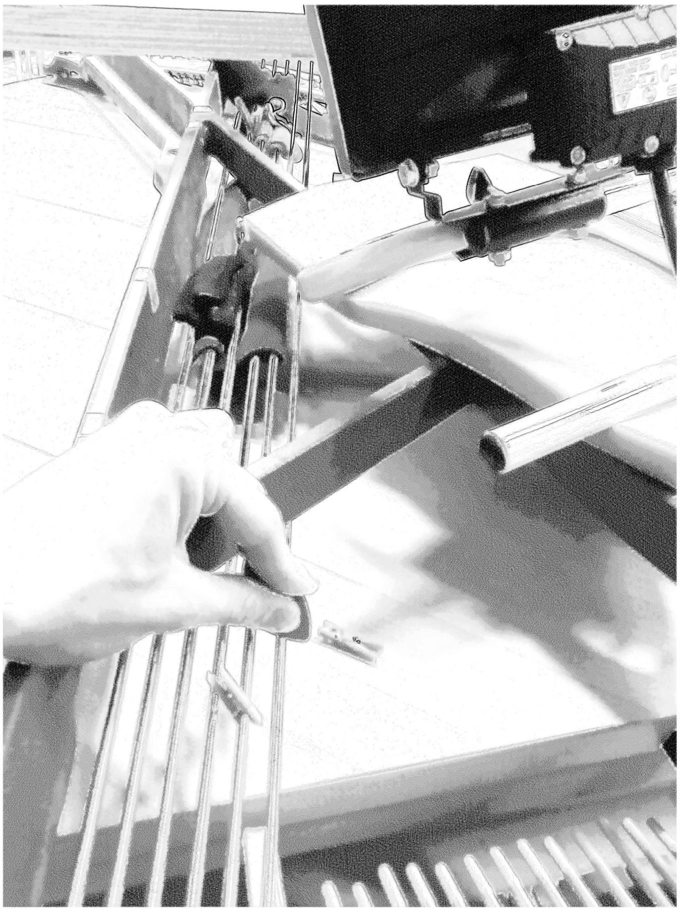


Fig. 3.1-1. Verifying the similarity of multiphonics on all monochord strings between A...D before loosening the higher strings to make space and concentrating on the lowest string. The Estonia half-built instrument with its movable hammer mechanism visible in the lower right. A lamp was used to make the string visible to the line camera which was situated behind the lamp further away from the keys and held by two stands in isolation from the soundboard. Small clampers were used on the next string to indicate the slot and to rest the plectrum on.

After our measured results and simultaneous listening, there is no reason to suppose that high monochord copper strings such as E and F would react to multiphonics differently in any essential aspect apart from lacking high partials’ (mostly multiphonic) nodes. The multiphonics on the remaining monochord strings were also listened to before loosening them. No piano pedal was used, no keys silently pressed, and treble strings were covered, thus minimising resonance – even for the non-struck steel parts of strings.

The striking point used lies at approximately 1/7 of string length. This point varies up to 1/9 according to manufacturer but 1/7 was used for the measurements.

Various decay timings were experimented with, yet no timbral variation attributable to object release times was found with this accuracy T08. Two possibilities without using dampers have been examined:

a) leaving the key down while the object stays on the string. Results in a faster decay and weaker amplitudes for high partials.

b) leaving the key down and removing the object from the string after a certain time (500 ms, 1000 ms, and 2000 ms). The object is not allowed to scratch or hit the string during the removal. This option results in a slower decay and seems to favour all kinds of partial components. In the time range of 500...2000 ms, there can be found empirically optimal object release times for each multiphonic according to its highest partial and complexity, although this knowledge was implemented by concentrating on three contact times. Generalised in Fallowfield (2009, 111), "contact time is inversely proportional to the frequency of the harmonic – – As contact between finger and string increases beyond the optimal, overtone content and duration reduce sharply."

On the lowest string used on the Estonia piano, there are 6.5 slots per centimetre on a string length of ca. 141 centimetres. As there were no sources and no consensus stating that only the copper part would partake in vibration or determine frequencies of partials, our measurement of the string started and ended at the vibrating steel part, i.e. at the agraffe and the hitch pin, and not only concerned the copper-wound part.

A detailed explanation of the camera type and placement can be found in the paper (Kubilay et al 2015b, 3). Using only one point of observation, any vibrations that have a zero point at the point will not be visible to the camera. The camera position had to be calculated and adjusted according to the multiphonic node played and the hammer striking point to avoid at least the most severe filtering effects. The reductive effect of the camera position can be compared to an additional multiphonic node or a hammer striking point. The line camera was set up to register changes in the vertical placement of the string. Minor issues with the line camera included calibration according to changing luminosities at the string and the low resolution in the image file given by the camera software. The advantage was a faster rate of perception than that of a human. See Fig. 3.1-2.

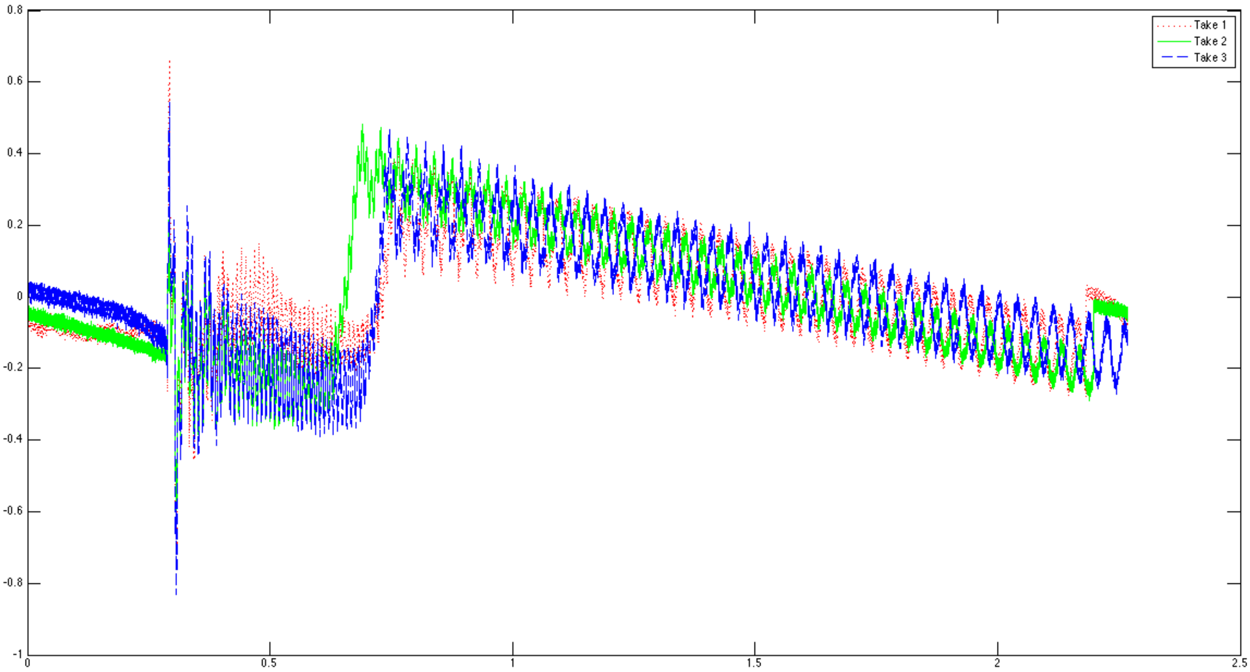


Fig. 3.1-2. Line camera output signals of three takes of a piano multiphonic compared. The X axis plots time in seconds and the scalable Y axis indicates a difference in the

string's vertical position, which can be understood as a change of amplitude as in an acoustic sound wave. The leftmost unified time region of the graph shows the movement before the attack while the plectrum is pressing the string down. The widest peak right from it is the hammer attack. All three plots were aligned to have their hammer attack start at the same time. After the attack, the vibration remains rather wide and the plectrum further presses the string down. The plectrum is lifted after about 0.5 seconds and the string is allowed to rise with it, according to the direction of the hammer's initial impulse. Gradually, the vibration loses energy (width) and the string will eventually return to its resting position at zero – unless silenced manually, as in takes 1 and 2. Any one of these plots can be further interpreted as a sound wave to derive a mono audio file. This basic contour was acquired with a small Estonia grand piano yet the contour ought to be scalable to any grand piano, with widest vibrations around the string midpoint.

In conclusion, there were factors of uncertainty involved in the measurements. Future research would do well in including at least two similar cameras in complementing positions, a more consistent angle and force of attack, and a stable source of pressure at the node at a constant angle perpendicular to the winding itself.

The ideal complementing positions of the cameras would be those that lie somewhere on opposite halves of the string, i.e. one in the half nearer to the performer, and in combined effect do not completely filter out any significant partials nor partials of partials. See Fig. 3.1-3.

Fig. 3.1-3.
The line camera setup for the final measurements. All monochord strings other than the A are loosened and damped. The camera has a limited area for moving as it would hit the crosswise bar on the left or the bridge for the hitch pins on the right. Outside the picture to the left, the hammer hits and the plectrum lies on the node marked by a laser beam.

3.2.1 Audio Recording Guidelines

For the needs of live electronic processing, amplification, and for composers looking for audio samples, the optimum circumstances for recording piano multiphonics are an acute consideration. For the pianist's rehearsing, such verification for having found the right slot is not practical unless it provides real-time readable analysis results. After all, the pianist has to become agile in distinguishing between the multiphonics by ear alone. For the purpose of our study, however, it is necessary to prove the differences of individual multiphonics by means of audio recording followed by FFT analysis. This chapter does not aim to chart minute but systematic differences between individual pianos or models, as has been started in Onofre & Bragagnolo (2014, 96-97) [30].

The most used strings and thus fundaments for these recordings have been A (to represent the bass extreme), Bb (to represent a more recognisable but still low sound), C# (to present the average between the usable monochord string range A to F), and E (to represent the higher fundaments). The piano has been played from the side most convenient for the player. A Zoom H2N recording device on a tripod was used with the settings of a bit depth of 24 bits and a sampling frequency of 96 kHz. The recording device has stood inside the piano, capturing sound at a height of about 30 cm above the strings in the treble side curvature in such a way that it would not obstruct if playing in the most frequent modes of mobile playing. For this reason, the sound is disproportionately louder on the left channel. The setting is quite realistic for many concert contexts with amplification or live electronics, although if the pianist is following a conductor, a microphone would probably have to be set even lower or further inside the piano. See Figure 3.2.1-1.

Apart from conversion to a lower-rate format, the audio has not been edited, and any clipping onsets have been simply left out of consideration.

Accompanying this chapter, the audio consisting of the CD and Appendix 6 is referred to. It features several instrument individuals, rather in the sense of evidencing the availability of this mode of playing than comparing grand piano models.

[30] Onofre & Bragagnolo also mention differences between the Yamaha CS 1 and Steinway B models. Spectral analyses of the same multiphonic node have been compared on both instruments. It is however hardly possible to calculate and find exactly the same node on two different instruments and especially with different striking lengths of strings. In this sense, resonance and other acoustical differences between instrument models should only be judged quantitatively after each – typically over 1 000 – of the respective instrument's node slots have been recorded and compared. Hirvelä's (2013) more methodical comparisons are based on this qualitative viewpoint.

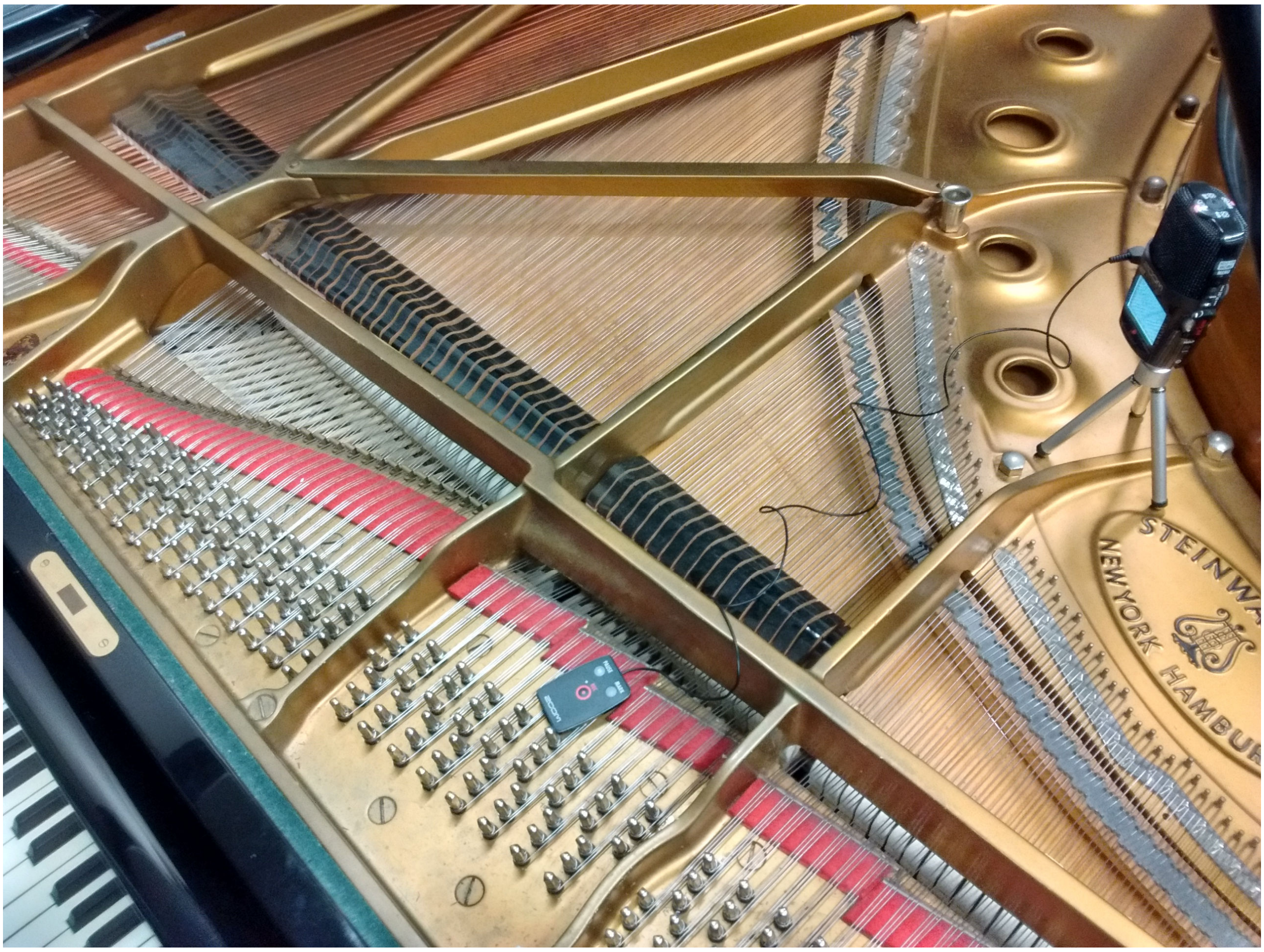


Fig. 3.2.1-1. The default recording setting where a Zoom H2N recording device with a remote control is resting on the piano plate. Although connected to the sounding body of the instrument, the isolated tripod and device are far enough from the bass strings. This example shows a Steinway B model yet the setting is transferrable to all manufacturers' grand pianos where the covering lid can be opened.

3.2.2 Laboratory Setting

Many multiphonic sounds of the Estonia piano have been recorded with the recording device simultaneously with the line camera measurement. This time the recordings are, however, of mediocre quality because of extraneous noise. T09.

The MATLAB-synthesised samples from the line-camera data and Estonia audio recorded samples have been produced during and for Kubilay et al. (2015b) T10. The rest of the recordings in Appendix 6 have been made with the same device on various Steinway D, Steinway C, Fazioli, and Bösendorfer instruments. No significant differences have been found as long as the multiphonic node itself was reachable inside that instrument model.

3.2.3 Analysis

From a stereo recording or even a mono recording, it is fairly simple to decipher which frequencies are presented by spectral peaks and in which loudness order, using the algorithmic analysis method called Fast Fourier Transform (FFT) [31]. It finds out which component sine waves and thus frequencies make up the complex sound wave. The findings can on some programs be mapped on frequency and time axis, distantly resembling musical notation. The analysis of multiphonics tends to be simpler than that of most other sound sources as the peaks stand out clearly and are spaced regularly apart, when viewing the frequency axis as linear instead of logarithmic. The FFT algorithm requires a window size, a precision of the analysis which should be set to the highest available. For all the sounds in this study, the examples in a mapped “notational” view have 16384 Hz and in the frequency-loudness analysis 65536 Hz as the setting on the Adobe Audition software.

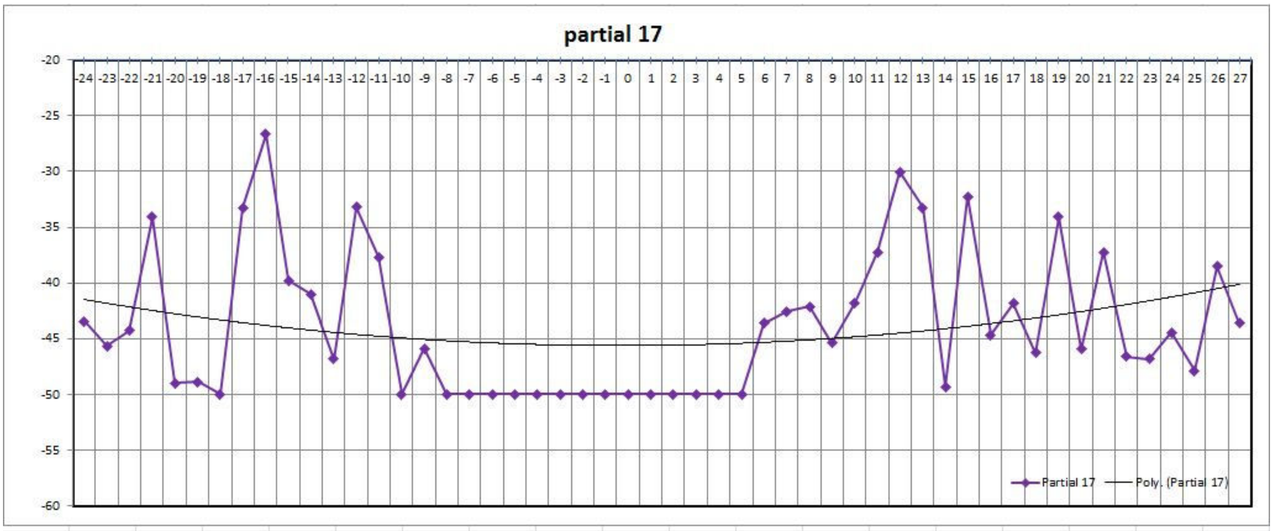
The luxurious 96kHz accuracy of the recording still enables using spectral reassignment with applications such as the GRM Warp Tool (available for ProTools among others) if, otherwise, the recordings weren't deemed clear enough with FFT.

For visual analysis from the spectrogram, the amplitude levels can be processed to further differentiate the peaks and valleys. Many FFT analyses have been explained in the context of a sound file in Appendix 6. For aural analysis without relying directly on an FFT result, the audio can be slowed down by the stretching function and played back at half the speed, or less. Two of the FFT figures have also been checked by generating synthetic audio from the 15 strongest frequency peaks in the figures T11 and T29. The peaks were reduced to a uniform volume level – a neutral solution since spectra tend to fall in intensity with higher partials and the human hearing curve also has its peculiarities in terms of range – and were synthesised with the SuperCollider coding environment.

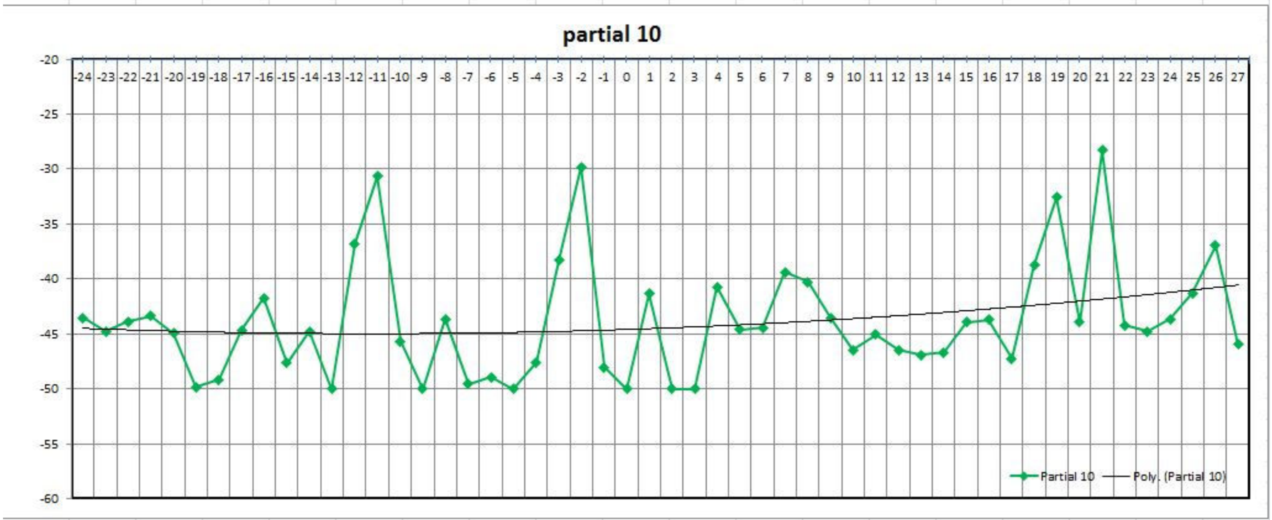
The FFT method was used to prove proportional changes of loudness in partial components of multiphonics within a node progression around the 5^{th} partial (see Fig.3.2.3-1). Although there are many outliers, all partials’ tendencies proceed as expected and when the individual partials are combined, one will arrive at several different multiphonics even within this range. Notice the little correspondence between the 5th and its own second harmonic, the 10th.

An audio recording and spectrogram of a synonymous 5^{th} partial’s region can be found in T12.

[31] The human hearing curve renders the following comparison of FFT results more complex and less objective.



partial 17
Partial 17
Poly. (Partial 17)



partial 10
Partial 10
Poly. (Partial 10)

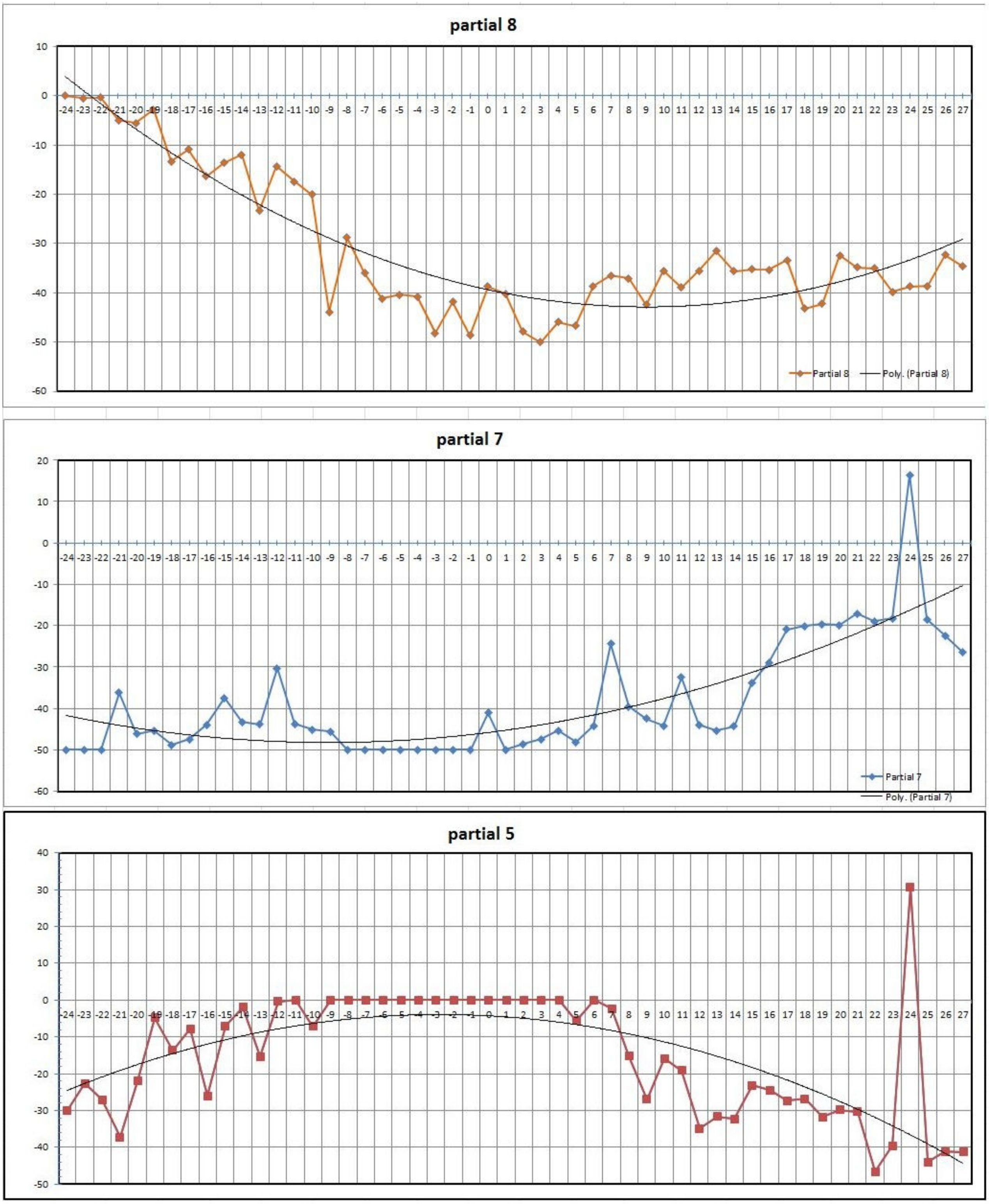


Fig. 3.2.3-1. Spectral scanning by moving a plectrum one slot at a time and pressing the key. The zero position on the X axis is the theoretically supposed and measured node of 2/5 at 40%, negative values are percentages smaller than it, thus nearer to the keyboard. Polynomial curves in black average the tendencies of these values. Y axis plots the amplitude in dB with different scales.

3.3 Producing and Listening to and for Multiphonic Sounds

Listening to multiphonics as a member of audience can be different from playing them on the piano by oneself, although producing multiphonics on the piano is fairly straightforward. What is intended and technically succeeded in not always comes across in what is heard. Finding the right nodes, object release timings, dynamics, and sophisticated hand movements can be described as the part taking the most dedication. Exercise will develop skill together with an ear for multiphonics.

While learning different nodes on the instrument without a reference pitch – either a mental or a live FFT analysis one – the right hand will have to, as one might say, commute between the string and the treble keys. As a by-product of this method, tuning differences can be heard by comparing the beating of the partial's sound against the tempered key of the same pitch. Intentional or not, this context is exemplified in Mark Andre's *S1* (Fig. 3.3-1 below).

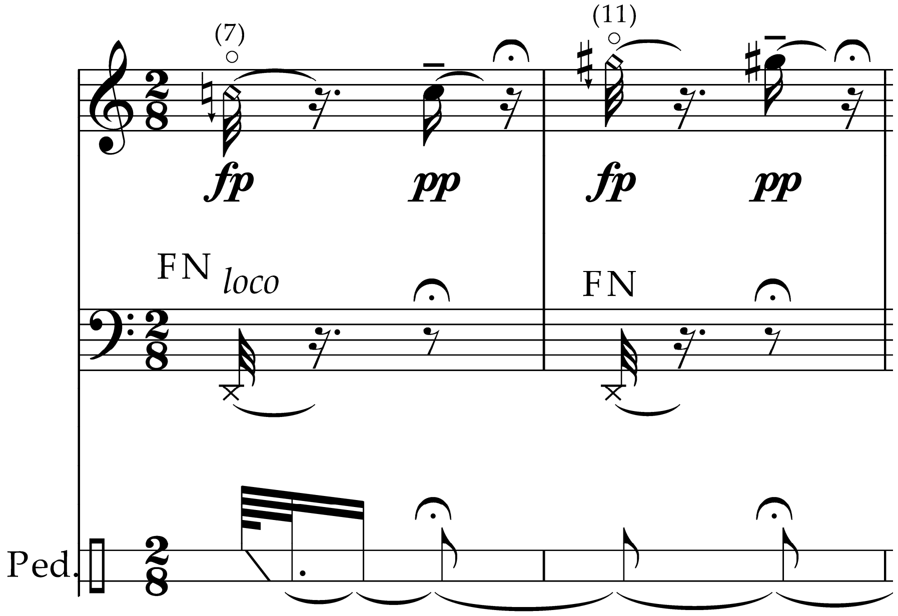


Fig.3.3-1. Flageolets in a passage of acoustic beating in M.Andre: S1, *b.196-197, second piano part. FN is the instruction for fingernail.*

Before delving into experimentation with multiphonics, though, the restrictions of the instrument have to be clarified. When performing unfamiliar actions on the piano the instrument is compromised. The rest of this section serves as both a reminder and a warning.

The pianist should always interact with the bass strings with an intermediary material that is not the pianist's skin and never with a material denser than the strings themselves:

> "foreign substances such as oils from the fingers are detrimental to the strings. – – The oils can contaminate the copper wrapping and may deaden the string." (Hudicek 2002, 186.)

> "Although there are not many appropriate substitutions for metal [preparations] in the bass strings, the pianist should experiment with different sounds and find one that he can live with for that performance." (ibid., 172.)

Playing the repertoire can include considerable back-and forth movement between the keyboard, lid, pins, agraffes, dampers, and the string itself. Of these, the most fragile are the dampers (ibid., 187).

”The dampers – – can be damaged by non-traditional techniques. – – damage can occur from pressing too aggressively on the lifted damper and bending the wire, pushing the felt into the strings, placing a preparation too close to the dampers so that it does not sit correctly, knocking into the dampers when playing a glissando, or any other careless motion. This type of damage usually can be fixed by replacing the damper head or the felt. – – because dampers work best in sets, the entire set of dampers may need to be replaced. The dampers can also be damaged cosmetically by leaving labels on for an extended period of time, which can leave a tough residue on the damper heads.” (Hudicek 2002, 187-188)

Also, if chalk used for marking strings “gets into the joints of the damper mechanism or the action, movable parts can become jammed” (ibid.).

Hudicek also notes the tenderness in the hands when novice players are playing on the inside (ibid., 190). Pianists’ education does not address holding a plectrum correctly T13, T14. There is always room for improvement and adjustment in ergonomics and listening. When playing multiphonics and given that the access to the concert instrument has been granted, the pianist should use time with the instrument most efficiently. Hudicek (166 ff.) instructs on practicalities of choosing and keeping preparation materials and rehearsing without preparations in place, which may come in handy with compositions where multiphonics are the result of preparations.

Any markings on the agraffes or sounding parts should be done with hair tape or non-residue tape, see Fig.3.3-2. Markings next to, under or above, but not touching the strings are recommended. Rubber wedges used by piano tuners should be used when damping any nodes on the the bass strings for extended times since blu-tack will stick inside the winding. The wedges can also be employed in many modes of playing. T15, T16.

Fig.3.3-2. Selected pitch names labeled on the agraffes for ease of playing, especially with dichord pitches.

4. Multiphonics in Composition

4.1 Compositional Practice and Strategies

In this chapter, various compositional methods using multiphonics are discussed and in a few cases backed up by analyses of compositions in the repertoire.

When composing with piano multiphonics, the **following notions** ought to be relevant to composers and performers because they can be calculated beforehand and are luckily not too dependent on the peculiarities of an instrument: the proportion between fundament-amplitude and partials-amplitude; the complex spectral makeup of partial frequencies, their dominance and relative dynamics, and the audible non-tempered partials' proximity to the tempered 12-tone scale; and which string will the multiphonic be realised on. Scaling of the parameters may occur with small grand pianos, though.

Some parameters more dependent on the technical and room-acoustic circumstances include loudness of a multiphonic compared to the open string; degree of inharmonicity (multiphonic flageolet vs. harmonic flageolet)[32] ; decay rate (also decay rates of individual audible partials where applicable); possibility of reaching the node and accuracy of finding and playing it; the optimal release time that grants the longest decay and includes all the desired partials.

When composing with contemporary modes of playing, one should also walk in the shoes of the musician: with which part of the hand or an object, which part of the instrument is contacted, how and with how much strength is the movement made, when, and for how long.

When these practical details about the excitation and the obstacle are taken into account, the composer can even call for three **categories of multiphonic onsets**, each with their distinctive sound identity:

1. multiphonics with attack: node-obstacle and excitation are introduced simultaneously
2. attackless multiphonics: node-obstacle is introduced after the excitation
3. transverse multiphonics: exciter also functions along the string as the node-obstacle.

The typical example of the first onset category is the piano hammer and a plectrum. Other options include excitation with a mallet and obstructing with a plectrum. Preparation materials are also possible in this category as an obstructer, in which case the exciter can be freely chosen. The objects used in this category have to be marked verbally in the score.

In the second onset category, a plectrum[33] can be brought to rattle or buzz on the string either for a long time (*buzz multiphonic*) T17 or smoothly without audible rattling (*smooth multiphonic*) T18. Josel & Tsao (2014, 131) has mentioned the possibility of attackless harmonics on the guitar: "This approach works best on the lower nodes such as the 2nd, 3rd, 4th, and 5th harmonics." T19.

[32] This should not include "sidebands" or shifting phenomena as they are not perceived independently.
[33] Or, perhaps even more characteristically with a paper clip, as in Amy Williams' *First Lines*.

The third onset category consists of multiphonics where the piano hammer is not necessary at all. The chosen object is moved on the string windings to make the string vibrate, and when the movement stops the node position of the object determines which multiphonic will sound. The energy given by the friction determines the loudness and is generally less than that of a piano hammer attack. This category of onsets is produced by scratching with a plectrum (*scratch multiphonic*) T20, T21 or as a *friction multiphonic* either with a friction mallet or a piece of rubber tyre, preferably of a bicycle inner tyre [34]. T22.

Having absorbed this practical and technical knowledge, a vast space opens for the composer's own aesthetic choices, many of which are familiar from composing for other instruments as well. There are at least seven **composition methods** with their corresponding technical approaches and aesthetics.

1. limiting expression by using only one of the three categories of multiphonics, granting unity of dynamic contour and timbre
2. choice and ordering of multiphonics based on spectrally, microtonally, and registrally informed voice leading
3. choice and ordering of multiphonics based on tonal functions
4. multiphonic nodes differentiated based on visual or theatrical aspects of multiphonic playing
5. selecting multiphonics intent on making acoustic beating or masking the primary perceived element
6. composition using multiphonics as a mere rhythmic or fading durational impulse or a timbral effect, without differentiating various multiphonics in a grammar
7. multiphonics that receive heavy live electronic processing and where consequently pitch or spectral details are almost a non-concern as such instrumental capacities can be widened, "supersized". A "super instrument" results. [35]

These methods can be seen interrelating freely in most of the repertoire. Beating phenomena called for by the method 5 are not numerously found in the repertoire, and usually only with combinations of multiphonics on two strings. Compositionally, they are tedious to predict as the result also is vulnerable to minute differences in grand piano tuning.

No work based on approaches 3, 4, or 7 has been encountered during the writing of this study and they might remain still to be discovered by composers. The individual mix of composition methods will reflect in the concept of the work. Especially in the case of Furrer's ensemble work soon to be discussed, the multiphonic strategy combines seamlessly with strategies on other types of sounds.

Mark Andre's *S1* corresponds to the types 2 and somewhat 5. The expression is quite varied and has multiphonics with and without attack as well as friction multiphonics.

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[34] This category has been erroneously mentioned by Ishii (2005, 16) and others as being a type of glissando and even comparable to the glissandi that progress from one string to the next. Here, however, the changes in spectral (multiphonic) content are not linear as is required of a glissando and the type of contact to the strings is intense instead of slight. Only the movement on the string is linear. In Mark Andre's *S1*, b. 257 onward, the tyre is indicated "Fahrradschlauchgummi", a direction and movement from 21 cm towards the dampers on the strings is indicated and the location is alluded to by a silently pressed cluster.

[35] Terms by Kallionpää (2014, 6-8). Spectral details can be best modified if the acoustic input remains predictable.

4.2 Timbral and Spectral Considerations

For many a composer, the most fascinating prospect of multiphonics supposedly lies within their timbral dimension instead of the pitch class one. Composition methods 1 and 2 especially point to a timbral approach. Timbre can be seen either as a musically associative, or a purely auditive, parameter. In the former case, descriptive words might present the subjective categorisation and contextualisation of timbre to some degree, whereas in the latter more objective observations can be made of the sound wave only. In the following, the latter auditive case is considered, since the musical viewpoint would lead to psychoacoustics beyond the scope of the present study.

Most, or perhaps all sounds can be effectively observed already in terms of time, frequency, and loudness. Multiphonics make no exception. In multiphonics, the domain of time interacts with those of loudness, frequency, and location. Multiphonic sounds are not stable and instead each frequency band fluctuates in loudness and the frequency bands themselves also change slightly in constellation T23. What the brain then interprets is an average. These findings can be made visible with any simple FFT analysis software, albeit in a manner useful to a composer and slightly less to an acoustician. Some of the fluctuations, such as the strongest beating phenomena, can stand out from the otherwise acoustically stable multiphonic sound. This may be highly individual to each listener.

Loudness is the second most decisive factor in multiphonics. Generally, the different stages of the multiphonic sound present the same shape as the conventional piano sound, thus: attack, body, and decay. Even in *ordinario* playing, individual partials also have different loudness curves and their loudness peaks do not always coincide. Of these, the recognition of spectromorphological properties of the short noisy attack phase that reveals which instrument is being played is central to a blunt evaluation of the sound's musicality and identification of source [36], whereas the body of the sound matters to the auditive approach since the body allows probing into sustained details, allowing different multiphonics to be perceived as unique. A composer hopes to steer acoustic details, which are driven by yet unknown factors.

Presenting the entire spectral data of a multiphonic is not possible. Even when locational data is left out, this requires a three-dimensional graph, consisting of time, amplitude and frequency range (or frequency band). A two-dimensional alternative for composers' purposes is to present the frequencies on a staff with the chosen microtonal accuracy, and draw loudness data on the side (refer to the illustrations for T07) . Time is taken to be irrelevant because the evolution of a string vibration always follows the same principle, with notable differences between individual instruments. The data will be selected from a region where volume decreases constantly and all relevant frequencies are still present above noise level.

4.2.1 B.Furrer: Wüstenbuch, 2009

A large-scale work taking the compositional approaches 2 and 6 is Beat Furrer's (b. 1954) *Wüstenbuch*, a *Musiktheater* in twelve movements, finished in 2009. In this ensemble context, Furrer gives preference to the multiphonic's fundament pitch and specifies no resulting

[36] Moore (2012, 284 ff.)

pitches or grips. In a sense of indeterminacy, the multiphonics also serve as a timbral and impulse effect as one layer of the instrumental fabric.

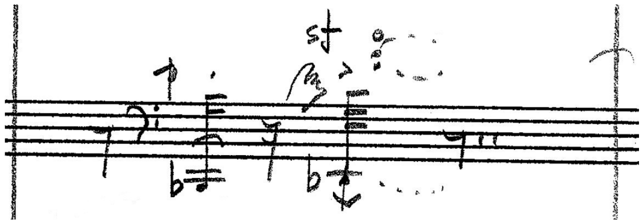
Furrer counts among the most prolific composers also using the flageolets and multiphonics on other stringed instruments. The piano notation used in *Wüstenbuch* indicates at least one fundament pitch. The pitch is first damped with the hand, then annotated further right with an open circle for the flageolet and two filled circles where *lasciare vibrare* slurs start (see Fig. 4.2.1-1a). Furrer's notation does not call for a specific multiphonic node to play, thus allowing the pianist more freedom inside the instrument among the occasionally rapid changes of playing modes. In what can be described as a performer-oriented notation, any resulting pitches are not notated – apart from conventional flageolets, which can be required up to the fifth partial. Even when the piano features as a soloist alternating with the ensemble, the composer does not designate multiphonic chords.

There is still some interaction with the pitch framework of the ensemble with the partial series of the piano fundament. The first instance of multiphonics (mvt. I, b. 9, see Figure 4.2.1-1a) happens to find either acoustic blurring near to a partial or an exact spectral reinforcement of its C# fundament in at least the saxophone, voice and double bass (partial 3), cello and trombone (P6), bass clarinet (P9), horn (P12), trumpet (P15), 2nd flute (P18), and accordeon (P20) – also refer to Fig. 4.2.1-3. In this strong spectral field, the piano multiphonic, regardless of its chordal content, will blend with and unavoidably correspond with some of the other instruments[37]. While the texture of the winds and strings generally introduces new pitches at a faster pace, the piano onset can be seen as, rather than intruding, as emerging from this volatile fabric and perpetuating a local event or state of that fabric. After all, few instruments play pitches foreign to the partials of the piano fundament during this slice of sound.

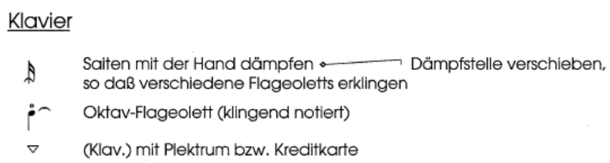
a)

b)

c)



d)



Figures 4.2.1-1a, b and c. a) a notation for a damped string (brace on the stem and a staccato dot) that is released as a multiphonic (flageolet circle and an interval with slurs for lasciar vibrare*) in Furrer:* Wüstenbuch*, movement I, b. 9.*

b) a complete notation for a more conventional multiphonic to be played on the node with the hand indication, a downward arrow and an accent, as well as pressing the key (mvt. IX, b. 11). In the damped case, multiphonics are sometimes not even desired and the flageolet dot marking is left out. The third variant, c, (mvt. I, b. 50) exemplifies this difference. Notice

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[37] Movement I, b.17 & 23 form a chromatic progression all the way to b. 50, which combines Bb with the starting point C#. b. 73, 79, and 83 form the same progression again. In b.100 the lowest point, A, is even introduced and alternated with Bb in b. 104, 107 and 146.

that in the case of damping and release, the flageolet dot marking is often placed above the next pause, not earlier. This notational system cannot be entirely deduced merely with the legend (d) given with the score.

Furrer uses multiphonics in at least four distinct contexts:

1a. Identical fundaments with, depending on the performer, slightly different partial content each time, create continuums of pitch and timbre in time. In passages of dense instrumental writing, any kinds of attacks by the piano have often been placed at equal distances in time, mostly of three bars, to form a longer-term pulsation.

1b. The linear or gradual timbral changes predominantly present in Furrer's output are provided by the piano by shifting the node point but retaining the same fundament string, i.e. node progressions. The direction towards the player is indicated by "immer höhere Obertöne" (in movement III, b. 67-69).

2. pulsating pattern with the multiphonic timbre, perforated with pauses (combines with the type 1b in movement III, b. 67-69, 93-96, 124-125, 134-137, and 150-153).

3. damping with hand without a multiphonic functions as a concluding element of a downward crescendo of the whole ensemble and a starting point for new downward or upward lines in a new texture. This timbre does not result in clear partials, and gesturally comes close to that of hitting the low strings with the palm of the hand (XI, b. 44, 91, 95, 119, 132, 186, 188). To a less noticeable degree, this sound can interrupt or initiate individual linear directions within a texture (VI, b. 86-88 interrupts the 1st flute, 1st basses, marimba; initiates 1st sopranos and violins) as well as those lines which were active but stationary in terms of pitch.

4. Multiphonics alternate with *ordinario* playing of or around the same fundaments. (II, b. 6-60 and 64-152). Some of these fundaments are reinforced by the contrabassoon or the double bass.

There are also conventional flageolets, notated on the treble staff with a flageolet circle above (IV, b. 1). They are probably intended to be played on the marked string at the octave node, thus sounding an octave higher, although the context would contradict, as the same notation at that exact same register has been used for the cello and a singer as well. A functional separation, the flageolets are not built into the same fabric as the multiphonics.

There is timbral alternation with **other instruments of the bass frequencies**, in this case the (contra)bass clarinet, contrabassoon, trombone, tuba, and double bass (VII, b.2-8 alternating with the double bass and imitating its phrasing, II, b. 64-96 alternating with held pitches of the bass clarinet, contrabassoon, trombone, and double bass – see figure 4.2.1-2 below). In these contexts, the piano survives and remains salient as the instrument with the richest spectra. The lowest strings are alternatively hit with the hand in singular gestures, mostly resulting in an obscure cluster held in the pedal, and occasionally with higher frequency content (movement II, b. 180-195; XI, b. 28-44). These sounds function as a marker for metric structures in a time horizon of several seconds.

An extraordinary combination of the upper frequencies occurs in VIII, b. 10, where a piano multiphonic interferes with a pattern of the violin's highest possible flageolet glissando downwards, followed by accentuated overblown pitches by two flutes which meander around the same fundament pitch class of the piano, the grips of the overblown pitches starting three octaves higher.

The contrasting use of multiphonics against or amidst the rest of the ensemble in *Wüstenbuch* might be in keeping with the work's themes as interpreted by Maintz (n.d.) and Maintz (2010): of getting one's voice or identity heard in a placeless place, the desert. The degree of acoustic utopianism is diminished by a remark in the orchestral score proposing unique amplification for the piano.

Figure 4.2.1-2. Furrer: Wüstenbuch, II, b. 66-70. Edition Bärenreiter. Piano multiphonics in an acoustically discernible environment (7th labelled part from top).

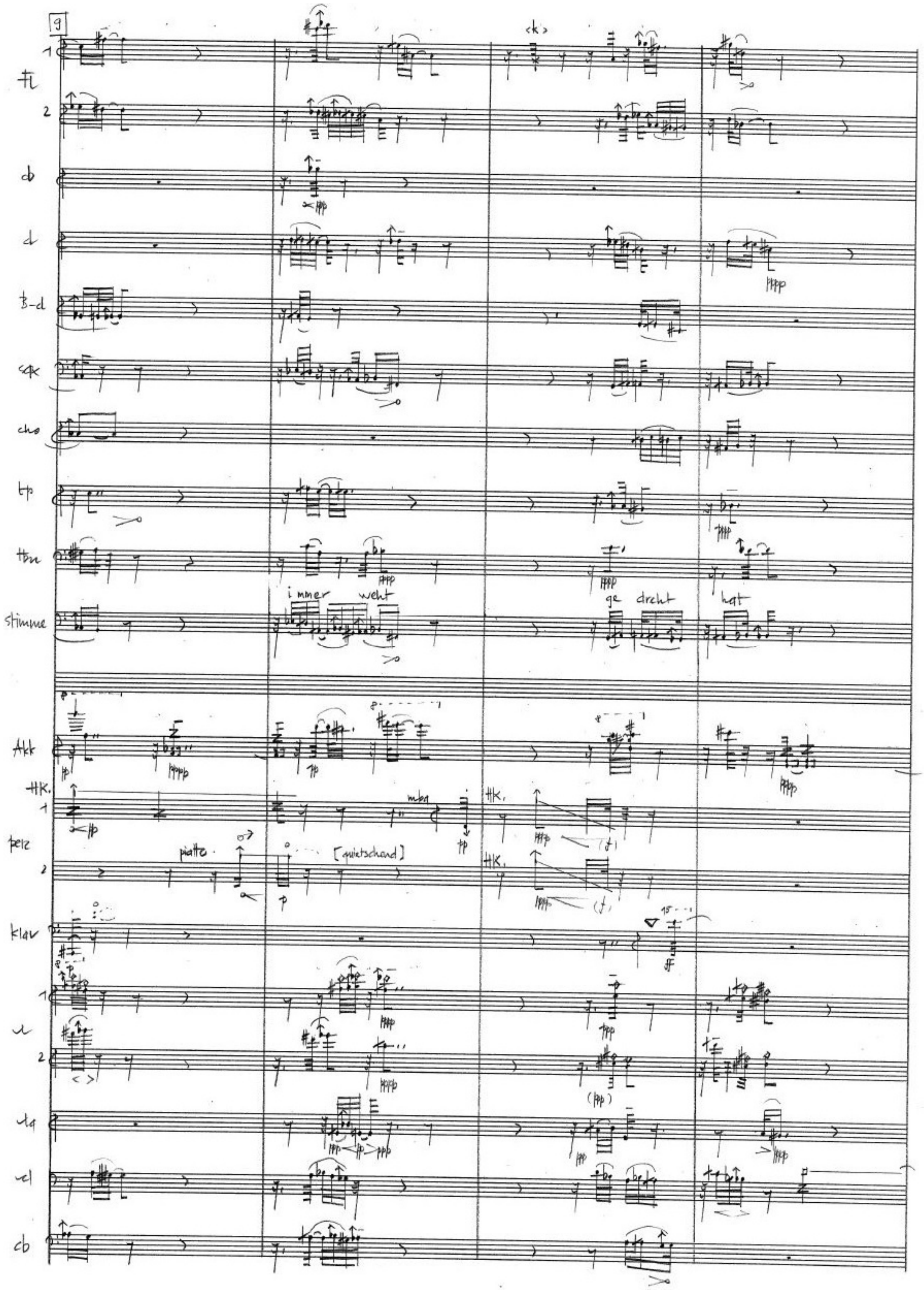


Figure 4.2.1-3. Furrer: Wüstenbuch, I, b. 9-12. Edition Bärenreiter. Sparsely situated piano multiphonics providing obscure fundaments for and as an integral part of a spectrally aligned texture.

4.2.2 H.Lachenmann: Serynade, 1998

Serynade for a solo piano also employs multiphonics in a registral role and as a timbral category without an apparent emphasis on accuracy of pitch, corresponding to the compositional methods 2 and 6. The methods are the same as with Furrer, though the composers use them to a notably different effect.

In Lachenmann's *Serynade*, both scratch multiphonics and multiphonics with attack have been used – see Figure 4.2.2-1. The fundament and sounding pitches have been notated for the multiphonics, and the context would imply an identical node distance for each. No differentiation between different multiphonic nodes has been achieved in the notation itself. Lachenmann places significant demands on the quality of sound, such as instructing to specifically use the nail of the middle finger and resulting loud resonances of the open string are to be avoided. A Steinway C or D is preferred in the performance instructions, alongside a hall "with acoustics suited to the resonances of the harmonics – – in halls with a short period of reverberation" (Edition Bärenreiter, preface text for the score of *Serynade*). The additional requirement reads "in halls where it is difficult to hear the reverberations of harmonics, or with pianos that produce only weak reverberations of harmonics", a certain microphone has to be placed inside the case of the Steinway D, "close to the third sound hole – – at about the level of the strings for g^1", as well as a loudspeaker and good software such as compression, parametric equalizer, and a regulator for "frequency, gain and bandwidth" (ibid.).

> "– – holding the hand over the low strings they should be touched in the proximity of the damper in a harmonics-like manner in m. 296, 300 etc., while the notes in question are played by the other hand. This should result in audible overtone mixtures which correspond approximately resp. partially to the notated sounds in parentheses" (ibid.). [38]

In Lachenmann's rather restricted use of the multiphonic mode of playing, the partials marked as "Flag.-Reservoir" seem to constitute all the partials between 1/7 and 1/12. No action notation is shown apart from the dynamic, timing, pedaling, and the fundament itself. The performer is given no hints as to which node should be pressed. The obvious guess is that not all of the marked partials have to sound and the performer should play as near to the damper as possible, staying on the performer side. On the preferred Steinway D model, the area between at least 1/8 and 1/11 would be covered by the damper (Hirvelä 2013, 3rd appendix), which renders Lachenmann's marking rather philosophical. The desired partials are not jointly available elsewhere on the string, and even at around 50% of string length mostly only odd-number partials are audible as a cluster.

[38] "komplexe Obertongemische" for "overtone mixtures" in the German original.

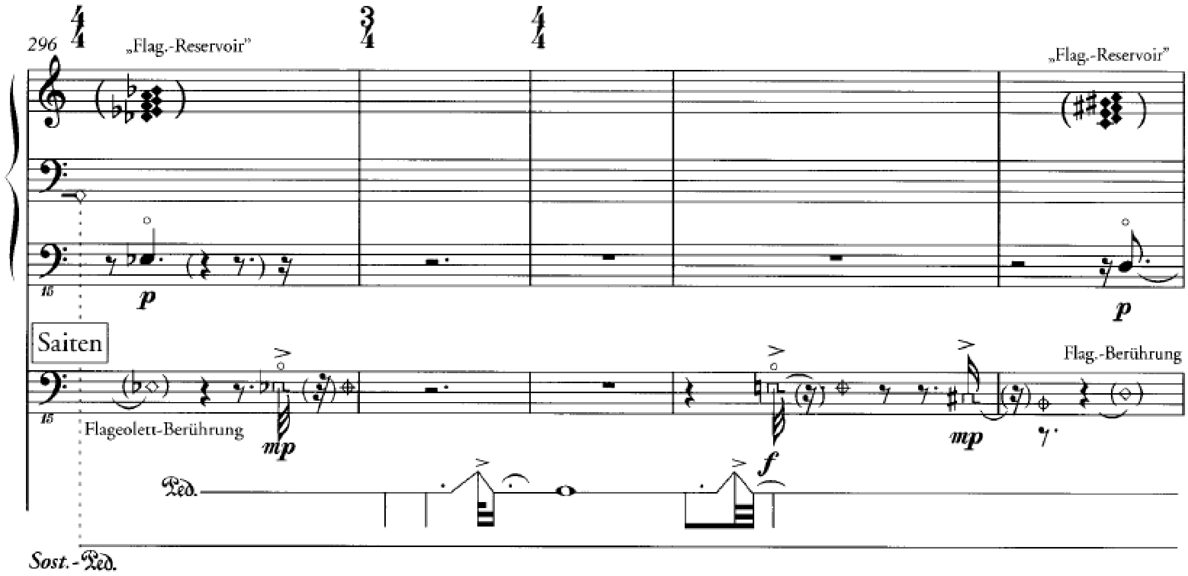


Figure 4.2.2-1, Lachenmann: Serynade, b. 296-300. Edition Breitkopf.

The same multiphonic constellation appears transposed in an almost chromatic manner in bars 303 (fundament D-flat), 305 (B-natural), 306 (A), and 308 (B-flat).

4.3 E.Oña and C.J.Walter. Multiphonics in Pitch Composition

Of the few composers using multiphonics as a constantly present sound material, C.J.Walter (b. 1964) composes with multiphonics by seeking shared pitches with other instruments in what is best described as a fixed pitch framework. This corresponds to the composition method 2, of preferring the spectral, microtonal and registral properties of multiphonics.

In Walter's *split tones 3* there are bitones as a result of preparations on non-copper strings – see Figure 4.3-1 below. The preparations have been designed carefully and once in context, the sounds blend well with multiphonics on the bass strings.

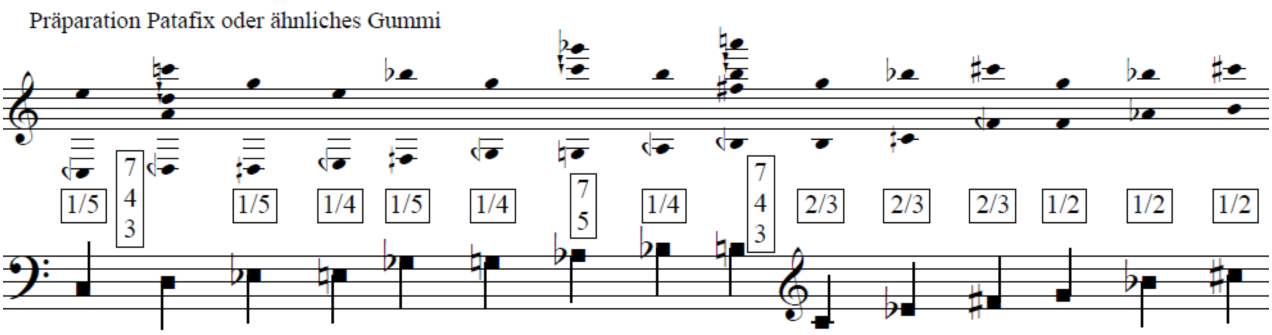


Fig. 4.3-1. Flageolets and bent tones (or, grip tones) as blu-tack preparations in C.J.Walter's split tones 3 (2nd version).

In the composition *3 Studien für Klarinette, Cello und Klavier* (2011) (as referenced in Onofre & Bragagnolo 2014, 96), the piano multiphonics also combine with multiphonics simultaneous but slightly differing in pitch content from the clarinet, in a way that seems to seek out shared pitch classes, whereas *Versunkene Form* (2009) uses multiphonics on the piano alone. Bars 16 and 17 use the same multiphonic node on two strings one octave apart, which might hint at a more pitch class oriented way of composing. Generally, a few conditionalised multiphonics are alternated with each for timbral variance and also with conventional keyboard playing to achieve beating phenomena to simple flageolets or partials that are components of the multiphonic. Flageolets, multiphonics and conventional playing is given somewhat equal space. Some combinations of sounds, such as those based on fundaments Bb and F, are seen intertwined at various stages, hinting at a motivic approach. For notational examples of this work, see Fig. 5.2.5-2 in the chapter for notational solutions around grip intervals.

In a composition using pitch material only, Erik Oña's (b. 1961) *Jodeln* features beating phenomena and semi-pure octaves in an environment where no actual multiphonics are used. The pitch constellations are formed from a selection of six flageolet node positions on 19 strings each and allow for sounds almost as complex as multiphonics – see Figure 4.3-2 below. The flageolets strongly resemble multiphonics in the many cases of simultaneous onsets of flageolets. *Jodeln* may be seen as a study where some of the numerous theoretical partial combinations have been used to motivic effect. In the following the compositionally most prominent passages will be explained.

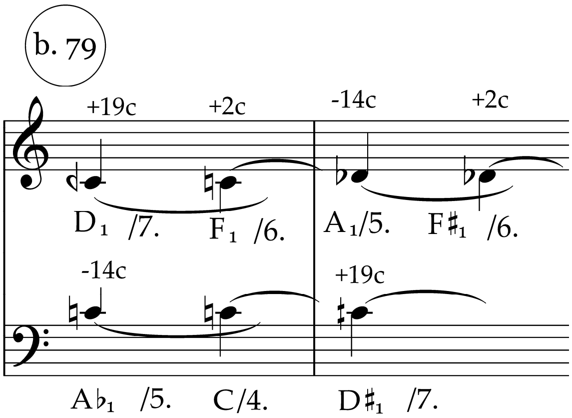
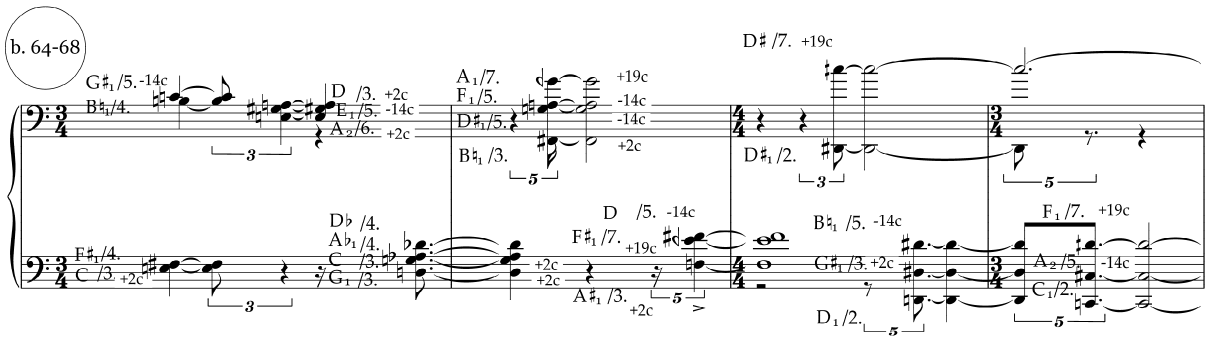


Fig. 4.3-2. Erik Oña: Jodeln. *Above left: b. 79. A semi-unison timbre, a reduced notation failing to show finger releases. Below: b.64-68. A reduced notation of semi-octaves and beating phenomena, far too complex to be allocated to one player.*



If the same multiphonic node is transposed up or down to the next string it might sound different because of two reasons. Firstly, strings have different lengths so higher partials will be more blurred on the shorter string and there are slightly different physical and acoustic properties. Secondly, the frequencies heard will differently correspond to pitches stored in the musical memory. Such memorised frequency regions could be those used for speech recognition and vowel formants. Many of the frequency peaks heard in piano multiphonics fall into the range of vowel formants, the lowest of which is the first formant of vowels i, u and y in the wide region around 250Hz (B natural 0 + 21¢) and if the 19th partial on the highest monochord is still audible and around 950 Hz, the highest formant region will resemble the vowel o, being its second formant. [39] The formant regions of multiphonics can be taken advantage of in composition especially with the voice.

Some intervals can be described as more spectral than others, depending on how high they are in the overtone series. The pure fifth, the pure major third and the natural seventh are low partials that are strongly present in the open string spectrum and are easily recognised even in the filtered overtone series of a multiphonic. Clear single partials from different strings can be combined to deceptively sound like a multiphonic on one fundament. Multiphonics are hard to combine in this way because they constitute many partials that exactly match a fundament and cannot build such an illusion of another fundament.

Mark Andre's (b. 1964) *S1* presents a case between timbral and pitch composition yet there are not many salient pitches present in the passages where partials are used. For acoustic beating effects, the composition uses the partials 4, 7, and, the two latter ones of which will sound as multiphonics. There is a node progression of adjacent slots with a tuning wedge, effectively going through several multiphonic nodes on two adjacent strings, and a similar combination of pitch-driven timbral changes can be found in Furrer's work (Fig. 4.3-3a & b).

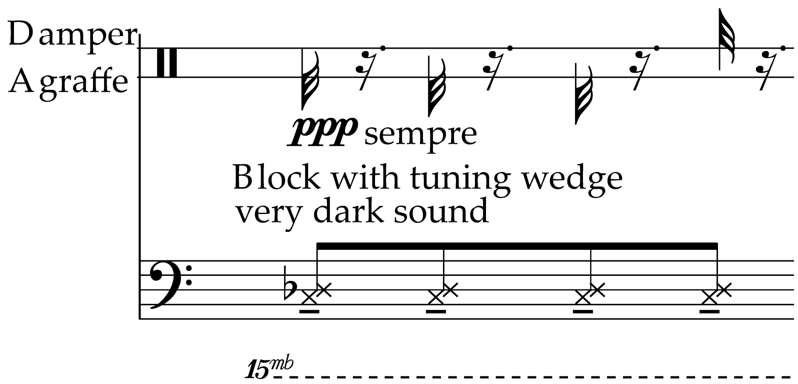


Fig. 4.3-3a. Notation (above) and setting (right). Use of tuning wedge multiphonics for a node progression in M.Andre: S1*, b.220. Reduction of the notation made from the second piano part and translated into English.*

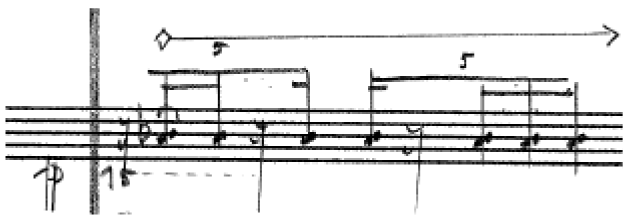


Fig. 4.3-3b. A similar progression can be found in Furrer's Wüstenbuch *(mvt. III, b.150) where an arrow is enough to indicate the direction of the node progression. Here, a finger is used instead of a wedge.*

In contrast to Furrer's diamond-symbol notation and a brace through the stem, in Andre, a filled circle is used for completely damped strings. None of these notations for sounds between flageolets and different degrees of damping enjoy established status.

[39] Using approximations for the spoken female and male voice from the established work of Pols, Van der Kamp, Plomp (1969, 464).

4.4 Prospects for Timbral Instrumentation

The piano multiphonics have proven to be a versatile resource as they provide compositional possibilities both spectral and pitch-oriented. Considerable widening of the pitch, timbral, and dynamic range, however, is only achieved with the addition of other instruments or preparations, as will be seen in this and the following chapter.

When the concept requires the singularity of one piano and one performer to be kept, the composer still has many options to match the multiphonics or to slightly contrast them. The most versatile solutions are those where the matching sound does not acoustically mask the multiphonic sound out of perception, be it preceding or succeeding.

Softly played *ordinario* sounds can certainly be alternated with a multiphonic that shares some or all of those pitches. The contrast between harmonic and tempered sounds tends to be quite severe though, and there is a resemblance to a pattern of correcting mistakes. There is also a further question of the time needed to perceive, even dwell upon, harmonic sounds of one string versus conventional tempered sounds on many strings. After all, multiphonics have a stretched temporality that might be caused by the unaccustomed sonic details inherent in the evolving dynamic contours of the bare partials.

More about the combination of piano multiphonics in alternation with itself or another piano can be read in Appendix 2. In the following, a small fraction of the prospects and possible equivalents with other instruments are observed.

In the compositional method 2, multiphonics are charted for availability and treated as a spectral or microtonal resource although with a somewhat narrow range of transposition if only monochord strings are used. The considerations are especially applicable to other instruments as well where multiphonic timbres have been sought out or categorisations of multiphonics on other instruments are used to complement categories of piano multiphonics.

As discussed in chapter 2.4, difference and summation tones are an essential characteristic of multiphonics and thus continuing a multiphonic's branch of difference tones by adding instruments can smooth out otherwise less balanced combinations of timbres. The same can be said of any kind of spectral warping traditionally favoured in spectral composition. When a piano multiphonic's spectrum is taken as a starting point and the frequencies derived from it are gradually stretched or condensed, there is a fair chance that at some stage of warping some other multiphonic constellation will match.

As mentioned in Appendix 2, there are many ways to produce microtones inside the piano in addition to multiphonics. Microtonal sounds can bridge different instruments not by virtue of timbre but by simply being out of tune compared to some other sound material. In this sense they are similar to either lightly (flageolet grip) or conventionally stopping the string in instruments with fingerboards. On many wind instruments similar non-tempered sounds can be found by overblowing. Approximations of the microtonal partials in multiphonics can also be achieved with flageolets played on string instruments with or without a scordatura, in which case some weaker partials can be made audible by doubling. On the short remaining steel parts of a piano string itself, untempered fundament frequencies are also available.

Almost any combination of two nearby microtones can be approximated as one piano multiphonic or as two flageolets on one string each, although the noisy timbre of a piano multiphonic may not be near enough to this concept. When microtones more than an octave apart from each other are desired alone and on one string, multiphonics may not present the best option since the distribution of frequency peaks is steady and there are no wide gaps. In these cases, a pitch-oriented composer might have had a certain partial relation from either the overtone or undertone series in mind. These partials of tempered pitches will be readily available on several other instruments. If shifts of octave are familiar to the composer's aesthetic, a partial relation such as 7:5 may be re-interpreted as 10:7, retaining the same pitch classes.

The fundament will almost always be audible in any multiphonic, but this notion can be ignored in favour of the frequencies desired. Most wind instruments' flageolet-like sounds and half-stopped noise registrations of the organ also have a slight hint of the fundament pitch. The more instruments and different fundaments are used to produce the microtonal interval, the clearer the result, as any foreign pitch material from the incongruous fundaments gets outbalanced.

For a regular distribution of small microtonal intervals such as exact divisions of 12-TET intervals, a group of several nearby scordatura pianos may be used. This can expand the possibilities for beating phenomena and fill the gaps that exist within tempered pitches and their partial series.

In addition to acoustic composition, multiphonics of the piano feature every now and then as a substance for fixed media electronic works and works of sound art. In that realm, multiphonics of the piano can form a real life substitute to the ring modulator method as known from electronics, as both produce harmonics of a fundament. Probably, the fluctuations in the sound of a piano individual will have a less regular morphology to them compared to a processed one. When the unique dynamic envelope of the multiphonic is taken as a starting point in processing, it lends itself to modifications of sound substance and the result will still sound somewhat like a piano. One of the established composers of mainly electroacoustic music, Wolfgang Mitterer (b. 1958), explains the applications of piano multiphonics recordings personally:

> "in very many [*of my*] works such sounds [*multiphonics of the piano*] are encountered, [*either*] hidden, [*or*] obvious and often processed, often also without attack, merely the decaying sound…" (Mitterer 2015.)[40]

For Mitterer's work, the concern seems to be mainly between contrasting large-scale spectral contours, i.e. multiphonics with attack versus attackless multiphonics, rather than modifications of pitch material. In many cases composers might want to retain the peculiar blend of a multiphonic spectrum with only slightly equalising it or modifying the attack.

4.5 Prospects for Comprehensive Multiphonic Preparations

As there are **ergonomic and technical limitations** that sometimes render especially multiphonics with attack almost impossible to play, these sounds could be achieved with the help of a **special device** that can be inserted during a performance or beforehand.

[40] "in sehr vielen werken kommen solche [*Klaviermehr-]*klänge vor, versteckt, offensichtlich und meist prozessiert, oft auch ohne attack, nur der nachklang,…"

Such a device would transform or simplify some of the mobile modes of playing to become prepared or fixed modes of playing. These kinds of preparations might be operated quite differently than the nodes would with a plectrum for example and might obstruct the hands from playing when not touching the device. In such an extreme case the device would disable any other kind of playing and the instrument becomes a **multiphonics-piano**[41]**.** If the device were to allow other kinds of playing, when not being pressed, the device might rest separated from the string surface and allow for conventional playing on the keys.

Among others, C.J.Walter's and C.Iannotta's recent work for the prepared piano has employed patafix, similar to blu-tack, to produce flageolets, multiphonics, and non-copper string bi-tones. While the sound of these fixed preparations and the amount of possible sounds they provide indeed is that desired by the composer, the limiting fact that there are not many suitable strings left unmodified on a piano causes large-scale use of different nodes inaccessible with fixed preparations. To encourage future repertoire, such a detrimental limitation ought to be removed so that with a mechanism a selection of different nodes may be reliably playable on any given monochord string (also on a few lowest dichord strings), separately or simultaneously with other strings. The mechanism should only work upon summoning and ought not to influence the strings at other times.

A more fixed **preparational device** vaguely described by Walter is made of elements that can be attached to the metal crosswise bars of the piano, and between the elements there are movable sliders along which pieces of rubber can be inserted (Walter 2014, 25-26.) This material avoids sweat from fingers from damaging the strings. According to an embedded picture by Walter, a **Steinway D version** of the device has either the names of the strings or the partial numbers labelled on the pieces of rubber. There are rubbers only where required by the music and they seem to be separated from the strings when left untouched. The note stand pointing to the side has been attached to the crosswise bar in the middle, the cover of the instrument has been removed and the performer would apparently play from the bass side of the instrument, still having right-handed access to the lowest keys. More cannot be inferred from the picture or the text.

Walter's device, if interpreted correctly, would be in keeping with technical and ergonomic findings. Let us deviate from Walter's concept and concern the following alternative with different materials and where the player is additionally free to play string glissandi and other mobile modes of playing **without hitting the multiphonic device** accidentally or unavoidably.

The device could be constructed so that glissandi on neighbouring strings and progressions on adjacent slots are freely accessible for the performer's objects above the strings – the device itself would function on the underside of the strings and would be applied only at pitches where required. The device has to base on an isolated material that does not make a sound when it recoils on the soundboard. The node obstacle could be a stiff enough thread about the width of the plectrum. The device would have a row of high enough push pins attached to the isolated material on the soundboard so that the vibrating string does not hit the heads of the push pins but is near enough to them. The heads of the push pins should be wide enough to retain the thread somewhat in place. Each

[41] The term has been previously coined by Marina Khorkova to describe the concentrated use of the piano in the composer's own work.

push pin would be label marked and installed right next to the desired node percentage at the height of the string, and there would be a row of similar push pins for the same percentage on each monochord string. In this manner, even the nodes that lie under a crosswise bar can be contacted from beneath without too much an effort.

To play a multiphonic without using a pedal or lever, one would have to temporarily raise both push pins bordering it. The thread between the two push pins would tighten and function as the node obstacle. At the end of the move, the push pins would fall back to their places, perhaps the hardest part to design and construct. This might require two hands but allows for at least two multiphonics to sound by raising four push pins. There will be no scratching noise from plectrums, and nodes can be located rapidly.

A handle could also be constructed to connect a row of push pins of the same node percentage from beneath. This handle could be regulated from the empty left side of the soundboard and would raise all the pins of that node, as if a pedal. Since there would be a thread connecting the pins, all monochord strings would be affected by the thread as the node object. The same safety measures apply as with any playing on the strings.

Previous suggestions have a linear object below the strings along the direction of the keyboard (see Fig. 4.5-1 a, b). A similar thread system could be installed to travel all the way below each monochord string. The thread would only touch the string at the point where it is raised from above with a push pin but would not have recoil from the push pin surface, let alone a contact time optimal for the node unless the thread travels through a surface that regulates the time of contact by being slippery or pointed (see Fig. 4.5-1 c). The edge of the soundboard and the hammers present a range limitation to all systems not tied to the bars.

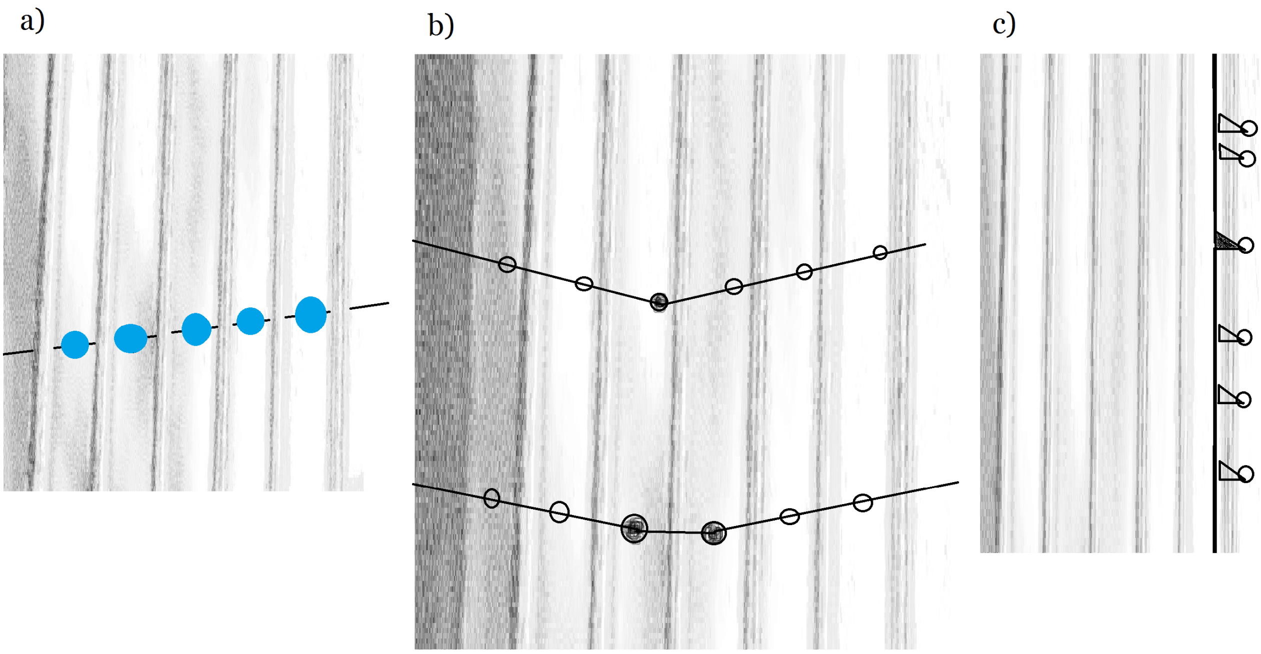


Fig. 4.5-1. Basic mechanics for a multiphonic device using thread.

a) View from the pianist's position, with blue hitch pins set as shortcuts to one multiphonic node on several strings. The system is at rest and the push pins only slightly emerge from beneath the string level. b) View from the soundboard beneath the strings. The upper thread in the figure has a push pin so near to the string that only one push pin is needed to touch the node (black circle), however, the pin may start to rattle with the string. The lower thread *requires two push pins, one between neighbouring strings – both push pins would have to be raised to make the thread touch the string. c) View from the soundboard beneath the strings. A thread that travels along a string, here installed for one string only. Only one push pin per string can be used at a time.*

The shortcut function of push pins becomes useful when the system in Fig. 4.5-1 c is installed on several strings and each provides different node positions irregular or otherwise tedious to locate. The other systems show slight bending of the thread towards a node on either the keyboard or other end. If the pins are fixed with a handle or otherwise, bending will be unavailable.

Ultimately, the question about the suitability of the present piano construction arises. The problematics of note stand placement, for instance, do not favour repertoire with several types of playing inside the piano. Some of the instrument initiatives considered in Appendix 1 could be a more suitable instrument for multiphonics but lies outside the scope of the present study.

5. Multiphonic Notation

5.1 Microscopies of Utopia

> We need markings [Zeichen] for that which is not self-explanatory and which should not be left to chance or to the interpreter. – – Normalcy requires no express description whatsoever. (Maurer 2014, 104)

Conventional notation has not been developed with multiphonic sounds in mind – to guarantee their most faithful reproducibility, extensions to conventional notation are needed by multiphonics. This chapter will deal with the suitable incentives of notation in various musical contexts where multiphonics can be found.

Multiphonics are a fragile mode of playing in which care should be taken both in the psychological aspects of performing from a score and in the precision of the composer's demands. In this sense any attempts at repeatedly and exactly producing a multiphonic can be deemed utopistic. Many of the multiphonic sounds are however available on all grand pianos more or less invariantly[42] . Some of the more complex sounds develop seemingly arbitrarily when a multiphonic compound interacts with the acoustics of the piano and are often not reproducible. For example, composers are not and perhaps should not be able to notate the occasional beating patterns that occur when more than one string is played.

The intelligibility of high partials will vary firstly according to the length of the strings on the piano model and secondly also depending on the node where the high partial is played. In the case of pure flageolets, the beginning of the string is the most suitable and provides each partial in descending order when starting from the player. The topmost partial and overall clarity are variables that will be compromised on smaller pianos.

The theory-based binary notation for multiphonic nodes devised by composer C.J. Walter should at this point be deemed far too specialised to serve even as a technical-oriented notation.[43] While no actual notation for piano multiphonics is shown in the context of a composition by Walter's article itself, Walter's compositions "*versunkene Form*" for piano (2004) [44] and "*3 Studien für Klarinette, Cello und Klavier*" (2011) were accessed and examined in terms of notation by Onofre and Bragagnolo (2014, 96) and the former and *split tones 3* (2014) were sent by the composer (see Fig. 5.1-1). Referencing an excerpt Onofre and Bragagnolo provide from Walter's trio work, the piano part introduces a notation on two staves connected together by brackets, according to convention.

[42] The comparison can be seen as the main topic for Onofre and Bragagnolo (2014). Also see Appendices 3 and 5.

[43] The binary marking uses a notation based on the conception of multiphonic nodes as a series that branches out much like the Fibonacci series. The principle is marvellously explained in Walter (2014, 17-18). Walter's conception of frequency is also portrayed by compositional techniques using difference tones and the undertone series, which also have a bearing on rhythmic thinking (Walter 2014, 30ff.)

[44] The year is referenced later as 2009 in the source. The year 2009 is also indicated in the score.

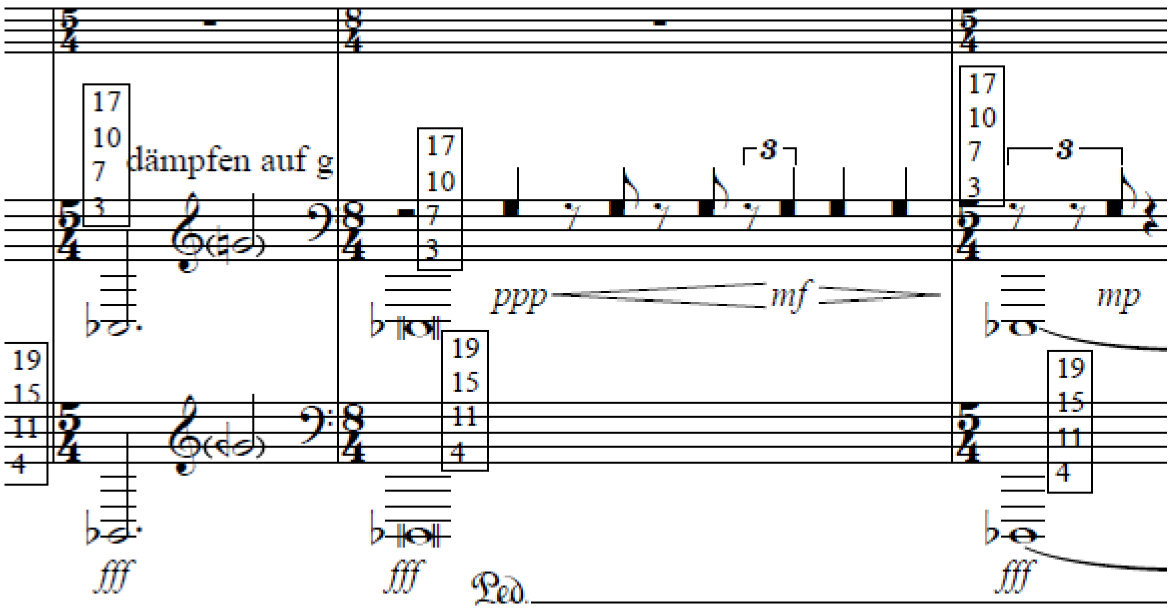


Fig.5.1-1. C.J.Walter: split tones 3, b. 31-33. Multiphonic notation and damping resonances of multiphonic components.

The upper one of the staves mostly uses a treble clef. The fundament pitch is notated on the lower staff which consistently uses a bass clef – the pitches with leger lines are rather low at such a sounding register, without using any octave shifts. The dynamics are written even below the lower staff. Four sounding upper pitches of a multiphonic are indicated inside individual brackets and in small notehead notation on the upper staff [45]. A stem runs conventionally tangentially to the small noteheads, and the same rhythm is indicated as on the corresponding fundament pitch. Between the staves just to the right of each multiphonic chord, there is an open narrow rectangle unfortunately overlapping with many staff lines. A vertical text inside the rectangle always lists four numbers of sounding upper partials, the largest number starting from the top. The largest number seen in these two works received are 11 and 12 respectively, while the smallest is 2, a wide enough range leading to occasional changes of clef to accommodate for changes in octave.

In the former work, Walter has indicated the fraction of the string where the multiphonic should be obtained by writing the fraction (Onofre and Bragagnolo 2014, 96 and Fig. 5.2.5.-2 and 5.2.6-8 below), with the notated sounding result and a similar rectangle, here spaciously put above the staff and including three numbers.

5.2 Notational Possibilities and Conflicts

Western notation, while remaining a system that can be adhered to, doesn't provide the optimum or even fertile ground for multiphonic notation for performers or composers. Even the most recent treatises on notation valuable for their unique insights have ignored the notation of both flageolets and multiphonic sounds on the piano. Until now, no standard notation has been proposed for multiphonics on the piano.

The following section will discuss the details of notation which possibly lead to conflicts.

[45] The partial components have not been marked as pitches in *split tones 3*. The additional staff is there and mostly empty and shows the results of percussive preparations, not multiphonics.

5.2.1 Action Notation vs. Sounding Result Notation

The main question on behalf of anyone reading a score is "how would this sound like?"

As a small slip of the plectrum onto another node would result in a decisively different sound, the sounding results of multiphonics are not intuitive. Methods of **action notation** highlight the mechanic or movement action by the performer on a modified, hardly controllable, or complex instrument, making them in the worst case unaware and indifferent to the sounding result. On the other hand, **sounding result notation** can leave the pianist puzzled even as to what kind type of a piano they should use. [46]

The methods of action notation for multiphonics are, starting with the exact and least obscure, to indicate fundament pitch on a staff or written as text, a grip percentage, a grip as a placement between two more standard grip placements, a **grip interval** [47], the marking "inside" or "outside", the marking of left or right hand, any signs or notehead shapes or fillings showing the pressure on the node, or any markings of preparations.

Likewise, the methods for sounding result notation would include indicating the fundament pitch (although also part of action notation), notated pitches on a staff or ossia staff , any partial pitch names, any partial numbers (for the experienced musician), any distinctions showing relative dynamics of partials, the marking M on the stem of the multiphonic fundament[48], or a musical character or imaginative description[49]. Both types of notation are discussed below and can be seen in the figures.

For most contexts, a combination of both notational methods is preferable, and one stave can be reserved exclusively for one notational choice. This has been done with many other instruments as well and can be named *suoni reali* (resulting sounds) and *diteggiature* (grips).

In figure 5.2.1-1, rather unfavourable notational choices can be seen. Most of the listed methods of notation are dealt with further below.

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[46] Increasing performance with modes of manipulated playing and with unconventional or modified instruments has called for more and more action notation which has widely problematized conventional (sounding result) notation.

[47] This is the notation calling for and supporting the somewhat controversial grip tone phenomenon as discussed under gripping distance in chapter 2.4.

[48] The marking "M" on a string instrument multiphonic was first proposed by Robert (1995) and is generally in use for wind instrument multiphonics as well.

[49] If a musical character or image such as "rich", "dull", "round", or "piercing" is given, an adaptation is already called for by the composer and the choice is left at the performer's discretion.

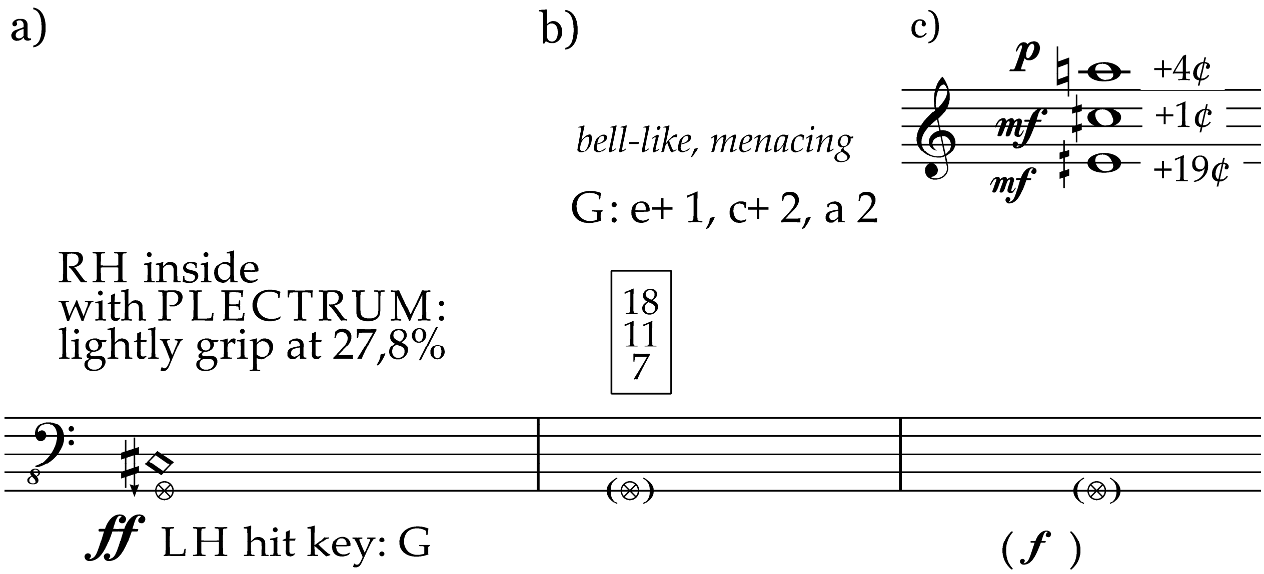

Fig.5.2.1-1 a) An extreme case of action notation for an unreleased multiphonic, as well as b) a subjective proponent of sounding result notation c) another subjective sounding result notation.

5.2.2 Distribution on Staff

The multiphonic sounding result can be approximated on the treble clef using a separate and noticeable **ossia staff**, preferably above the main staff and never on the same staff as the fundament pitch. Space permitting, the sounding result can also be marked on the right-hand staff if the multiphonic fundament is notated on the left-hand staff. The reverse order of registers is also acceptable but less intuitive to the player. In the case of no ossia staff, care has to be taken to show that the additional notes are not to be played on the keys by a third hand, as two hands are typically reserved for the multiphonic. The sounding pitch complex should thus be vertically aligned with the fundament, and preferably in note-heads of contrasting shape, size, or filling. Even placement within brackets or boxes could be considered, as with all the following methods. An ossia staff takes more space in an already crowded score and can be distracting if not used consistently on each row of the score.

The pitches should be preferably marked in 24-TET or a more precise approximation. For a 72-TET notation, see Appendix 2.

On the guitar, Josel and Tsao (2014,110) show Michael Pisaro's composition "mind is moving", where nodes to be played are notated below the staff on a separate line on which the node placement is shown as a relative distance from the two neighbouring frets – a notational advantage for the fretted string instruments in general. Should a composer ask for frets for some reason to be installed on the grand piano soundboard as preparations, this type of ossia notation would become preferable.

5.2.3 Inside vs. Outside

Conventional ordering of piano staves concerns itself with left-right hand division and seldom requires markings to the contrary. In conventional music, the entire expressive range has been made by the keyboard, which can be notated one-dimensionally, vertically, at the shortest time unit. In that repertoire, a notation which mostly couples one hand with one region has been practical. When composing for the piano in a more choreographic fashion, one might wish to consistently assign the two staves such that one is dedicated to playing on the inside and the other on the outside. Those staves do not even designate the hand to be used, which is nevertheless best left to the composer to ease the pianist's sight-reading – though at times when there are many preparation objects or obstacles inside the piano some markings may not be observable from a sitting position. The multiphonics, while in most cases played by both hands, would inhabit two staves simultaneously, one stave indicating the key and a second stave either the sounding pitch result as partial names and/or noteheads or numerically, grip interval, grip percentage, a degree of pressure or damping on the node, or similar. To avoid mentioning the fundament pitch on both staves, the solutions are (see Fig. 5.2.3-1):

a) the stem of the fundament-pitched note can be drawn to extend to both staves. In this case, the duration of the note has to remain intelligible or else indicated with extra symbols nearby.

b) a dashed vertical line can be drawn between the staves to indicate synchronization.

c) without using two staff lines, the names of the fundaments can be written out. The number of the octave can be left out if no confusion can arise.

d) the marking *with LH*, *same as LH*, or *coll' mano sinistra (coll' m.s.)* can be used. In the case of the right hand, one would use *RH* and *coll' mano destra (coll' m.d.)*, respectively.

As in solutions a and b, indicating for what staves are used is crucial if they are flexibly used for many locations and modes of playing. Durations of attacks, releases, and pedalling are only read from one stave. In these cases, vertical connecting markings are perhaps more intuitive to read than horizontal text. When labelling the locations and modes of playing on the piano, a consistent choice between English and the standard Italian or further languages also has to be made.

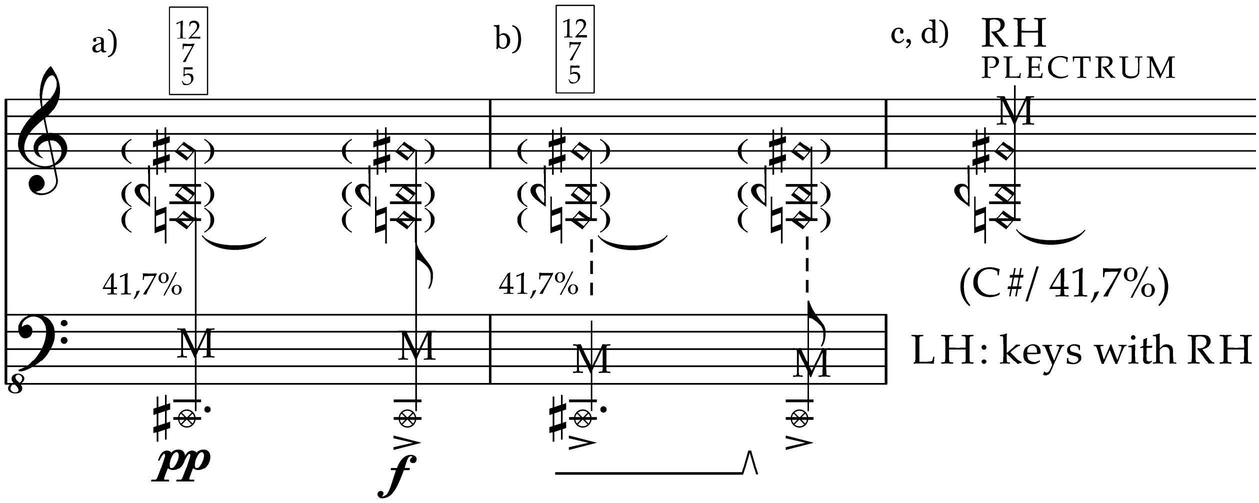

Fig 5.2.3-1. Notational possibilities when modes of playing change rapidly.

Any use of pedal would be marked on the lower stave. The dynamic would be marked either between the staves or on the stave on which the onset type is marked. When alternating multiphonics with more noisy modes of playing, any changes of clef and the number of lines per staves should be kept to a minimum. Again, consistency in the mutual placement and spacing of all this information is crucial.

5.2.4 Naming vs. Numbering

Another independent or additional method is to **spell out the names of the resulting pitches** in 12-TET or 24-TET approximation, preferably separated by commas. This requires a short text, which can be placed as a footnote so as not to overcrowd the staff. If different multiphonics abound, footnotes soon become weary to distinguish. Pitches can be readily demonstrated on the staff and still allow the option for marking a **number of the partial**. One could readily opt for only spelling out the numbers of partials heard in a multiphonic to give a fair idea of its sound. For finding the node position, marking some smaller partial numbers in the description would be required when the partial is of a large number and even the region on the string is not self-evident. See Figure 5.2.4 below shows four options:

a) without extra staves, with separate naming. The most compact notation but not always easy to decipher.

b) 24-TET approximation of a pitch complex on an ossia staff, with numbering in a box.

c) 24-TET approximation of a pitch complex on an ossia staff, with separate numbering. Such a visual presentation of the individual pitches doesn't require marking the fundament in otherwise crammed layouts, as devoted players will calculate the fundament pitch from any partial that is a power of two – the 8th partial in example b, the 4th partial in example c. This kind of notation does not suit itself to reading rapid rhythms from the ossia staff.

d) without extra staves, with a grip percentage and numbering in a box. This notation suffices in cases of experienced multiphonics-pianists and crammed layout and is the one to explicitly tell the node location.

All methods of marking partial numbers only require a fair amount of accurate hearing and knowledge of acoustic vibration. Hardly any advantage can be seen in choosing to write out both names and numbers of the pitches, as both are part of sounding result notation and ways for surpassing notation on an extra staff.

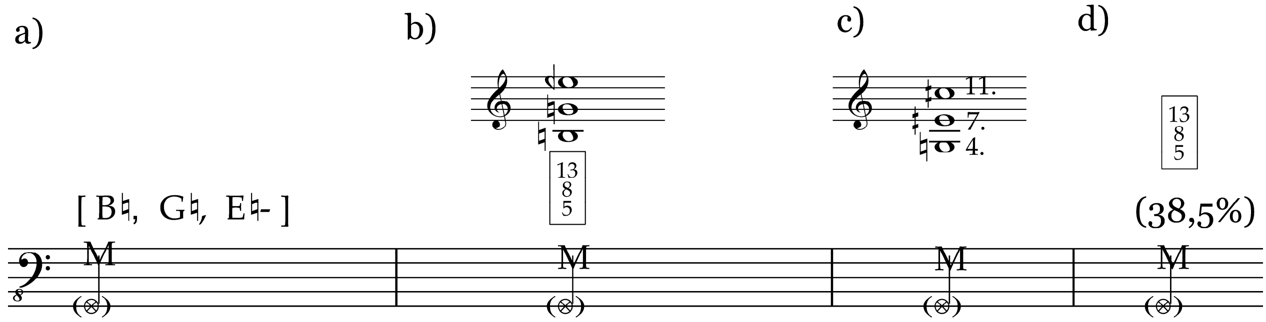

Fig. 5.2.4-1. Notations with named and numbered partial content.

5.2.5 Grip Percentage vs. Grip Interval

Marking grip percentage can be seen as a clearer alternative to marking a grip interval or numbering or naming of partials. Such a small amount of explanatory text needed is efficient and the percent sign is not easily mistaken for other markings.

Using the grip percentage becomes even more advantageous if fixed orienteering landmarks are inserted inside the piano. See discussion about the practicalities of playing above. Grip percentage is linear, and a composer could use a recurring partial (such as partial no. 7, distances of around 14%, or partial 5 and 10, distances of 10%) as a reference if a ruler or scale be fitted inside the instrument. [50]

The method of notating a grip interval is much less intuitive as the grip interval progresses logarithmically instead of being linear. It is the method used for bowed string instruments where positions on the string are memorised by the player much more intuitively. [51] In addition, the pianist cannot possibly verify at which grip interval the node-object is resting on, unless they press at the node bending the string forcefully and play the key, then impractically comparing the resulting pitch with the pitch of the string when released. [52] When the string is being bent, multiphonics cannot sound clearly, and instead the string vibrates like an *ordinario* sound of a bowed string instrument. Needless to say, the grip interval notation method should never be used with conventional pianists, with the exception of perhaps the octave flageolet, which remains quite intuitive.

Grip intervals and percentages in notation are compared below in Figure 5.2.5-1, where

a) the suggested notation: the M marking, a fundament pitch, a grip percentage and a precise sounding partial result (on a staff and as boxed numbers). The cent markings are not necessary in contexts where partials are not transferred to other instruments.

b) a fundament pitch, a grip interval, a fraction, and a percentage. An approximate sounding result. This wealth of information indicating the node is unnecessary.

c) a fundament pitch, a grip interval, a fraction, and a percentage if played by another player from the furthest side of the piano. An approximate sounding result. This wealth of information indicating the node is unnecessary.

d) The type of notation used in Walter's *Versunkene Form*; the M marking and a fundament pitch. A rather precise sounding result (on a staff and as boxed numbers). The multiphonic node can be calculated from the numbers around it: 1 + 3 = 4 and 3 + 10 = 13, thus 4/13. The performer has to know a few standard node locations by heart and in relation to each other or has to have them marked beforehand.

Each original example has marked the fundament pitch with a "phantom" notehead, a perfectly round empty note head – the cross inside it alludes to its noisy and percussive nature and to the fact that the pitch is exactly played yet intended to be inaudible.

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[50] From an experimenting approach, Onofre and Bragagnolo (2014, 98-99) have found the desired nodes on different pianos "quite easily". They deem grip intervals below a narrow minor third (interpretable as node 3/19) inaccessible due to the dampers. The authors seem to have conceptualised nodes on the piano in terms of (bent) grip intervals rather than calculating string lengths and deriving theoretical locations along the strings. The frequency that can be heard by bending, however, is faint and should not be rated as a reliable method for study. Charts showing relative distances to neighbouring nodes are faster to consult.

[51] Some of the earliest notations for a bowed string instrument harmonic can be found in Stefano Scodanibbio's *E/statico* (1980), Kimmo Hakola's *Thrust* (1989, rev. 1991) and Carlos Mastropietro's *En una carra* (1996), all of them for the double bass.

[52] Halldór Smárason's *_a_at_na* (2014) uses grip interval notation where the diamond noteheads are dismissed in favour of numbers indicating the amount of semitones bent, that nevertheless have to be attached on the five-line staff at their respective places. The number information has to be read together with the underlying staff with the fundament pitches. Node progressions of the finger or erasers are likewise not shown by noteheads but numbers and lines leading to and from the positions.

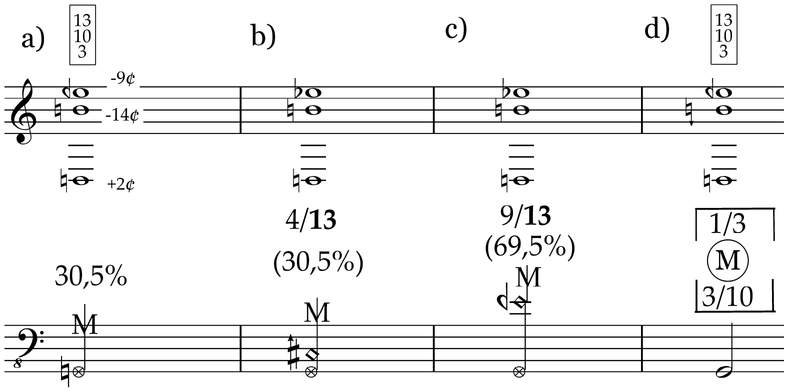

Fig.5.2.5-1. Possibilities for notating the multiphonic 3_10_13 with grip intervals and percentages.

The grip has been marked as a placement between two more standard grip placements in Walter's *Versunkene Form* (2009). When a multiphonic of 4_7_11 is desired, for example, the notation shows the symbol M and the fraction 2/7 above it and the fraction 1/4 below it (see Fig.5.2.5-2, left). Two simultaneous multiphonics, of for example such grips of 4_7_11 each, can be notated if the lower fundament's multiphonic marking is placed below the fundament (Fig. 5.2.5-2, middle). Two simultaneous flageolets can use a simpler notation as the sound is more obscure, there is less uncertainty and less pitch components than with two multiphonics; grip interval markings should be dismissed as confusing and even the percentage could be replaced with a simple partial number (Fig. 5.2.5-2, right). [53]

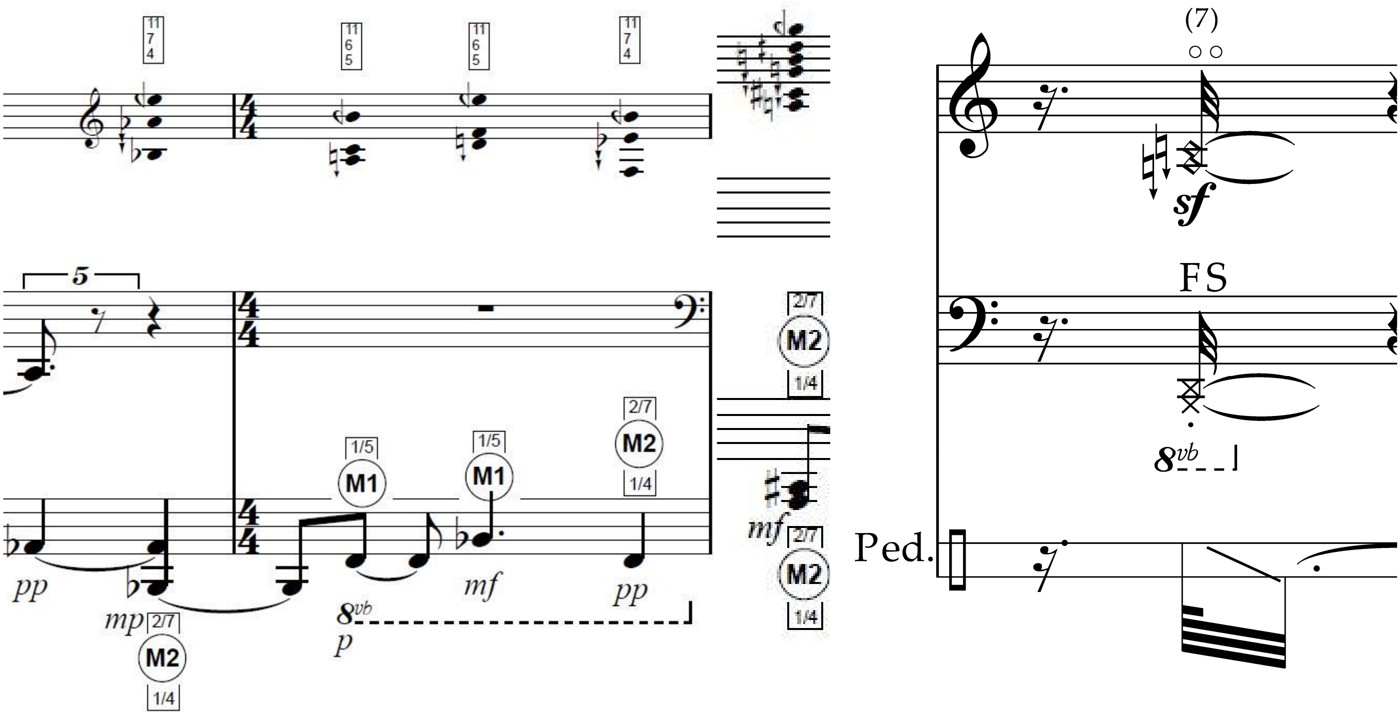

Fig. 5.2.5-2. Walter: Versunkene Form. Left: bars 28-29. Middle: bar 11 (treble & bass clefs). *Right: M.Andre: S1, b. 160. FS = fingertip.*

The notation of a multiphonic around 19% of string length has been named M1 and defined in a graph in the score to be played nearer to the performer than the 1/5 node. To further con-

[53] For bowed strings, Maurer (2014, 27) proposes that notation of the grips in two simultaneous flageolets on different strings be notated with stems in opposite directions. This can be applied to multiphonics – even if the grip interval is not notated, both percentages can be clarified to point at only either one of the strings.

firm that the performer side of the 1/5 node is called for, Walter writes the partials 5_6_11 as the result instead of 5_4_9 (or 4_5_9) and the M symbol is below the 1/5 marking.

No special noteheads besides the "phantom" notehead (explained in Fig.5.2.5-1), the stemless filled round notehead, and noteheads in parentheses should be used to mark multiphonics. On some instruments, empty diamond note heads have been used. They are not advisable since empty note heads do not convey rhythmic differentiation between minims and semibreves compared to any shorter durations. [54]

5.2.6 Beyond Intention – Substitutes and Aesthetic Choices

Even when a composer notates multiphonics in a manner that leaves no doubt, the instrument can create uncertainties during performance or limiting circumstances in which the composer's intention has to be compromised to perform the work. [55] These choices have less to do with notation than with general musicality of the pianist, both of which serve to carry a point, hopefully the one intended by the composer, across to the listener. Moreover, notation can never fully convey the composer's non-vague intention.

The pianist should bear in mind that it can be irresponsible to correct lacks or technical impossibilities in a composer's work without consulting the composer first. For some pianists however, making changes independently is the necessary step towards making the multiphonics playable on a new instrument in a hectic pre-concert environment.

If only **two resulting pitches** are notated for one string where they physically **cannot be found as a multiphonic**[56], the performer might deem it necessary to either play the pitches on two separate strings as simple flageolets (these cases may need some microtonal approximation) or play the pitches on a different string on a node where they coexist, along with other partials sounding. In both cases, try to damp the fundament resonance as the pitch is not the one intended by the composer.

It is often possible for the pianist in pitch-class-oriented and comparably less timbre-concerned music to adapt to the limitations of an individual instrument if no specific instructions were given by the composer. Both the action and the resulting sound might change somewhat. In most music for multiphonics, however, the multiphonic timbre is the main consideration.

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[54] This has been also considered by Josel & Tsao (2014, 116) on the guitar where diamond notation for flageolets is commonplace.

[55] Five common obstructions are mentioned by Hirvelä (2013, 26) for playing nodes on all copper strings when the note stand is removed: the dampers, the metal frame, the distance of the nodes from the player on long strings, the crossing of strings in the middle range, and a weak response of high partials on upper strings.

[56] This problem can only occur if those pitches are not members of the same overtone series, as a pair of any two partials of the same fundament can be always located on an extremely long string. There are "corridors" of all integer numbers starting with partial 2 (2, 3, 4, 5... and 2, 5, 8, 11...), with 3 (3, 5, 7, 9... and 3, 7, 11, 15...), with 4 (4, 7, 10, 13... and 4, 9, 14, 19...), also corridors starting with the lower 5 (5, 9, 13, 17... and 5, 11, 17, 23...) and so forth. Thus for any partial node n two corridors begin, the leap sizes of which are n-1 and n+1. As all leap sizes are eventually represented in the corridor even though multiples of those leaps have to be ignored in the case of adjacent nodes, any two partials of the same fundament can always be located together as a multiphonic node (physical precision permitting).

With small instruments it may be practical to indicate the highest partial in the multiphonic, without the lower ones, to increase its chances to be located. In the case of Walter, however, even the detailed instructions seem to be clear and realistic, and a concert grand is preferred.

Some types of notation raise uncertainty of a composer's intention. In Figure 5.2.6-1, let us consider three cases in point:

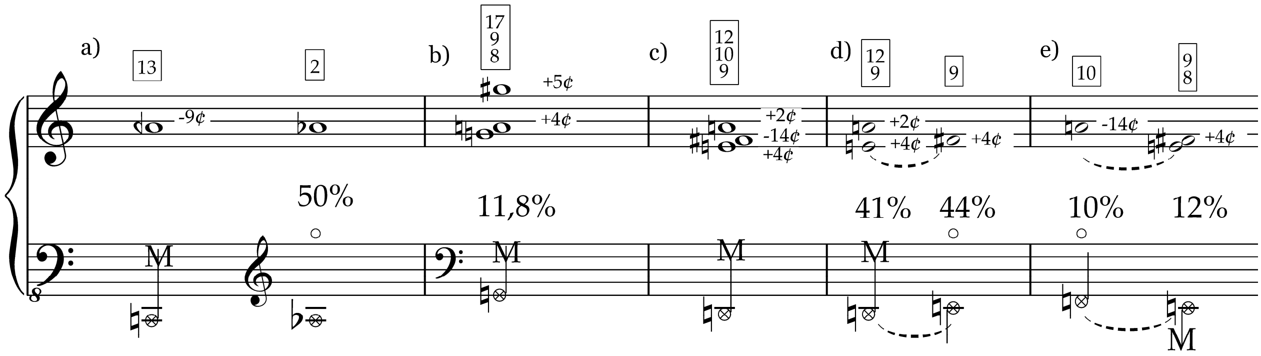


Fig. 5.2.6-1. Subtitution of multiphonic sounds.

a) the partial 13 (left) could be too obscure in the context of an otherwise clean pitch-oriented music and could be replaced with an octave harmonic approximation on a steel string (right).
b) 8_9_17, even when on a dichord string, lies under the damper and should be replaced with a nearby multiphonic or with 4_13_17 which shares the highest harmonic and partial 4 resembles partial 8.
c) 9_10_12 cannot be found on any string and is not even theoretically possible. To make it playable, two considerations follow in d and e. Lower partials such as P3 or P6 would be most suitable for cleanness of pitch but the limited amount of monochord strings doesn't provide those pitches in this case.
d) substitutes for point c, from edges to middle: a multiphonic D: 9_12 (41%) and a flageolet E: 9. (44%).
e) substitutes for point c, from highest to lowest: a flageolet F: 10. (10%) and a multiphonic E: 8_9 (12%) which would however lie under the damper on most instruments.

If **access to the node** on the desired string is impossible, the performer could change the fundament and node to one that provides at least nearly the same (+-33¢) pitch or substitute the node by another one on the same string. That node should still have essentially the same pitch-class components ignoring the octave, if these grips are available. This is one of the least discernible changes, and obstacles with bars are encountered often – this modification is likely to be allowed by and known to the composer. In the case of only substituting the node and retaining the same string, Figure 5.2.6-2 shows the following exemplifying methods:

a) 5_(8)_13_18 replaced by 4_(5)_9_13, by shifting the highest partial P18 down by one octave to P9 and P8 down to P4 as well. The partials 13 and 5 remain intact even if not essential to the sound.
b) 3_11_(14)_17 replaced by 6_11_17, where the highest partial P17 remains, P11 becomes somewhat stronger and P3 is shifted by an octave to P6, losing in power and becoming more balanced to the whole.

c) The method of octave shifting is also described as useful by C.J.Walter for the combination of 3_4_7_10 and 2_5_7_12 (Walter 2014, 24) T24, T25. Notice that when these multiphonics can be perceived to contain four partials each, the size of the "characteristic tritone" (ibid.) changes slightly, from the frequency proportion 10:7 to 7:5, and the partial 12 is shifted by two octaves to partial 3. In Walter's compositional thinking, alternatives found with this procedure sound "very similar" (ibid.).[57]

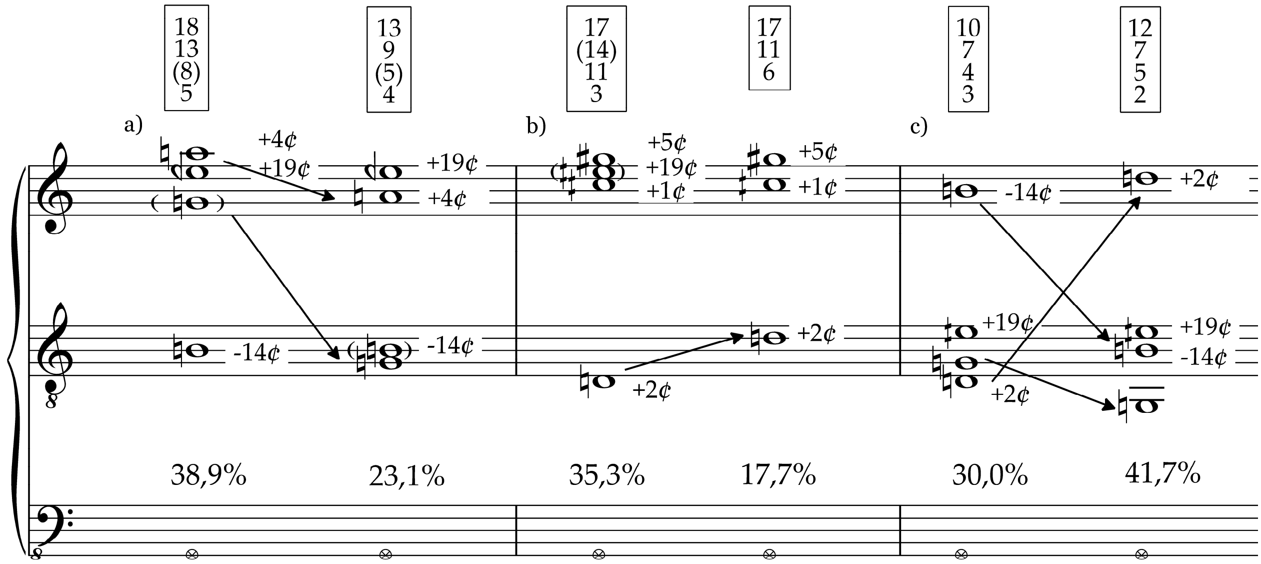


Fig. 5.2.6-2. Multiphonic node substitution while retaining the string.

An alternative substitution for an inaccessible node could be a similar procedure on two adjacent strings simultaneously: a combination of two specific multiphonic nodes with clearly standing-out partials can be found to approximate the pitches without the combination sound becoming too blurred.

As a last resort, one can play the intended multiphonics as half-damped strings because leaving out one pitch out of two could constitute a more severe breach.

Performer discretion is needed to interpret whether a composition is more pitch-oriented than timbre-oriented. For example, there is a difference between the flageolet-based pitch textures by Oña and single multiphonics by Walter.

In George Crumb's (b. 1929) music with flageolets, the placement of the node has not been specified because the composer aims for one pitch only. With partials such as the 5th, the actual sound will have other nearby partial components forming a multiphonic and thus the placement, whether 1/5 or 2/5, could be relevant. Crumb, in *Gnomic variations*, however, writes the actual sound as only one pitch, using one stave for each hand and a middle stave for resonating strings (see Fig.5.2.6-3).

[57] "Außerdem ist die Kenntnis alternativer aber sehr ähnlicher Mehrklänge nützlich. So gibt es z.B. für 3, 4, 7, 10 die Alternative 2, 5, 7, 12 an einer ganz anderen Position. Beide Mehrklänge haben dieselben Noten (allerdings in verschiedenen Oktavlagen) und beinhalten den charakteristischen Tritonus. Je nach Flügelmodell und gewünschter Saite ist der eine oder der andere dieser zwei Mehrklänge erreichbar, manchmal auch beide."

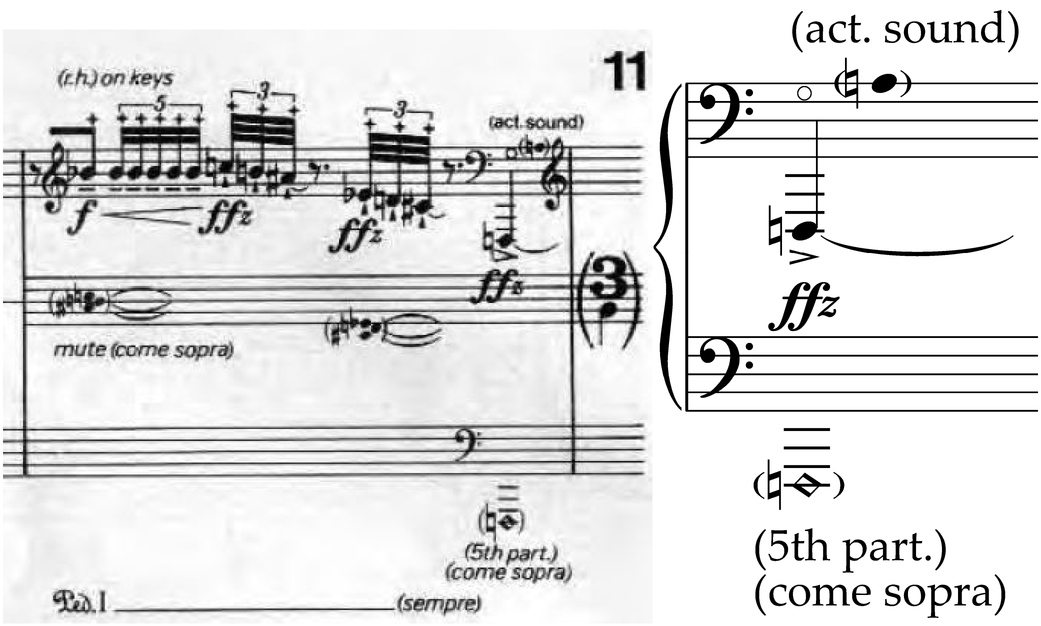


Fig. 5.2.6-3. G.Crumb: Gnomic variations, Var. 6. Left: in the work's context, publisher Edition Peters. Right: notation in detail.

There is one crucial degree of independence other than pitch that has conventionally been left to the pianist's own aesthetics in a concert situation and is valid for some works with multiphonics. **Independence with timing** can concern the durations of elements, their order, and the simultaneity of multiphonics. While not cases of substitution, some freedom in timing might even be compelled by the topological constraints of a particular grand piano. I have dealt with these notions in my own composition, which is exemplified below.

In Fig. 5.2.6-4, there is a specific back-and-forth node progression with independent timing for pressing the key.

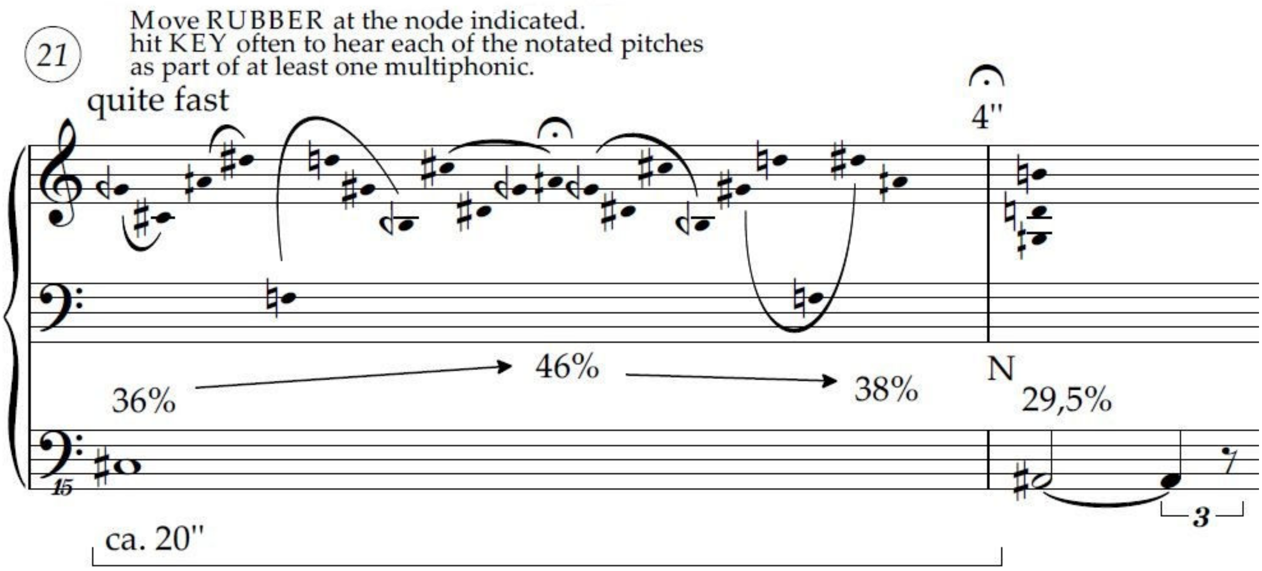


Fig. 5.2.6-4. J.T.Vesikkala: Readings.Kawara*, b. 21.*

In Fig. 5.2.6-5, shows on the left a specific back-and-forth node progression where the ascent and descent are divided into stages with an approximate number of pressing the key. On the right, notation intends that multiphonics are played on two adjacent strings with only one hand contacting the nodes in as interconnected a manner as possible. When possible, the still rather near nodes should be played simultaneously, and on smaller pianos, balancing one plectrum between nearby nodes on two adjacent strings is indeed possible although insecure. The marking $ means to play these appoggiaturas and the following pitch complex simultaneously whenever the distance between the nodes and string length allows; it is effectively a "double stop" as known from bowed strings.

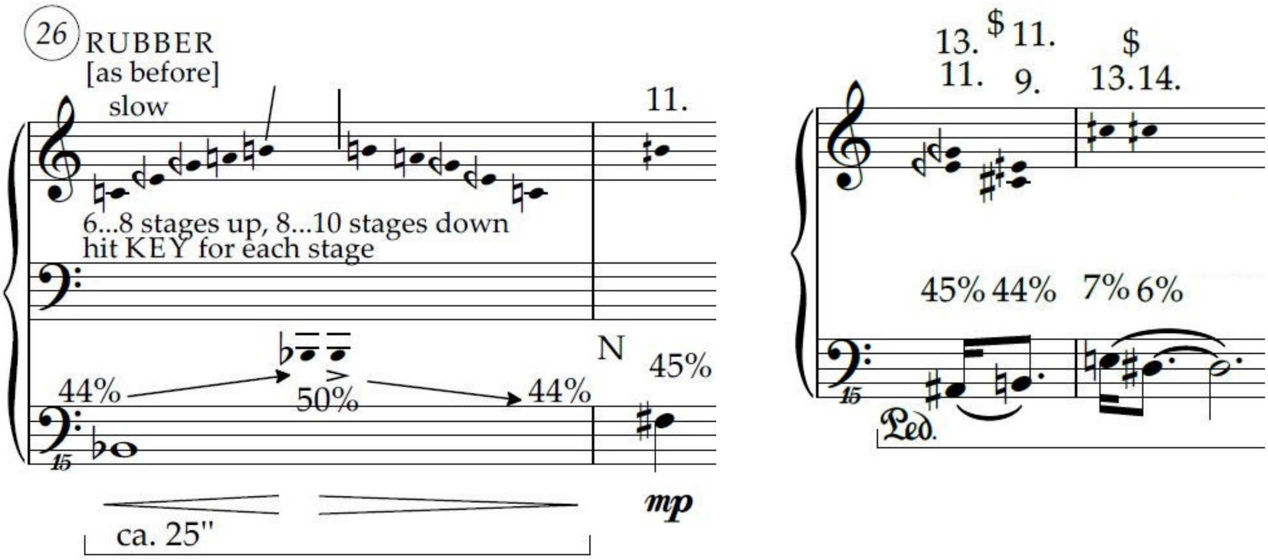


Fig. 5.2.6-5. J.T.Vesikkala: Readings.Kawara*, excerpts. Left: b. 26. Right: b. 83-84.*

The scratch multiphonic mode of playing will obscure the timing of the multiphonic onset. This can be indicated by text or by a notation that depicts temporal uncertainty by a symbol that proceed from left to right, such as the one in Eduardo Moguillansky's *double* (2007) – see Fig. 5.2.6-6.

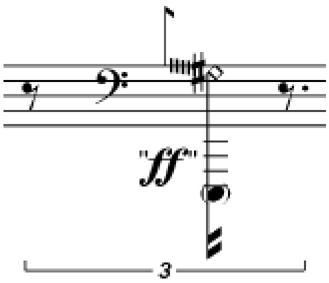
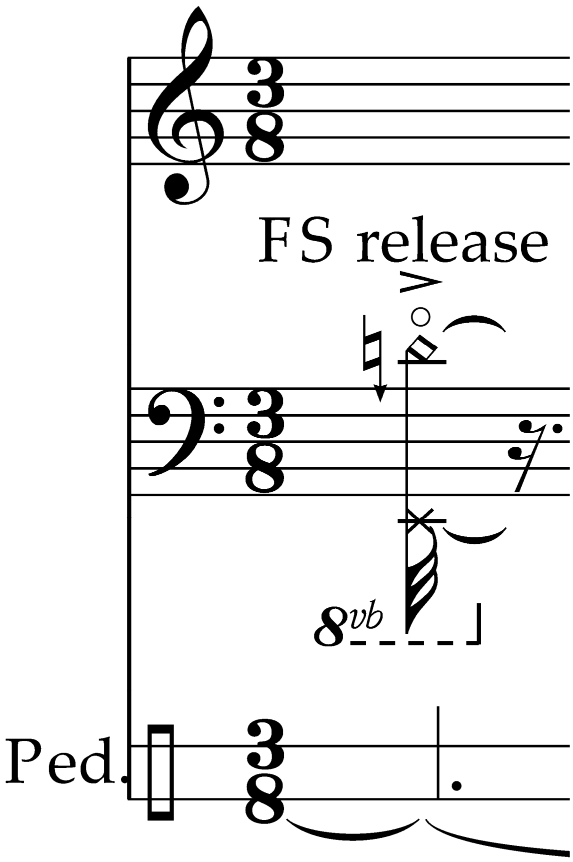


Fig. 5.2.6-6. E.Moguillansky: double*, excerpt in legend text. The string should be scraped "very fast", no key is being pressed, and the scraping should be stopped at the given node (here the 5th partial).*

Two types of flageolets can be found in M.Andre's *S1* indicating the timing of the node-object – in this case, the fingernail (see Fig. 5.2.6-7). The immediately released flageolet is rather self-evident, though even here performer discretion is required to find the optimal balance of timbre and decay time. The notation for an attackless flageolet, however, lacks the indication of the partial or a clear-cut connection to the fundament.
If the composer would wish the many pitch components of multiphonics (which the seventh partial essentially is) to be specified, this type of notation would become crowded and would probably no more serve the context of Andre's rapidly shifting sounds.



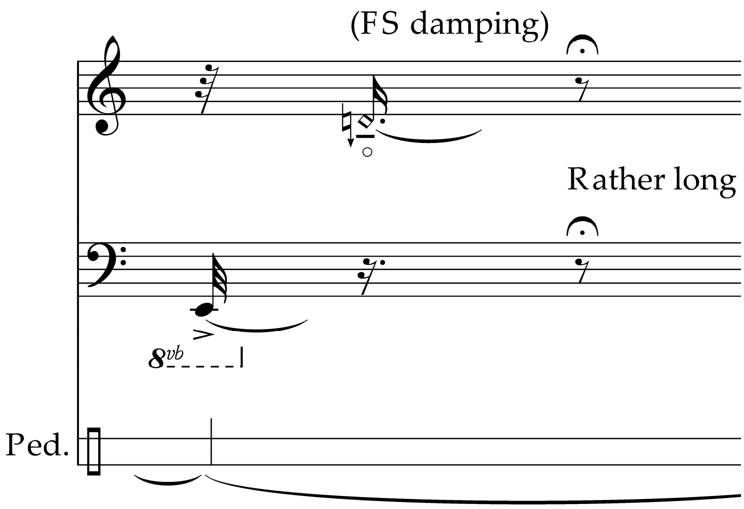


Fig. 5.2.6-7. Two cases of flageolets in M.Andre: S1. *Reduction of the notation made from the second piano part and translated into English. Left: b. 68 flageolet with immediate release. Above: attackless flageolet in b. 72.*

(FS = *Fingerspitze*, fingertip)

There are two node progressions on the strings Bb and F with an increase in action towards the end in C.J.Walter's *Versunkene Form* (see Fig. 5.2.6-8). Two fingers are used on the strings and have to operate two node progressions, the lower of which develops towards higher and higher partials. A slowing down applies to the passage, facilitating coordination.

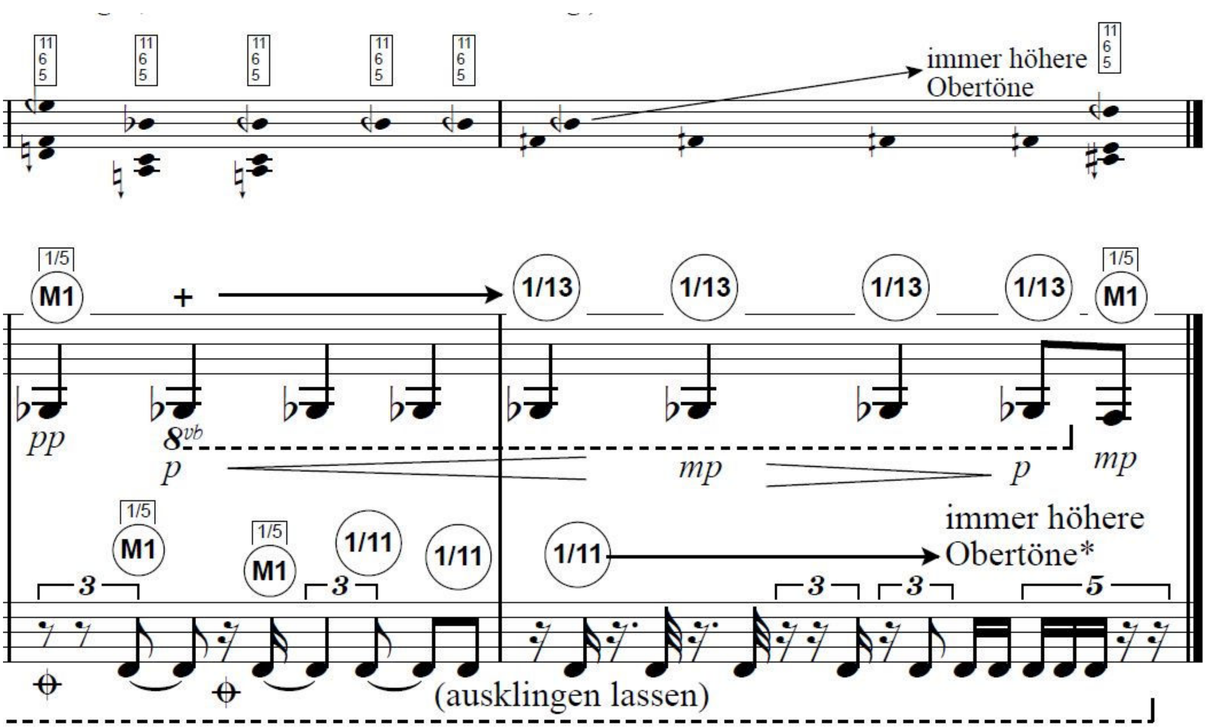


Fig. 5.2.6-8. C.J.Walter: Versunkene Form*, b.55-56. The two lower staves have a bass clef and the lowest has an additional 8vb marking. The sounding result uses a treble clef (the 13th partial of Bb in the last bar should read a semitone higher). Compare with notation in Fig. 4.3-3a & b.*

Jean-Luc Hervé's *4* uses text to indicate the new mode of playing each time when the mode changes between being either produced by the hand or a prepared harmonic, yet the composer does not differentiate their notations by other means. No copper strings are used. The preparation of the strings has been shown in the instruction text, meaning that the indication text in the score itself could be avoided by using brackets or a discernibly different note head for the note of a prepared sound (see Fig. 5.2.6-9).

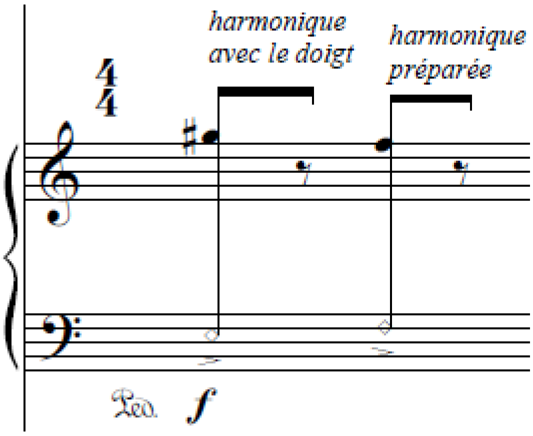


Fig. 5.2.6-9.
Notation of flageolets on non-copper strings in Jean-Luc Hervé: 4.

This notation stands in many ways in stark contrast to Furrer's. As seen in chapter 4.2.1, Beat Furrer's multiphonic marking requires only one stave, is not accompanied by text but always includes the key and string to play and can also instruct to let ring or to damp right away.

With the body of works that have been accessible as sheet music for the study and soon to be examined, the comparisons of notational solutions for flageolets and multiphonics on monochord strings have been compiled to the table in Fig. 5.2.6-10.

Title of work	**Fundament pitch shown**	**Sounding partials shown**	**Numbering of resulting partials**	**Gripping node shown**	**Specialties**
ANDRE: *S1*	on staff	in 24-TET or more accurately, on a separate stave	at first occurrence	no	
CRUMB: *Gnomic variations*	on staff	in 12-TET on a separate stave	[no multiphonics used]	no	
FURRER: *Wüstenbuch*	on staff	no	no	no	Multiphonics used mostly for percussive and timbral effect.
OÑA: *Jodeln*	on staff	in 24-TET or more accurately, on a separate stave	Numbering the partial as no multiphonics are used. Without fraction.	no	Two players share a piano.
LACHENMANN: *Serynade*	on staff	in 12-TET invariably using a whole-tone cluster of six pitches, on a separate stave	no	no	
MOGUILLANSKY: *double*	on staff	lowest notated in 12-TET, higher partials hinted at	no	No. Could apparently be played at any multiple of the node.	

VESIKKALA: *Readings. Kawara*	on staff	in 24-TET, on a separate stave	Always when individual partials. When multiphonics are complex the partials are spelled out.	As percentage of string length from player.	Rubato possible.
VON SCHWEINITZ: Waltz for Walter	on staff	in 24-TET or more accurately, on a separate stave	One (the highest) partial number marked, as fraction.	As an interval of a (hypothetically) stopped string in Extended Helmholtz-Ellis J I pitch notation	Rubato possible. Suggested fingering number on node shown. Only a few nodes are used because the left hand gripping the nodes has to stay around the same region to not lose the spot.
WALTER: *versunkene Form* & *split tones 3*	on staff	in 24-TET or more accurately, on a separate stave	Numbering all partials in the multiphonic. Without fraction	No. Has to be memorised with help of a chart and markings on the strings.	In *versunkene Form*, only a few nodes are used and can be found with help of the end of the dampers – those dampers are continuously raised.
WILLIAMS: *First lines*	on staff	in 12-TET	no	No. Could apparently be played at any multiple of the node.	

Fig. 5.2.6-10. Comparison of solutions in different notational elements.

5.3 Special Notational Contexts

Not all of the above-mentioned guidelines apply to all multiphonic notation. If a composer is to use the piano in a more limited way than offered by conventional notation but requires exceptionally refined playing in some other element, many more compromises have to be made.

In Wolfgang von Schweinitz' *Waltz for Walter*, the left hand stays inside the piano in a manageable region between 1/3 and 1/5. In this special case, notation of the grips has a positive illustrating effect, see Fig. 5.3-1. Note that the multiphonic compound at 4/15 corresponds to partial components 4, 11, 15, and 19. The high partials 19 and 20, when present in a compound, have been systematically left out from the number instruction and the next-highest number has been indicated instead. The partial 18 along the way of the finger, as in 4_7_11_18, is not made use of at all, possibly because of the common and detrimental hammer damping effect for partials 9 and 18.

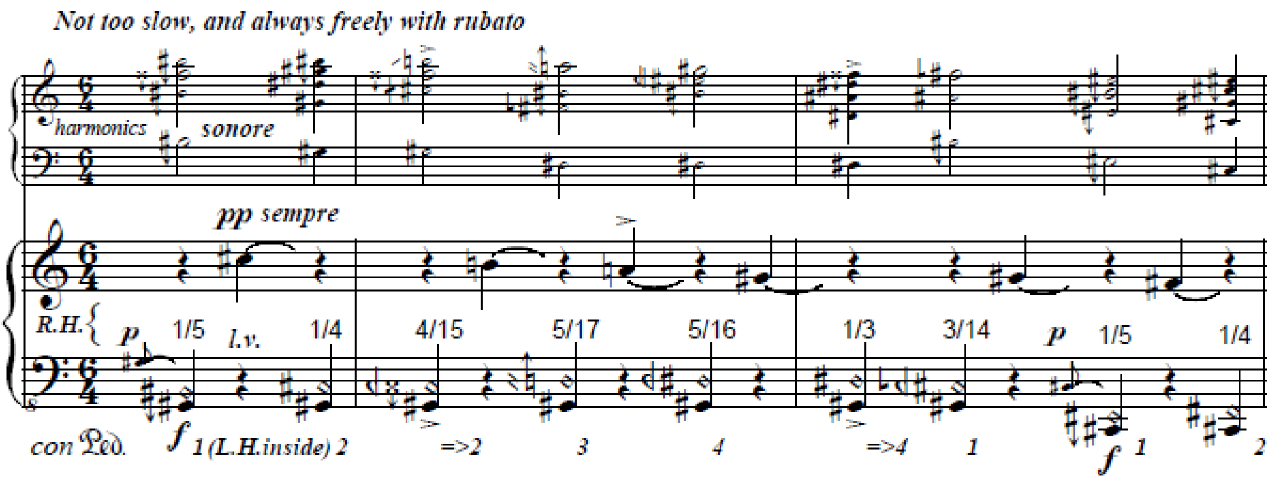


Fig. 5.3-1. W.von Schweinitz: Waltz for Walter*, b. 1-2.*

In *double*, E.Moguillansky takes a stance between action and result notation by acknowledging the multiphonic nature of partials such as the 5th and expecting higher components to sound if a second node object stops the same string at another location. The lower partial component is notated and supposed to be the louder one. The higher flageolet "is not precisely given but must be a higher flageolet than the accurately given" – see Fig. 5.3-2 a. When two flageolets on adjacent strings are played simultaneously, the composer reasons that it suffices to specify one of them and to request the other flageolet to be of a higher frequency [58] – see Fig. 5.3-2 b.

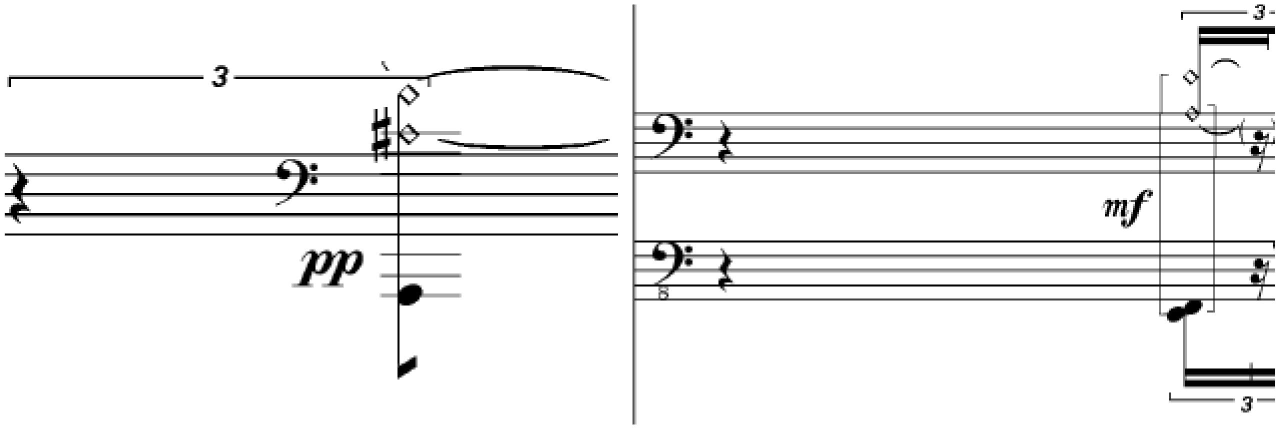


Fig. 5.3-2 a, b. E.Moguillansky: double*, excerpts in legend text.*

The notation in Erik Oña's *Jodeln* delivers an extreme case of action notation (see Fig.5.3-3 below) where deciphering the sound requires the presence of two players, although the sounding result has been provided for those who are fine with imagining.

Fig. 5.3-3. E.Oña: Jodeln*, b. 1. The three-system notation used in the manuscript.*

Jodeln has a theatrical element as the two pianists are facing each other from both sides of the piano. This setup has the advantage that the nodes that would be typically covered by the dampers are now accessible from the symmetrically opposite side. Both players have ample space for playing and a linear view to their medium of contact – one from the keys, the other from the strings. For this, a total of six staves are required, the lowest pair

[58] Other types of multiphonics with not entirely descriptive notation – rather, "flageolets" or "harmonics", as labeled by Moguillansky – are called for in the composer's work *re equestri* (2006-07). With most aleatoric placements of the node-object, the sounding result will be a multiphonic, a term avoided by the scores.

of staves for the keyboard, a middle pair for pressing the nodes, and the third pair for checking the resulting pitches.

In *Jodeln*, Oña has chosen simple flageolets – the highest of which (the 6th and 7th) will sound somewhat as multiphonics – and uses them predominantly as constellations of flageolets. The fact that typical harmonic series-based multiphonics are not used makes these inharmonic constellations sound even more unfamiliar. Oña is often looking for slightly warped octaves and frequency distributions not available in multiphonics. The compositional approach is near to multiphonic composition methods though, and there are two node progressions (b. 54-57 marked with an arrow and "gliss."), rendering discussion within this study feasible. Oña doesn't call for multiphonics at any point which also might have been a consideration of balance.

By treating the key onset energy as the same for the lowest and highest partials, no detailed notation of dynamics is required. The passages marked loud do not correlate with the partials of the highest number (the 7th), nor inversely for the soft and the lowest. There indeed are not many dynamic markings after the initial "mf", and just a few accents.

The number of strings required by *Jodeln* is rather big. The chromatic feel to the strings has been retained by **inverting the string labels** for the second pianist. For the second pianist, the partials between the 2nd and the 7th have been marked at their first occurring node from the end side of the string, meaning 1/2, 2/3, 3/4, etc. As there are six multiphonic positions used on each string, more grips than what can be reached with one hand fingers, the same kind of notational strategy as in the von Schweinitz composition cannot be used. Instead, Oña describes the setup as six "virtual keyboards". The middle pair of staves makes use of Roman numerals to indicate which partial node, or virtual keyboard to press. Without the reversal of the keyboard labels, or by retaining the black and white key chromaticism it would be difficult to handle all 19 strings reliably.

Even if there were only seven strings, all the monochords, used, one should perhaps not go for a new distribution avoiding collisions and notate the strings a third apart on just one stave. Jodeln requires two staves because the hands are designated on certain strings and occasionally inevitably cross each other. When hand movements have been thought out and notated beforehand, there will be no need for abrupt or risky changes. Rapidly changing simultaneous constellations of a variety of partials from different fundaments are perhaps best achieved by two players.

Compositionally, this notation is reasoned and the numerous timbral inventions are even visible with the score. A version of the notation if played by one player would seem equally crowded. Oña's notation for the second player excels in showing where to release the finger, which has a practical as well as a sonorous justification. Refer back to Fig. 4.3-2.

Yet another kind of multi-staff notation would be needed if a concept were to ask for two grand pianos, likewise covers removed, with two performers both pressing nodes at the end of the other's piano and also pressing keys on the own piano.

Exceptional measures in notation have to be taken if performers, whether pianists or not, need to be moving around the piano to produce multiphonics and other sounds. Such a composition has not been found perhaps owing to the fact that multiphonics by themselves require delicate positioning.

Yet another case of multiphonics can be found in preparations that are half inharmonic and half harmonic. Walter: *split tones 3* employs blu-tack in prepared bitones where the higher component pitch is a partial of the string and the lower pitch results from the stopping of the string and is thus not a partial but sounds as a shortened string, a grip note (refer to Fig. 4.3-1). The lower pitch can be calculated when the original string pitch and the stopping distance on it are known.

5.4 Proposed Standard Notation

Good multiphonic notation fills its purpose as it doesn't take up undue space, nor does it require an extra staff which is then mostly left blank when multiphonics are not being played. Not too much information is given – it will suffice in most cases to give one kind of action notation coupled with one kind of sounding result notation. The combination of the fundament, indication of left or right hand, and a grip percentage is the method I have used in "Readings. Kawara" (2014).

Intelligible notation cannot involve frequent clef changes at places where it can go easily unnoticed. The markings do not collide with any other markings in the score and they are self-explanatory. Markings for the piano in large ensemble scores should not be prone to confusion with a marking of a different instrument that would produce a completely different sound.

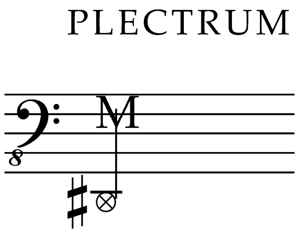
While multiphonics rarely can be played while sight-reading, a good notation should aim toward this ideal – at least for those occasions where the instrument already has markings inserted.

In all cases, using the marking M for multiphonics is advisable at each attack employing the playing mode, or the M can be marked under a bracket as applying for the duration of the passage. The meaning of the marking should be mentioned in a legend or as a local footnote at the first occurrence. A chart of multiphonic positions can be provided to aid in executing node progressions. Memorising locations of partials without notation or an extra paper could prove too time-intense.

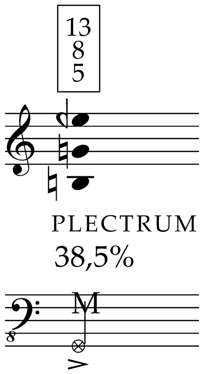
Flexible choice and notation of multiphonics allows room for constructional differences in individual instruments. Unless written for a specific instrument, substitutions of a multiphonic node with another like those seen in chapter 5.2.6 can be considered. Sometimes even the fundament string is physically inaccessible, so that in an explanation text it should be made clear what to aim for: either the precision of fundament pitch, timbral character, frequency range, or of dynamic contour. The objects held on the node are explained in text and then used with that marking in the score.

A summary of proposed multiphonic notation on the piano is shown below (Fig. 5.4-1), clarifying and seeking collisions of different notational elements that otherwise could be uninviting to solve.

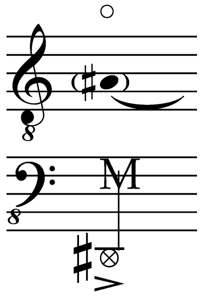
Multiphonic: string and plectrum only, no other specifications



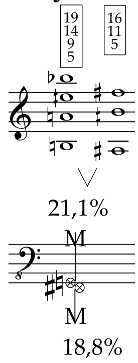
Multiphonic with sufficient specifications



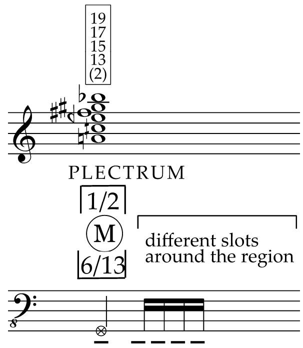
Flageolet



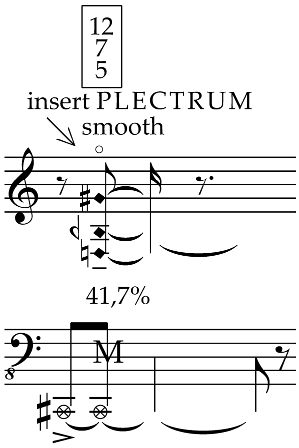
More than one string multiphonic simultaneously



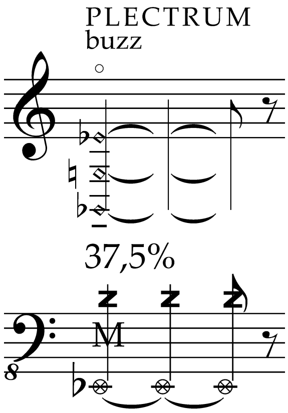
Multiphonic between two nodes



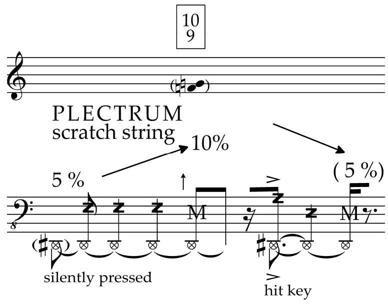
Attackless, smooth (plectrum or wedge)



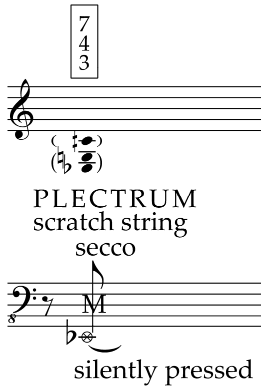
Buzz (rattle) multiphonic



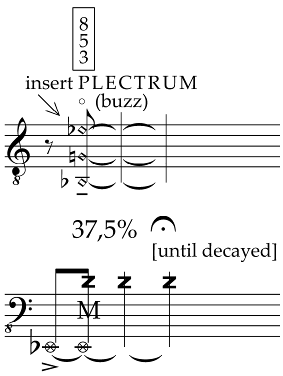
Scratch multiphonic



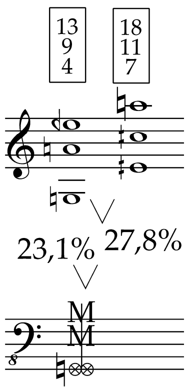
Scratch (single)



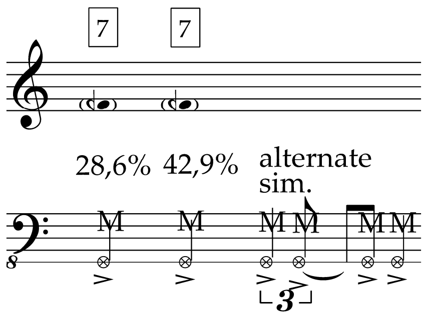
Attackless, buzz (rattle) multiphonic



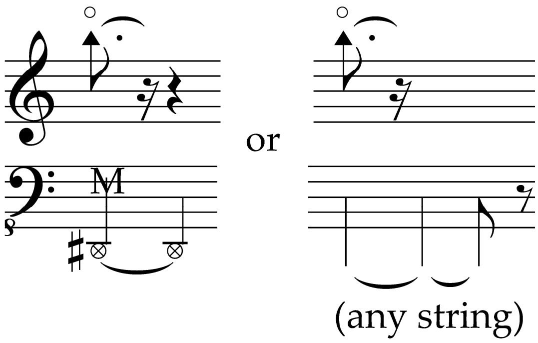
Double multiphonic (on dichord string)



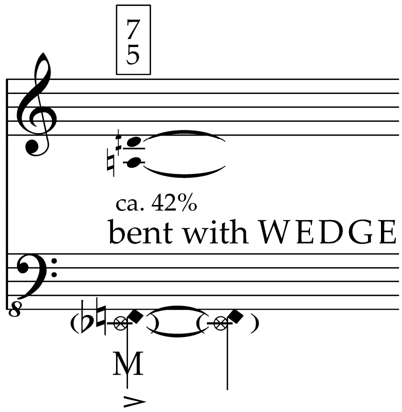
Synonymous nodes



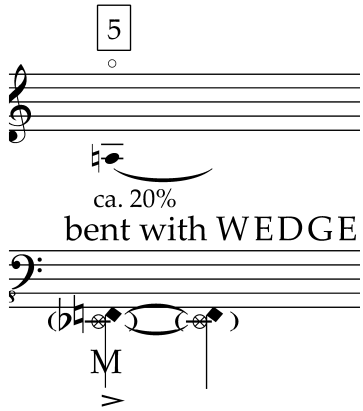
Flageolet, highest possible



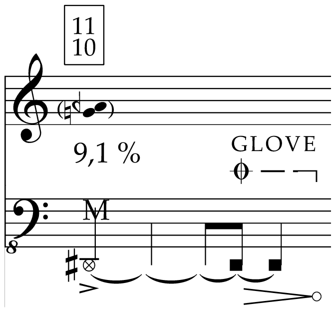
Artificial multiphonic



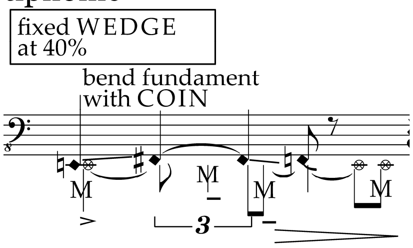
Artificial (flageolet) harmonic



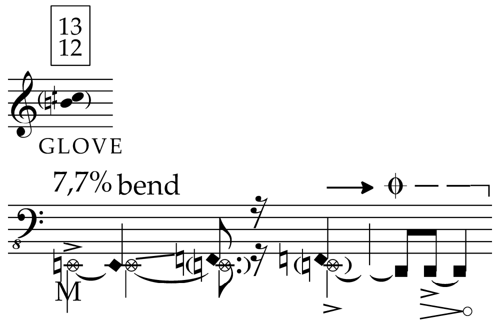
Damp (glove)



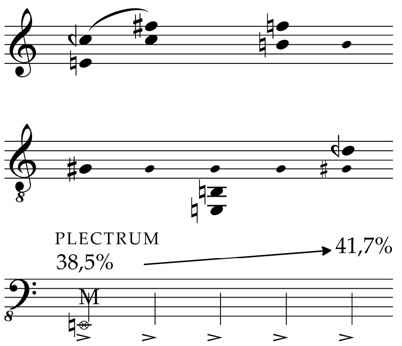
Bend-fundament multiphonic



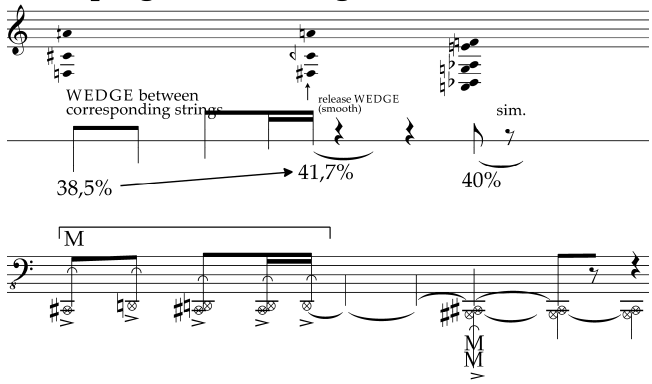
Multiphonic to bending to damping



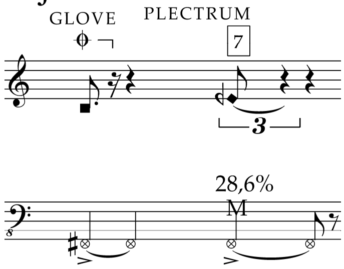
Node progression (plectrum)



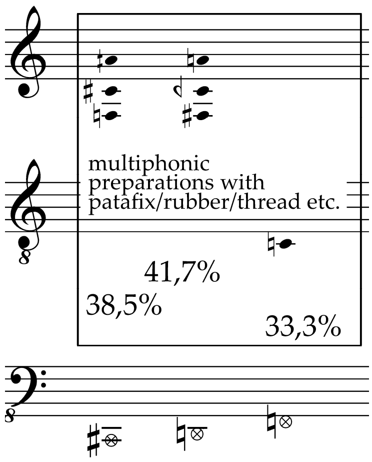
Node progression (wedge)



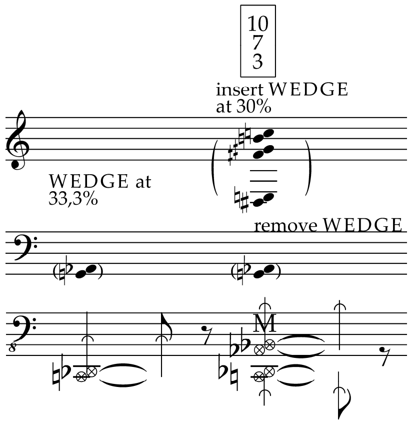
Releasing the node-object



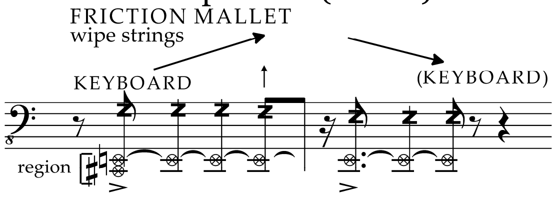
Multiphonic preparation



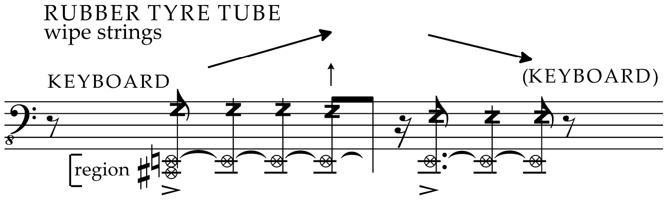
Wedges (fixed)



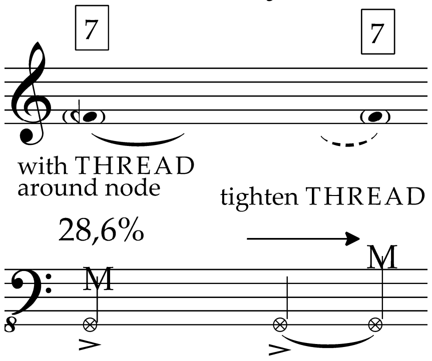
Friction multiphonics (mallet)



Friction multiphonics (rubber tyre tube)



Thread as node-object



Pretending to play

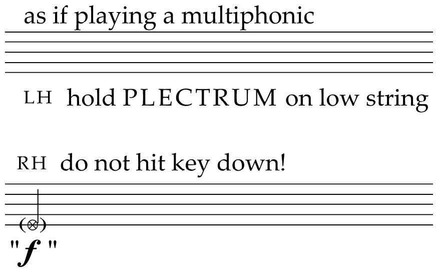


Fig. 5.4-1. Summary of notation. Note that the resulting pitches of multiphonic sounds need no brackets if that stave is never used for action notation. For muting, a + sign has been used in conventional notation where it cannot be mistaken for another marking.

6. Further Considerations and Conclusion

6.1. Developments

When I took up the task of investigating the multiphonics on the piano in January 2014, related interests in new music were much in the air.

I soon contacted Aalto University to find eager colleagues. Along the way as our measurements progressed I personally learned about results of similar scientific research being simultaneously published by other pianist composers (about C.J.Walter in August 2014 and whom I also met, about Oliver Thurley in March 2015, and about Marcílio Onofre and Bibiana Bragagnolo in July 2015). This has inevitably had its bearing on my ongoing research, which grew longer and became more and more specific as a result.

Many facets of the multiphonic sound, perception, mechanics, analysis, composition, repertoire, and notation still remain uncharted. Here I will elaborate on future directions.

Future **measurements of piano multiphonics** have to be made in more accurate conditions than done for this study, as noted in Chapter 3.1. Connected to the modes of playing, further investigation on the stopping materials has to be made, as different materials might help different partials evolve. The thin plectrum used in this study is not widely available and does not resemble a finger in a glove for example, which can be required by parts of the repertoire.

The E-Bow device, lately used in similar contexts with long strings such as on the harp (Einarsdóttir n.d.), cannot be used to facilitate playing the multiphonics on the piano. For an unknown reason, placing an E-Bow above the lowest strings does not produce a continuous vibration in the heavy and thick copper strings experimented with. It might be possible to overcome this limitation with the aid of processing and/or loudspeakers.

A **listening and perception test** should be made to verify the extent to which multiphonics can be differentiated by non-musicians and non-pianists and people who are not used to work involving listening to details such as mixing or editing audio. When harnessed for chamber music contexts, multiphonics can bring instruments audibly nearer to each other.

Recognition of multiphonics could have to do with their positioning relative to formant areas of human speech which, after all, constitute fixed and strongly memorised frequency regions. Perception of a multiphonic's character might be consolidated with its transposition and density distribution rather than with tonal functions of its component partials.

As to the **aesthetic reasons for composing with piano multiphonics**, statements by composers are scarce. Generally, piano multiphonics can be deemed to be one stream in a still ongoing process of refining the use of conventional instruments in current music. One could say that current music has taken a reflective stance to its own progress-oriented past, as well as to its place in present society. Also, standard Western instruments have been investigated to such a degree that new sounds become increasingly rare. In keeping with this halting moment of re-evaluation, composers now are sharing the same sound resources and are forced to find their own grammars in using these sounds. Perfomers' need for standardised notation is evident. One reason for the thorough investigation of instruments by composers has been the occasional lack of instrumental combinations. As Brian Ferneyhough formulates:

> "We don't write anymore for vast forces, we don't have those vast forces available. So we fall back upon sometimes quite strange combinations of instruments, which creates a new sensibility for acoustic transformation." (Ferneyhough 2015a.)

With careful planning on behalf of the composer, multiphonics can indeed be perceived differently from each other and become an auditive category of their own, disctinct from similar metallic noises.

The locations of piano multiphonics are not **intuitive** to grasp. As opposed to the scalar piano keyboard, multiphonics can prove difficult to someone used to keyboards or the overwhelming majority of instruments with scalar pitch production. Even though brass instrumentalists will be conversant with producing roughly the same amount of partials that are acoustically discernible in a piano sound, the compounds between partials will be unfamiliar to them. Via brass instruments' lip multiphonics, partials can only be merged in the order of the harmonic overtone series. Bowed string instrumentalists, on the other hand, will be most comfortable with grip tone notation, which in the context of the piano however is not the preferred means of notation. There could be a way of making this aspect of the instrument more accessible without considerable effort.

A last point for development considers the findings as opening possibilities for multiphonic **improvisatory elements** for and within a composition. Improvisation can develop after active listening and involvement with the sound substance, in this case immersing oneself with different categories of multiphonic onsets, objects, and the flageolet locations themselves.

Piano multiphonics lend themselves well to improvisation, either soloistically or in groups gathered around the uncovered instrument. As with notated music, exact flageolets are hard to achieve without any help from premeditated markings inside the instrument. In a typical improvisational setting where decay is hardly considered, one could have the sustain pedal fixed with a wedge in order to remain in a fully standing position and reach the strings with one hand and the keys with the other without stopping the sound. Or, one could use the prolonger pedal for the lowest strings only, to eliminate higher resonating strings. This results in rather ambient music with obscure fundaments, when several strings are sounding simultaneously. Some ways of notating multiphonics also convey this kind of freedom and uncertainty in timing or spectral content, among other properties. The thematic of improvisation and failure will haunt nearby, even in notated music with piano multiphonics. Improvisation is not as applicable to composition, however. Once the plectrum is released and complex sounds or the occasional beating phenomena result, there often is no intuitive way of knowing which flageolet caused the compound sound or deciphering the short-lived situation that was previously ringing. Even those pitches that can be identified are not easily retraced since the logic of node placements can be seen as rather discomforting.

After the initial excitement of locating multiphonic sounds, the improviser should pay special attention to observing volume levels, manner of damping, and frequency areas. The same placements and external objects are available as with notated music. With no note stand forming an obstacle, coordination of the hands becomes even easier. Many prospects can be seen in multiphonic improvisation and recordings of such sessions which are then crafted into influenced compositions – either electronic or transcribed in notation to be performed.

6.2. Conclusions

Regardless of the limitations of the rather composition-oriented study, it covered topics related to multiphonics. The topics were the existence and nature of the multiphonic sound, its notation, performability, and differentiation with flageolets. They will be revisited shortly.

The study has empirically proven the availability of multiphonics on the monochord copper strings of a grand piano. Many more multiphonics than typically used in the repertoire can now be seen to exist– and almost as many different modes of playing them have been identified. This information will support composers in creating original music based on practical knowledge of what is possible and personally interesting to them. The composer will be sufficiently familiar with multiphonics to instruct pianists who may or may not have previously worked with this mode of playing. Many more works could be composed for the instrument, using more complex multiphonics and more daring combinations of modes of playing, as the extent of limitations is now known.

To lay down the results of acoustic and visual measurements, a paper has been published as a by-product of this study and referred to. The findings can be replicated on any grand piano. General theoretical literature on the subject is scarce until late 2014 and lacking in many respects, as is the role of piano multiphonics in many of the compositions under scrutiny. Because of the lack of concrete statements in the literature, not many points of conflict have been encountered and differing views mostly result from differences in piano construction. The rather condensed findings of Walter (2014) and Onofre and Bragagnolo (2014), in particular, have been mostly replicated during the stages of the present study. A vast number of compositions with various solutions to the use of multiphonics have been examined, though by contrast, few of them assume multiphonics as an independent driving element. No listing of the repertoire has previously existed. Connections between different aesthetics or composers are hard to pinpoint.

With thorough knowledge of the locations of multiphonic nodes and issues with producing the sounds, pianists will become even more comfortable performing the repertoire and improvising on their instrument. Other musicians will view multiphonics as a valid musical substance that in many cases can be combined with sounds on their own instrument successfully.

A notation has been proposed for many of the common modes of multiphonic playing as notation has not been consistent in the repertoire and not covered by the literature. This notation can readily be adopted as a standard, bearing in mind that each score and compositional context call for slightly different choices of music notation.

The contexts of using multiphonics in the repertoire have been examined. The multiphonic timbres have been described verbally and documented with recordings, which will help to incorporate multiphonics in the wider context of compositions for large musical forces. This body of knowledge will hopefully remove some mental obstacles composers may have when composing for both multiphonics and simple flageolets.

The limitations of the study largely have to do with the accuracy of acoustic measurements made to prove the phenomenon. An indicator of the accuracy with which a composer or pianist operates, however, is the ear and perception, compared to which any measured and analysed results are secondary.

Five points for future research have been stated in chapter 6.1. above, namely: accuracy of the measurements, perception and listening, compositional aesthetics, intuition of learning the multiphonic locations, and improvisation.

Previous use of piano multiphonics has been limited, remaining at an experimental stage in many compositions. A vast field opens for composers as timbral experts and for pianists on their even more familiar instruments who now have a resource similar to a handbook, presenting most aspects of one of the rare almost unknown instrumental resources.

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Many grand pianos that are held in good shape in **Sibelius Academy** premises.
Providers and holders of physical library and electronic web sources.
The weather and working conditions in Helsinki where this study mostly took shape.

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Composers' biographical information, with the exception of Erik Oña in Michaels (2011), has been retrieved from their authorised webpages during the year 2015.

Musical score sources

All photos, notational figures and pictures have been made by the author, except for the scores attributed to publishers below.

B.Furrer: Bärenreiter, referenced by kind permission.

C.J.Walter: Thürmchen Verlag, referenced by kind permission.

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Appendices

Appendix 1. Further Playing Terminology

The distinction is made between the terms partial, harmonic, and overtone. Especially the two first ones differ in that harmonics always are exactly whole-number multiples of the fundament frequency and partials describe frequency bands in the sounding result which may or may not be spectrally warped multiples of the fundament.

"The terms *partial*, *harmonic*, and *overtone* can refer to three different but overlapping phenomena. Indeed, partials on the guitar need not be whole-number multiples of a fundamental frequency, as is the case with many percussion instruments such as cymbals and gongs. All higher partials that exclude the fundamental are called overtones. When the partials do refer to whole-number multiples of a fundamental frequency, then they are called harmonics. The fundamental is the 1st harmonic." (Josel & Tsao 2014, p.98)

The modes of manipulated playing on the keys and pedals are discussed further below. The following figure shows the most important modes of manipulated playing the inner parts of the piano effectively.

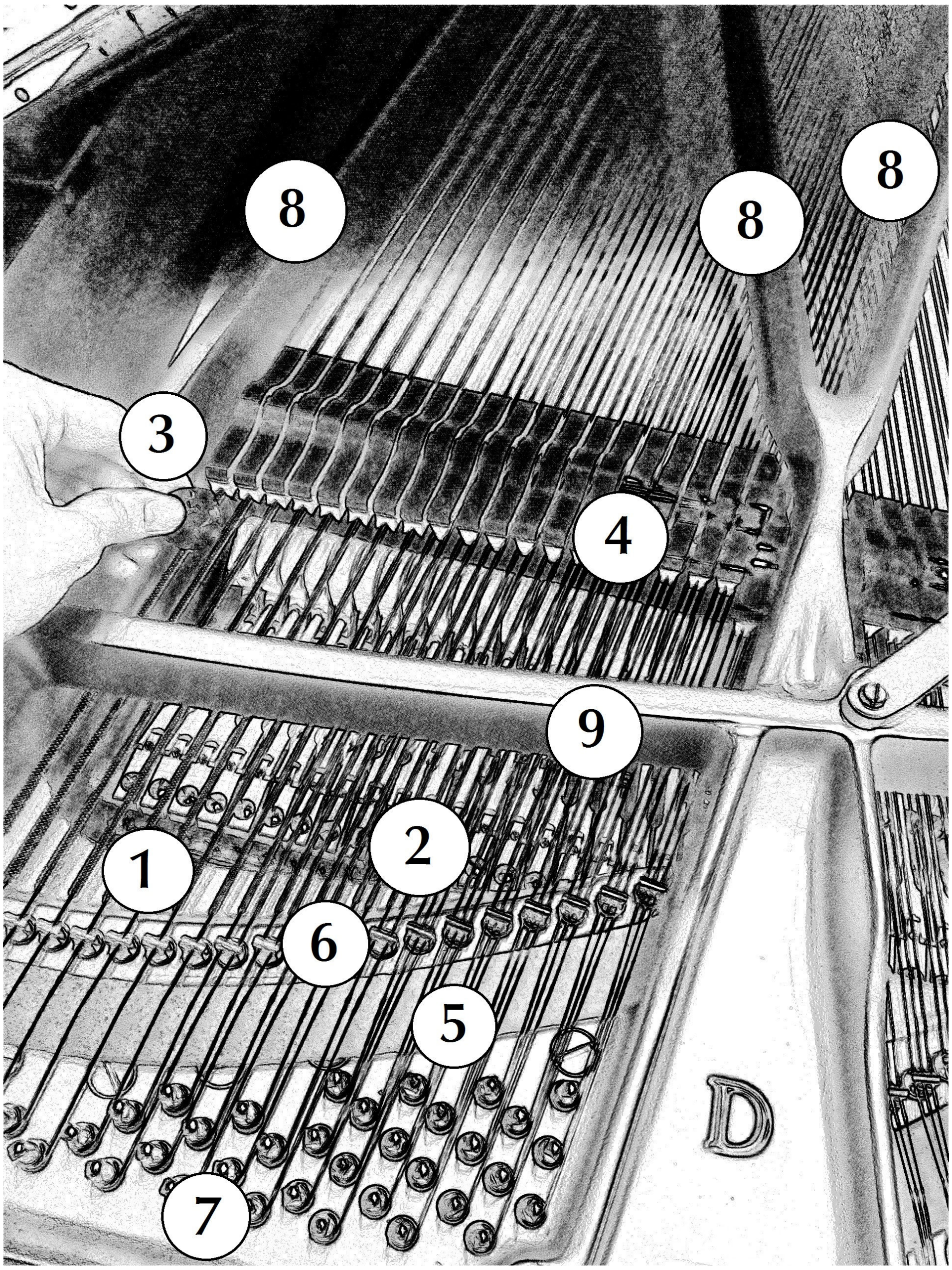

Fig. App.1-1. Markings explained: 1 monochord copper strings (on this Steinway D, ranging from A to E); 2 dichord and trichord copper strings; 3 plectrum held in hand; 4 dampers & hammers; 5 short remaining parts of a string; 6 agraffes; 7 tuning pins; 8 lengthwise metal bars; 9 crosswise metal bar, not present on all grand pianos.

The string terminology used in this study defines the word **slot** as indicating the recurring construction on the winding, and **valley** indicating the part of a slot that locally has the thinnest amount of winding, thus being more flat and not on the slope. A **monochord string** is an only string that is coupled to a given key. These couplings of key and string are situated in the lowest end of the piano. Higher keys on the piano have two or three strings connected to them.

Exciter means any object that sets the string to vibration. Conventionally this is achieved by the piano's own hammer mechanism.

The stopping object or **node-object** means the object that contacts the node on the string. The stopping object has the implication that the stopping is heavy and the stopping point on the string functions as an acoustic bridge, thus disconnecting two parts of the string. A node-object does not have to press the string as heavily and can imply transverse playing for instance. A specific timbral progression is achieved when the node-object moves in either direction along the string and several nearby slots are being played one after another. This is generally called **node progression** though especially if some slots can be skipped, **spectral scanning** [59] if no slots in the region are skipped, or, in a case of more rapid changes and skipping several slots, **node wiping** T26, T27. These should not be confused with a **node glissando** T28, T29, T30, T31, the retaining of a node distance while the string changes.

Striking length is the part and length of the string that is not stiffly fixed under the agraffes in the two ends of the string. It is often referred to in a reductionist manner as the **string length**.

Each monochord and dichord string additionally consists of a copper winding which can be divided into peaks and slots. The plectrum will slip from a peak to one of the two neighbouring slots quite easily so the slot becomes the primary location for all small-scale activity on the copper strings.

Particular kinds of rubber such as **a bike inner tyre** can be used to produce harmonic sounds as well when rubbing it on the upper non-copper strings in a wiping movement (Fig. App.1-2 a). This mode of playing could aptly be called friction harmonics. To some effect, the method produces sound on the longest of the copper strings as well. When the tube is **wrapped around a pencil** the sound can acquire more definition T32, otherwise there tends to be more low-frequency rubbing noise involved. In the case of the copper strings, the sounding result is not too far from the sounds of a **superball**[60] or any other type of **friction mallet** can produce on those strings. Also, external friction from a double bass bow has been found effective when **plastic wineglasses** are attached with scotch tape to catch resonance from the copper strings, or **plastic tupperware boxes** on steel strings played in a mobile manner. [61]

The piercing sounds of friction harmonics are inharmonic and again, only one series of frequencies is heard - a frequency between the 13th to 15th harmonic of the string forms the lowest discernible and most dominant pitch. Acoustic response seems to be best around nodes of these numbers and especially around 1/7 and 2/7. Differing from the multiphonics which build on the entire string length, this series of friction harmonics frequencies follows the harmonic series of a fundamental established by the rubbing movement.

The physioacoustic basis of the friction harmonic sound has, it would seem, not yet been researched.

The advantage for the player is that pieces of rubber are not expensive, rare, big, nor heavy. The same piece of rubber can be used to press at a node and to damp a string at its agraffe, also not with peril to the instrument.

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[59] The latter term is used in Robert (1995). Proulx (2009, 66) uses “longitudinal glissando”.

[60] Alcides Lanza is referred as an early composer using a superball mallet in Plectros III (1971, although the superball idea developed as early as in 1965) to produce friction multiphonics on the piano strings and other structures (Jones 2007, 131).

[61] By Santiago Diez-Fischer in *one poetic switch* (2014) for piano. Plastic boxes with thin edges constitute two node-points on each string pressed against. The sound resembles an artificial flageolet “seagull” glissando.

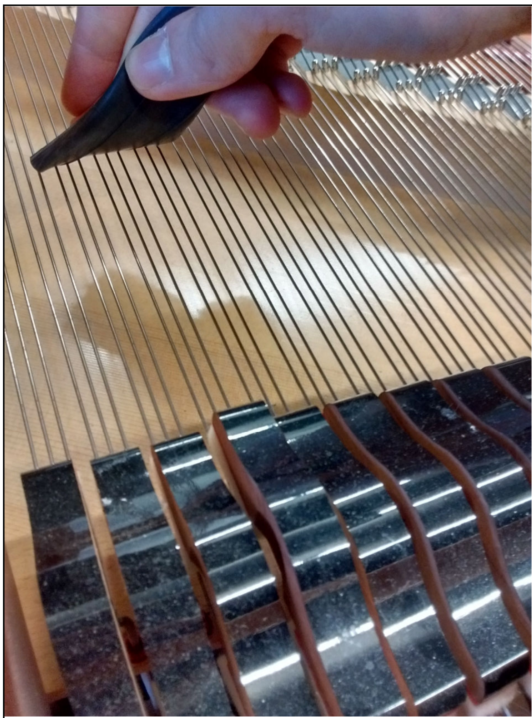


Fig. App.1-2 a. Friction multiphonics by wiping treble strings with a piece of bike inner tyre. T33, T34.

Fig. App.1-2 b. Tuning wedges as preparations covering several multiphonic nodes each.

The dampers cannot be played under any conditions. Moreover, one should take care that the dampers are raised so as to not receive any damage. A further location on the soundboard, the resonance holes might be used for playing though the shape of the hole does not make the sound more distinctive than a contact on any other flat surface of the soundboard.

In composition, the placements should be referred to in the most self-explanatory manner. Thus the placement 5 could be written in a unique font and called Short strings. Their frequency range is rather narrow since they share the same material and have almost uniform string lengths between a pin and an agraffe.

Any external mobile objects that have to be taken by the hand could be written in capital letters to distinguish them from more local instructions, thus PLECTRUM, COIN FIELD (when the surface should be even, for bending glissandi), COIN EDGE or COIN RILING (when the surface should vary periodically to form a granular sound), RULER, GLASS, RUBBER TYRE, THREAD, CAPO, GLOVE, SPOON, CARD (for a stiff credit card for example), WIRE (for friction noise with a thin metal wire on the bass strings).

The grand piano can be **prepared** with external objects inserted either inside the frames or on the surface of the instrument. However, the manner historically associated with the word preparation is that of inside the frames and on the strings.

While some type of physical contact remains in order to play the instrument, steady preparation alters the sound and sometimes even the feel of playing.

Theoretically, piano playing can be divided into conventional and manipulated playing, with some shared areas in between. Interacting with a prepared instrument always belongs to manipulated playing.

The Conventionally Played Grand Piano (CPGP)

Fingers press keys and this is the realm of a pianist's technique rather than modes of playing. All conventional playing is nonattached playing, without external objects used or attached. This includes body-operated piano keys with force enough to use hammer mechanism as well body-operated piano pedals, neither of which is considered a manipulation.

The Manipulated Grand Piano (MGP)

Some of the following combinations are rather hypothetical or can serve a transitory role when the pianist has to move objects from one hand to another while playing.

A. Mobile mode of playing (MMP), external objects possible

*** no steady-objects are attached for modifying or operating**
A1. held-object-operated piano keys (with enough force to use hammer mechanism)
A2. body-operated piano strings
A3. body-operated body-modified piano keys without using hammer mechanism
A4. held-object-operated body-modified piano keys without using hammer mechanism
A5. held-object-operated piano strings
A6. body-operated piano surface or inner parts other than the strings
A7. held-object-operated piano surface or inner parts other than the strings
A8. body-operated piano keys connected with hammer mechanism to body-modified strings*, such as multiphonics with a plectrum*
A9. held-object-operated piano keys connected with hammer mechanism to body-modified strings
A10. held-object-operated body-modified piano strings
A11. held-object-operated body-modified piano inner parts other than the strings
a. influencing resonance of other piano parts
b. not influencing resonance of other piano parts

B. Attached, steady, fixed, or prepared objects playing (AOP)
*** body, held-objects, and steady-objects are available for modifying and operating**
B1. held-object-operated piano pedals *considered a manipulation if it results in a different sound than with feet.*
B2. steady-object-modified piano strings, piano is being (body/object-)operated somewhere else
B3. steady-object-modified piano inner parts other than the strings, piano is being (body/object-)operated somewhere else
a. influencing resonance of other piano parts
b. not influencing resonance of other piano parts
B4. body-operated steady-object-modified piano strings,
B5. body-operated steady-object-modified piano inner parts other than the strings,
B6. held-object-operated steady-object-modified piano strings,
B7. held-object-operated steady-object-modified piano inner parts other than the strings,
B8. body-operated piano keys connected with hammer mechanism to steady-object-modified strings

B9. held-object-operated piano keys connected with hammer mechanism to steady-object-modified strings
B10. instrument operated directly at the steady-object without displacing it (by a bodily gesture or impulse)

For the subcategory AOP of MGP, the types of objects would then have to be examined in detail.

The types of preparation that can produce multiphonic sounds under certain conditions are, all of them inserted on the strings:

a) small pieces of wood when fixed
b) pieces of glass when fixed
c) pieces of plastic when fixed (credit cards, rulers)
d) metallic or plastic screws, clips, and nails[62]
e) coins
f) styrofoam
g) metal chains (the size of each ring makes a difference to decay times and spectral content, which can resemble a multiphonic)
h) skotch tape (the glue will however be detrimental to the copper in the strings)
i) thread
j) rubber wedges (typically used for tuning)

The acoustic mechanism of different screws, for example, is not quite known and would require further investigation. For the purposes of multiphonics consisting of harmonic partials, we will concentrate on the two last ones on the list.

The preparation has to be accurate in both cases. One could prepare a node with a tightly woven thread, with the limitation that the string can only be used for that multiphonic and it will decay rapidly as the node point is not released. If the thread is only loosely attached, it can be moved a few slots a time. When preparing a rubber wedge it will hit either a fixed area on the frame of the instrument or another string. The wedge can rest on the soundboard and has no audible impact on resonance. The wedge should be narrow enough to not block many nodes on a string. Again, steady preparation considerably limits the possibilities of a string.

Whenever the grand piano has been permanently or firmly modified, any playing on it should be considered manipulated playing. This kind of modifications go beyond preparations in that removing the objects or reinstalling standard piano parts is no more practical within the context and time of a concert break, though the materials of preparation can be the same.

There have been many **initiatives** that have found a new approach to the piano. Some of these approaches have developed an entirely new instrument, much more than those initiatives proposed in chapter 4.5. An instrument can be seen as **independent from the piano** when it does not rely on the clavichord features, namely the standard soundboard, untampered strings that are supported identically with a piano, the hammers, or the conventional keyboard. Use of most modified instruments has however remained marginal, as the initiators often are engineers or visual artists with little ambition in gathering a repertoire. Even a conventional instrument, when remade with modifications, may not

[62] Most notoriously investigated by John Cage and by G.Aperghis in *Simata*.

meet the demands of a greater community beyond the project for which the initial instrument was designed and for which music was composed (McPherson & Kim 2012, 1). Using electronic sound, lights, or sensors does not constitute a new instrument if the clavichord features are also used as such.

Among these instrument initiatives are, from the least to the most permanent, “The Bowed Piano Ensemble” using a number of threads founded by Stephen Scott, the position called “sound icon” where the grand piano rests on its side with the lid removed (in this definition no preparational objects are necessary), Rio Mäuerle‘s “Raumklavier” with buzzing metallic resonators installed connected to and above the strings with threads, the “Magnetic Resonator Piano” and “TouchKeys” – both by Andrew McPherson, as well as the “Fluid Piano ™” by Geoff Smith. It should be noted that Henry Cowell’s “string piano” is not an instrument but a concept of using only the inside parts of the piano. [63] Theoretical possibilities of electronically enhanced pianos are presented in Britt (2014).

A common reason to develop the piano seems to be making certain sounds more ergonomic, expressive or accessible by a single performer while retaining tactile feedback to the pianist (McPherson 2012, 1). Such would be the case of a multiphonics-piano which is discussed in chapter 4.5.

[63] The *timbre piano* developed by Lucia Dlugoszewski in 1951 is another early incentive outside the present scope but presented in Lewis (2011).

Appendix 2. Timbral Complements to Piano Multiphonics

Besides ordinario playing, there are both harmonic sounds, tempered chromatic sounds, nontempered sounds, and inharmonic sounds available on the piano to complement or contrast the multiphonics. Examples of these include

a) the component harmonics as tempered pitches or octave flageolets on other strings
b) the component harmonics on other strings as before, hit by a mallet
c) double multiphonic on a dichord copper string, i.e. where two multiphonics sound when playing one key because a different node point is pressed in each. [64]
d) ordinario key followed by sudden pressing of node
e) Pedal accent using the available chromatic tempered pitches (possible marking APed)
f) selected resonance pitches by the prolonger pedal
g) selected resonance pitches by silently pressing (nearby) keys
h) hitting bars
i) short strings
j) bending with coin to produce exactly same untempered component harmonics
k) steel strings prepared with screws, nails, wood, scotch tape for a damped complex sound that not necessarily has shared pitch components
l) damped strings with pitch components that obstruct or correspond to those of the multiphonic
m) bowing with bow hair or thread at a partial (as in Curtis Curtis-Smith: *Rhapsodies*)
n) single scrapes on a winding
o) fast scraping on a winding

Some spectra can also be imitated by swift movement, such as arpeggiations of many pitches, a psychoacoustics topic which unfortunately lies outside the scope of this study.

To imitate the **microtonal** property of multiphonics, the piano itself has microtonal resources that can be matched with other instruments. Individual microtones can be found as partials in all categories of multiphonics, in the short non-tempered parts of strings, bending the string by shortening the sounding length (with the edge of a coin, a wedge, or similar substance), artificial (or bent fundament) multiphonics, simple flageolets, and as partials in a multiphonic.

When combining piano multiphonics with pitches on other instruments, it is advisable to use a precise notation for microtonal pitches. The twelfth-tone equal temperament based on the octave (or 72-TET) is especially accurate and useful in chamber music contexts with instruments that have flexible tuning. Each step is roughly 16.7 cents, six steps making a full semitone. Several notations have been proposed by different composers, some of them using as-

[64] Vaes (2009, 983) also uses the term "double-note flageolet" but doesn't tell whether one flageolet position on two different-fundament strings is meant, or a multiphonic on a dichord pair. The term double multiphonic has to be further distinguished from simultaneous multiphonics, which use different fundaments but may result in a similar sound complex – the way double flageolets are defined on bowed string instruments by Maurer (2014, 27) is playing flageolets on two neighbouring strings simultaneously. Maurer's ambivalent term is suited to the bowed strings; on the piano, double flageolets are executed on the two strings of one dichord key, which has practical acoustic considerations. One should however refrain from assigning such specialised terms to each amount of simultaneously sounding multiphonics or even flageolets. For example, a "triple multiphonic" on the piano would hardly merit for the term, even if available. On the piano, simultaneous multiphonics on various strings are commonplace, and reaching the nodes with fingers of one hand is hardly a concern because extreme simultaneous locations can be easily substituted or overcome with preparations without changing the excitation.

signed specific accidentals to mark the nature of any given non-tempered partial. The following suggestion approximates partials of 12-TET fundaments in a standard 72-TET way without introducing tens of new accidentals. [65] It has been derived from the usage in the scores of Georg Friedrich Haas where many transitions and spectral re-interpretations between partials arise.

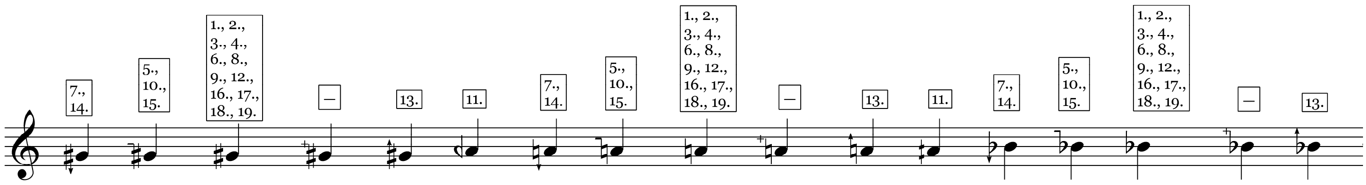


Fig. App. 2-1. The 72-TET pitches (twelfth-tones) and the use of accidentals to approximate microtonal partials of tempered fundaments.

To imitate the **noisy pedal element** of multiphonics, different modes of pedalling such as pedal accents and post-pedalling can be used firstly as chromatic cluster methods. Similar sounds when the pedal is pressed can be found in glissandi on strings, knocking or hitting a metal bar or other resonant parts, or preparing the strings in a manner that changes timbre but not the discernibility of pitch (such as a metal chain). Also timbral or pitch alternation can be achieved by *una corda* playing on keys when the left-out string has been noisily prepared and the other string not. These sounds are inherently chromatic and tempered.

Alternatively, the noisy pedal aspect can be simulated by non-tempered sounds. This can include sounds on the keyboard lid with no objects required, or mobile methods using an object – for example playing the tuning pins with a comb, spoon, plastic card, etc.; the agraffes with a spoon, the edge of keys with a plastic card, spoon, scratch and friction (i.e. transverse) multiphonics and buzz multiphonics, with a plectrum on string, the resonance holes with a coin, or resonating an external sound source such as chimes or a loudspeaker on the soundboard.

Thus, non-diatonic-tempered **noise methods** can have placements including but not limited to the keyboard lid and they can make use of mobile methods, using an object:

> the tuning pins with a comb, spoon, plastic card, etc.
> the aggraffes with a spoon, etc.
> the edge of keys with a plastic card, spoon, etc.
> scratch and friction (i.e. transverse) multiphonics and buzz multiphonics.
> a plectrum on string
> the resonance holes with a coin, etc.
> resonating an external sound source

[65] A composer would do best in avoiding combinations of notational systems where accidentals' meanings interfere. The limitations of microtonal accidentals and a simultaneous combination of quartertones, sixth-tones, eighth-tones and twelfth-tones are also discussed in Maurer (2014, 36-37).

Appendix 3. Catalogue of Piano Multiphonics

The simplest of multiphonic flageolets are available on most grand pianos and thus the catalogue below represents a small selection compared to the most reliable instrument models, which could reach higher partials than the 19th. There are 60 multiphonics listed that exist on each string from A to F#, totalling 600 different multiphonics. For reasons of space and ease of transposition, here the chart represents 60 different multiphonics for only one fundament has been reproduced, and it is for a hypothetical fundament G1, ca. 49 Hz, near to the monochord strings. This pitch is not a monochord on the piano yet serves as the most convenient point for transposing the multiphonic pitch content on the piano and further on to open strings of bowed string instruments. The same chart can and should be transposed for any fundament string in use, and the percentages for node positions given are universal.

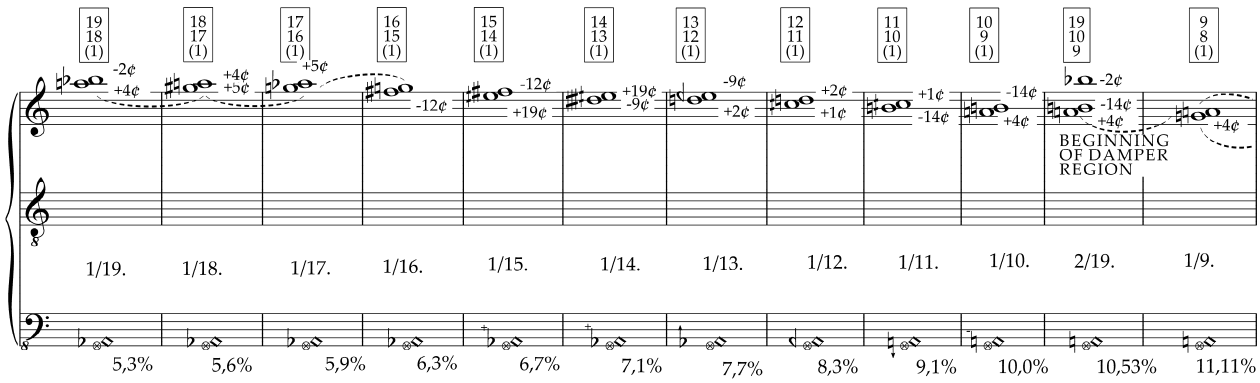
The gripping distance has also been marked using the node nearest to the performer, and for reachable nodes, on the mirroring side as well. These grips have been calculated and remain far removed from practicality as the strings are so stiff that bending, or strongly gripping, is not an option. This flageolet notation, however, is the one most familiar to bowed string players who get to memorise most the distances on a string by heart. Gripping distance pitches, although strongly discouraged in final notation, are shown here in 72-TET approximation whereas cent amounts are given for partials.

The notation used in the catalogue follows the one proposed at the end of chapter 5.4.

The microtones marked in cents are the theoretical deviations from the tempered system as calculated from the harmonic series. A small-number partial will be present in several successive multiphonics. It will be loudest at the middle of a succession. Big-number partials are not available on small grand pianos, are more local and weak in sound level but not always in perception. There highest available partial depends on the instrument.

The 19th partial is the highest component taken into account. Taking the 20th partial into account would increase the collection by several new multiphonics and a limit has to be set also based on audibility. The highest available pitch in this accuracy, the 19th partial on a F#$_1$ string would sound at around 879 Hz (a^2 -2 ¢). In multiphonic constellations of the upper three pitches, the lowest available pitch will be the second partial on an A_2 string, A1, at around 55 Hz. Each individual flageolet has not deserved its own box as from around the 5th partial onwards individual partials cannot be produced without also invoking nearby partials. Thus, each uppermost pitch in a multiphonic has to be understood as the first and main occurrence of that partial in that region.

Notice the octave-transposing clefs.




END OF DAMPER REGION
2/17. 1/8. 1/15. 1/7. 2/13. 3/19. 1/6. 3/17.
11,8% 12,5% 13,3% 14,3% 15,4% 15,8% 16,7% 17,7%
2/11. 3/16. 1/5. 4/19. 3/14. 2/9.
18,2% 18,8% 20,0% 21,1% 21,4% 22,2%
mirroring grips: (75,0%) (73,7%) (73,4%) (72,7%) (72,2%)
3/13. 4/17. 1/4. 5/19. 4/15. 3/11. 5/18.
23,1% 23,5% 25,0% 26,3% 26,6% 27,3% 27,8%
(71,4% etc.)
2/7. 5/17. 3/10. 6/13. 7/16. 6/19. 1/3. 6/17.
28,6% 29,4% 30,0% 30,8% 31,3% 31,6% 33,3% 35,3%

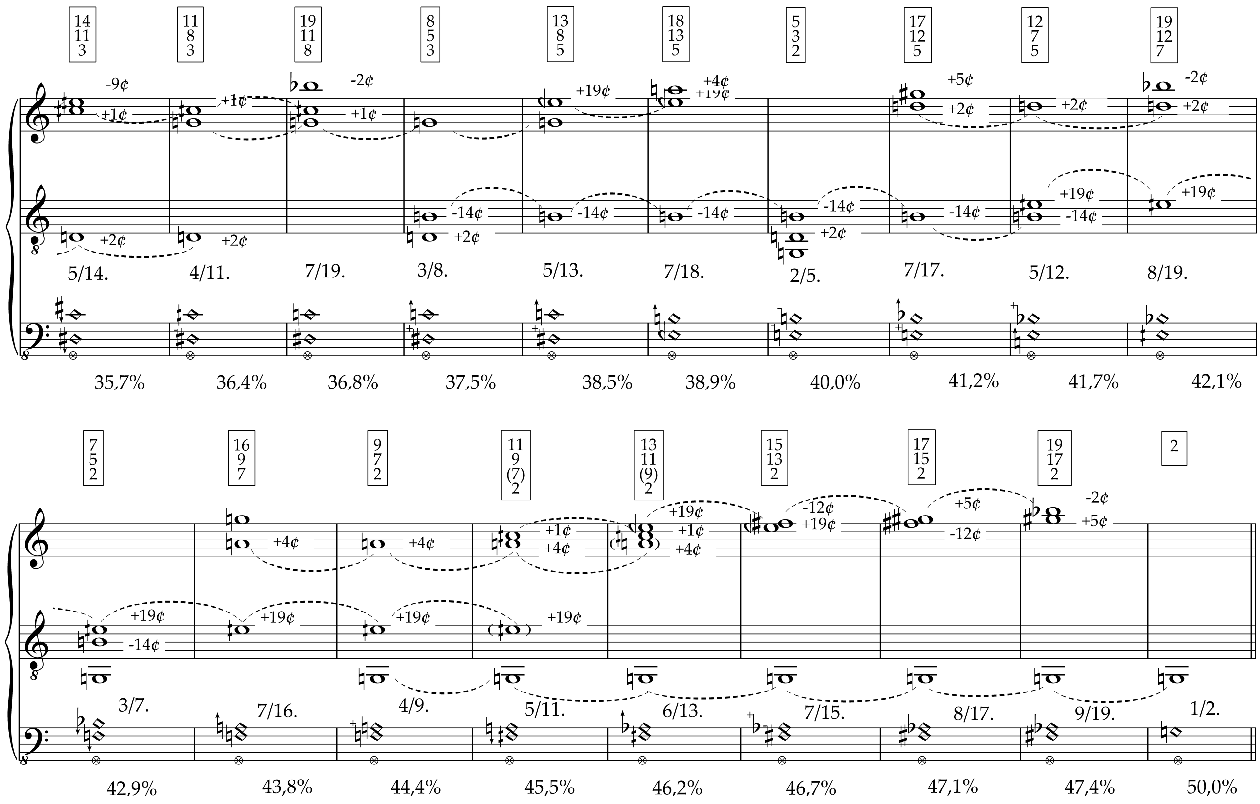


Fig. App.3-1. Catalogue of piano multiphonics on the dichord G1.

This catalogue could also be sorted in terms of node position, difficulty, or highest pitch. Difficulty levels have not been marked as they can be deduced from the highest partial and distances to the next independent multiphonics.

For practicality of playing, the chart shows the multiphonics sorted by node position, i.e. the distance from the pianist. As a result, any multiphonics timbrally similar to each other will be distributed widely apart. For compositional use, comparison of multiphonics on all the available strings ought to be helpful. To not overcrowd the presentation, similarities in pitch content (especially useful for pitch-concerned composition) have not been specifically pointed out, though exact similarities can be found by locating the “synonymous” multiphonics (having the same uppermost partial) on the same string, or for identical or almost same pitches within multiphonics on different strings, which makes ground for notable creativity. A chart with all the 600 possible monochord string transpositions of multiphonics has not been provided and the composer will in many cases do well by first comparing microtonal differences between the overtone series of different strings and only then locating the multiphonics that include those partials, in their respective “synonymous” nodes.

Appendix 4. Chronological List of Repertoire

The following list indicates the scope of the repertoire and is by no means exhaustive. I have come across these works in concerts, by hearing recordings, or sometimes only having seen the notation.
Compositions without copper-strings, i.e. using "simple" non-simultaneous flageolets or any objects on the steel strings are much more numerous and have been accordingly excluded from this list, such as the work *4* by Jean-Luc Hervé (2012?). Likewise, works for prepared piano where multiphonic-like sounds are achieved on prepared middle register non-copper strings, such as *Simata* (1969) by Georges Aperghis are also not included. Attackless and friction multiphonics have been accepted to the list.
Years of composition were retrieved from the composers' websites, Soundcloud sites, or performing organisations' announcements of premieres in the internet.

Chronological List of Compositions Featuring Piano Multiphonics

A. Mobile multiphonics or simultaneous flageolet constellations. On piano(s) only.

Henry COWELL: *Sinister Resonance* (ca. 1930)
Christian WOLFF: *Duet I* (1962) for one piano, 4 hands
Earle BROWN: *Corroboree* (1963-64)
Heinz HOLLIGER: *Elis. Drei Nachtstücke für Klavier* (1961/1966)
Donald MARTIN: *Pianississimo* (1970)
Curtis CURTIS-SMITH: *Rhapsodies* (1973) features friction multiphonics played with bow thread, also called the bow piano.
Erik OÑA: *Jodeln* (1996) for one piano, 4 hands. No multiphonics but simple flageolets in combinations. The second pianist observes the strings in reversed position. The earliest sheet music evidence acquired during the research that shows resulting partials being notated.
Helmut LACHENMANN: *Serynade* (1998).
Erik OÑA: *Andere Stimmen* (2003/2004) for a piano, 6 hands. Multiphonics are a sounding residue of violent wiping on the string.
Wolfgang VON SCHWEINITZ: *" 64 : 57 : 51 : 48 " / Waltz for Walter*, Op. 51 (2009)
Caspar Johannes WALTER: *versunkene Form* (2009)
Mark ANDRE: *S1* (2012) for two pianos. See discussion in chapter 4.3.
Oliver THURLEY: *Network for pianos* (2014)
Richard VALITUTTO: *as above, so below* (2014)
Juhani T. VESIKKALA: *Readings. Kawara* (2014) for piano and electronics ad libitum
Wolfgang VON SCHWEINITZ: *Plainsound Lullaby*, Op. 59 (2014)

B. Mobile multiphonics or simultaneous flageolet constellations. On the piano, alongside other instruments or live electronic processing.

Alcides LANZA: *Plectros II* (1966) pf., fixed sound media

Roman HAUBENSTOCK-RAMATI: *Pour Piano* (1973) for piano and live electronics. Scratch multiphonics only, no multiphonics with attack.

Brian FERNEYHOUGH: *Transit* (1972-1975) for orchestra. In the *Verse I* movement, multiphonics occur in a piano solo accompanied by vibraphone and flute among others. It is the composer's only composition using this mode of playing, according to Ferneyhough (2015b).

Elliott SCHWARTZ: Souvenir (1974 ?) for cl., pf.

Mesias MAIGUASCHCA: *Agualarga* (1978) for 2 pianos, vibraphone and electronics

George CRUMB: *A Haunted Landscape* (1984) for horn and orchestra (with amplified piano)

Beat FURRER: *Retour an Dich* (1986) for vl., vc., pf.

Beat FURRER: *Gaspra* (1989) for ensemble. Fundaments but no exact partials marked.

Beat FURRER: *Nuun* (1996) for two pianos and orchestra

Beat FURRER: *Presto* (1997) for fl., pf.

Beat FURRER: *Spur* (1998) for string quartet and piano

Misato MOCHIZUKI - *Intermezzi I* (1998) for fl., pf. One bass string is hit on a node directly several times.

Erik OÑA: *Alles Nahe werde fern* (2001) for fl., cl., perc., pf., vl., vla., vc., cb.

Marco STROPPA: *Ossia - Seven strophes for a Literary Drone* (2005) for violin, cello and piano. It is the composer's only composition using this mode of playing, according to Stroppa (2015). The composer also notes that the use of such fragile sounds has proved itself utopistic.

Beat FURRER: *Canti notturni* (2006) for orchestra and two sopranos

Beat FURRER: *Phaos* (2006) for orchestra

Amy WILLIAMS: *First Lines* (2006) for fl., pf.

Michael BEIL: *Doppel* (2009) for two pianos, video, and electronics.

Elliott SCHWARTZ: *Facebook Chronicles* (2009) for sopr., guit., tpt., trb., 2 perc., pf.

Beat FURRER: *Wüstenbuch* (2010). See discussion in chapter 4.2.1.

Clemens GADENSTÄTTER: *Bildstudie: Ruttmann op. 3* (2010). Multiphonics repeated within a shifting node progression, i.e. flageolet "glissando".

Lauren Sarah HAYES: *kontroll* (2010) for prepared piano, electronics, and self-playing snare

Marcílio ONOFRE: *Inane II* (2010) for fl., cl., vl., vc., pf.

Marina KHORKOVA: *VORderGRENZE* (2010/2011) for cl., vc., pf.

Marina KHORKOVA: *DUO* (2011) for bass-baritone and multiphonics-piano

Marcílio ONOFRE: *Ekphrasis I* (2011)

Marcílio ONOFRE: *Estudo sobre os arrependimentos de Velázquez* (2011)

Caspar Johannes WALTER: *3 Studien für Klarinette, Cello und Klavier* (2011)

Yair KLARTAG: *No symbols where none intended* (2012) for lupophon , bcl., contraforte, vl., vc., pf.

Wen-Cheh LEE: *Spieluhr* (2012) for ensemble

Santiago DIEZ-FISCHER: *como solo podían sus ojos* (2013) for pf., fl., sax.

Beat FURRER: *linea dell' orizzonte* (2013) for ensemble

Diana SOH: *Arboretum: of myths and trees* (2013) for ensemble

Simone MOVIO: *Incanto VI* (2013-2014)

Juhani T. VESIKKALA: *boxes, open/close* (2013-2014) for afl., pf.

Mark ANDRE: *riss* (2014) for ensemble. Multiphonics repeated within a node progression.
Eugene BIRMAN: *Addío* (2014) for fl., ob., cl., vl., vc., pf.
Yair KLARTAG: *A Villa in the Jungle* (2014) for fl., bcl., vl., vc., pf.
Marcílio ONOFRE: *Caminho Anacoluto* (2014) for vc., pf.
Marcílio ONOFRE: *Motor Ignoto* (2014) for vla., sax., guit., pf.
Halldór SMÁRASON: *_a_at_na* (2014)
Caspar Johannes WALTER: *Split Tones 3* (2014) for vc., pf.
Davide GAGLIARDI: *...Principio* (2015) for fl., sax., pf., piano strings and live electronics
Clara IANNOTTA: *The people here go mad. They blame the wind* (2013-2014) for bcl., vc., 12 music-boxes, pf. (multiphonics not verified, as given by Iannotta 2015)
Marcílio ONOFRE: *Eiras* (2015)
Diana SOH: *Incantare: take 2* (2015) for ensemble

C. Multiphonics or simultaneous flageolet constellations. As fixed preparations (solo or more).

Caspar Johannes WALTER: *durchscheinende Etüde VIII/d* (1991) for ob. solo, fl., cl., perc., pf., vn., vla., vc., db.
Clara IANNOTTA: *Il colore dell'ombra* (2010) for piano trio
Anastasija KADIŠA: *Ben articolato* (2010) for vl.,vc., pf.
Marina KHORKOVA: *falsche Spiegelungen* (2012) for two prepared pianos
Clara IANNOTTA: *Àphones* (2013) for 17 instruments
Clara IANNOTTA: *Clangs* (2013) for cello and amplified ensemble
Clara IANNOTTA: *D'après* (2013) for fl., clar., perc., pf., vl., vla., vc.

D. Recorded multiphonics of the piano, as a sound substance in fixed-electronic-media.

Wolfgang MITTERER: *konzert für klavier und orchester* (2000)
Wolfgang MITTERER: *coloured noise* (2005)
Wolfgang MITTERER: *crush 1-5* (2012) (not verified, as given by Mitterer 2015)
Wolfgang MITTERER: *das tapfere schneiderlein* (premiered in 2012). Children's opera.
Juhani T. VESIKKALA: *Walkthrough* (2015) for lighting, video, performers & electronics. Piano multiphonics feature commonly in the fixed media part and combine theatrically with actions at the MIDI keyboard.
Juhani T. VESIKKALA: *Exorcist for the perplexed mind* (2015) for hichiriki & electronics.
Wolfgang MITTERER: *music for checking e-mails* (not verified, as given by Mitterer 2015)
Wolfgang MITTERER: *marta* (2015-2016?) Opera (to be premiered in 2016) (not verified, as given by Mitterer 2015)

E. Works without multiphonics, with non-simultaneous flageolets on copper strings.

George CRUMB: *Gnomic Variations* (1981). Only the flageolets of partials 2, 4, and 5 are used.
George CRUMB: *Zeitgeist (Tableaux vivants)* (1988) for 2 amplified pianos, 4 hands. Only the flageolets of partials 2 and 5 are used.

Use of the multiphonic mode of playing on the piano has increased exponentially, exemplified by three decades between the probably first instances of *Sinister Resonance* by Henry Cowell (around 1930) and *Duet I* (1962) by Christian Wolff after which more compositions followed suit. It is not quite clear how composers have initially gotten in touch with the phenomenon. The earliest found composition on the European scene might have been a major influence, the Donaueschingen premiere of Brian Ferneyhough's *Transit* (finished 1975) that year, although it is not known which future multiphonic composers attended this performance.

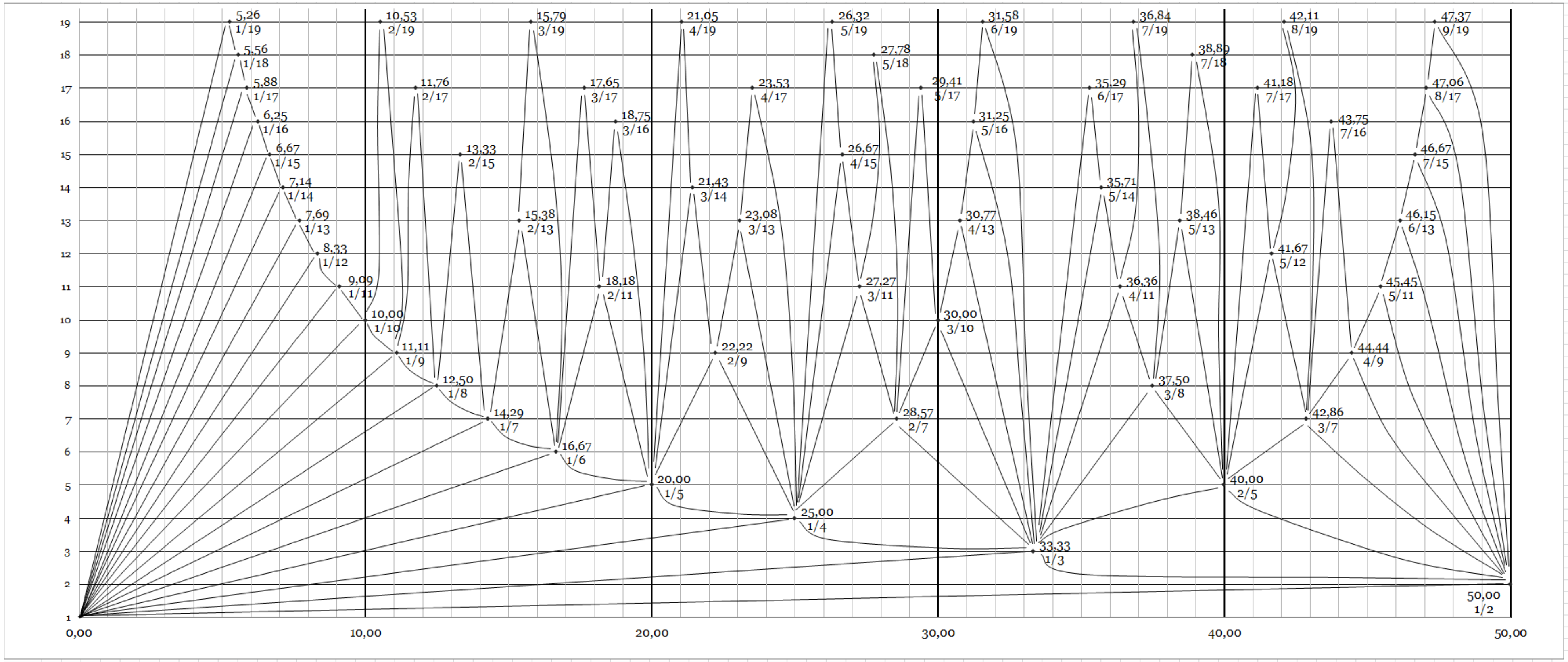
Moreover, tracing stylistic lineages or sources of influence will not be easy with such limited data. As it seems, the mode of playing has been rediscovered at many points in history. In the particular case of Erik Oña, not enough biographical information has been found to verify any exposure to the earliest piano multiphonic repertoire.

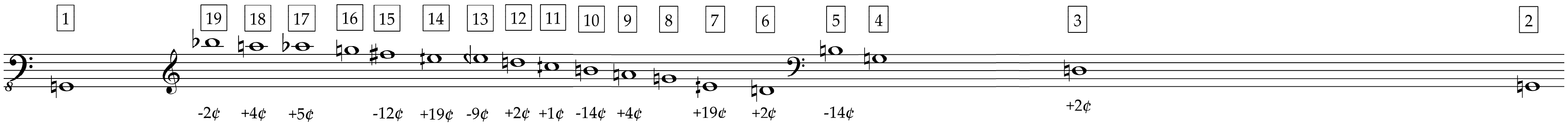
As to the question whether for composers who have discovered piano multiphonics for themselves, individual reasoning about the acoustics of strings has been enough to infer their existence, there is no definitive answer. Some composers and pianists with an experimental mindset may have found this mode of playing without an outside influence. There are however stylistic centres for multiphonic composition which would point at a few influential teachers or other figures. Those early centres are Buenos Aires in the 1960's (composers Maiguaschca, Lanza, later Oña[66]) as well as Freiburg from the 1970's (Ferneyhough, later Maiguaschca), transferring to nearby Stuttgart and Basel from the 1990's onwards (in Stuttgart: Oña, Lachenmann, Stroppa, Walter; in Basel: Oña and Walter). The beginnings of Furrer's multiphonic repertoire can hardly be explained with an established Viennese scene, but perhaps with Furrer's teacher Roman Haubenstock-Ramati's exploratory approach in numerous works for the piano such as *Pour Piano* (1973). Some of these centres might hypothetically also have served as centres for multiphonics on other string instruments – Fallowfield's thesis research being supervised by Oña[67], both working in Basel and Birmingham, Josel working in Stuttgart, Tsao working with Ferneyhough at Stanford. It is not known what kind of an impact such presence of instrumentalists and composers could have on both. The earliest works in the USA may have developed by second-hand encounters with Cowell's work, in which case the mechanics of producing the multiphonics would have been developed individually.

Please suggest additions to this list for future updates – contact: vesikkala@gmail.com

[66] Oña's biographical information is provided in Michaels (2011, 10-15) based on a first-hand interview. Nicolas Alessio and José Antônio Almeida Prado were the composer's teachers. As to the years in La Plata, Gerardo Gandini and Mariano Etkin are mentioned as having great influence on Oña and might be inferred to have taught the composer (Michaels 2011, 12). No singular event leading to Oña's discovery of piano multiphonics can however be traced from the sources.
[67] The acknowledgments section in Fallowfield (2009) mentions Oña's support, which can be read as supervising in the section's context.

Appendix 5. Flageolet Node Chart





X axis: percentage of string lightly gripped (grip intervals are shown in Appendix 3). Y axis: number of partial or of partial component in a multiphonic. The strong vertical lines denote markings that could be inserted on the soundboard. Thin lines indicate branching (“Bruch”). First occurrences of partials with their tuning are shown below (slightly slanted spacing) for a G1 fundament. The range 50%-100% mirrors this chart.

Appendix 6. Audio Examples List with Analyses

The audio examples have been ordered by their appearance in the study, and roughly by their thematic: compositional, technical, accuracy, timbre.

The recordings are either synthetic or produced with the method as described in 3.2.1. FFT figures of selected files, made with a Hann window of 65536 Hz and duration of at least one second each, can be found in the chapters or below. All files are stereo. In FFT figures with two lines the protruding yellow line corresponds to the left channel, the blue line to the right one – in the remaining FFT figures an average of the signals has been taken.

List of tracks

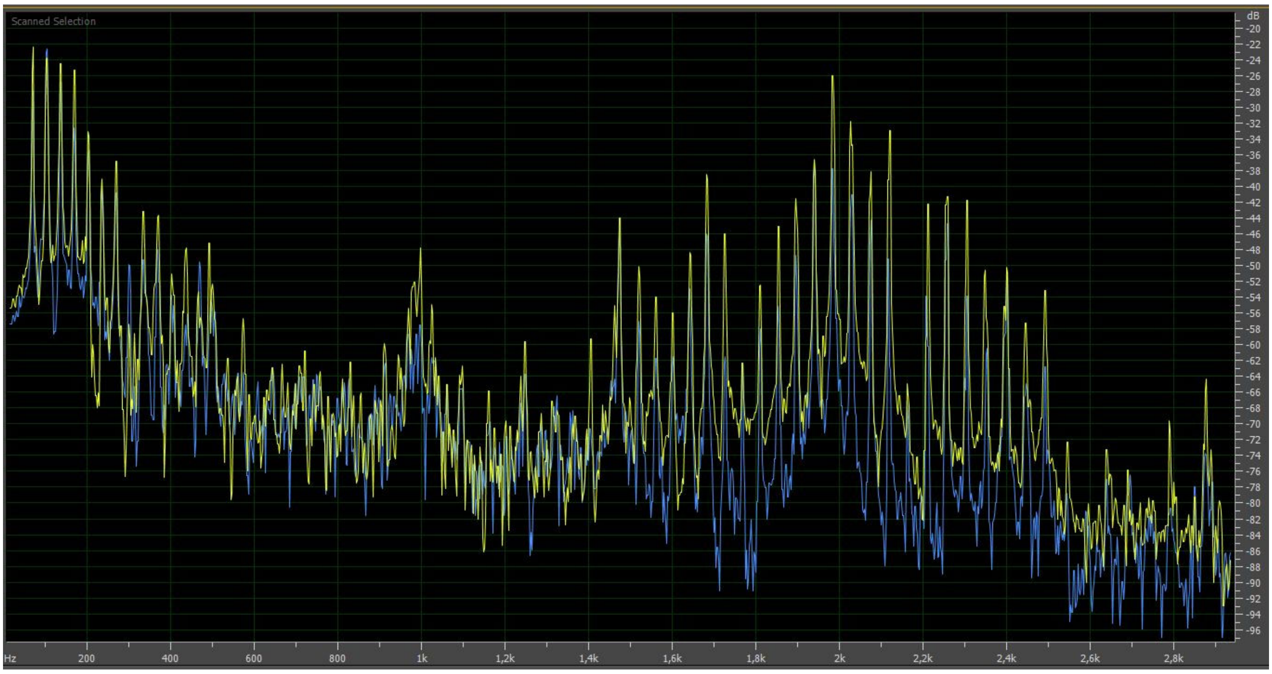
As a by-product of using a high volume level of recording in order to maintain clear pitches during the decay, some of the attacks clip. Thus the signal has been modified ("healed") at some attacks. The string names referenced are the lowest ones with monochord strings, with the exception of the Bösendorfer which had strings lower than A0.
The instruments used for the recordings were

Bösendorfer 225 (a model with added bass strings to F0)
Estonia grand piano, half-built for use in the acoustics laboratory
Fazioli F212
Steinway B, 573xxx series
Steinway D (1.), 590xxx series
Steinway D (2.), 590xxx series.

Track no., description, and instrument

T01. This is the highest partial that was achieved on a C string of a Steinway D, making for a peculiar sound.
The fundament of the C string is around 32 Hz but only partials from 64 Hz (P2) onwards are found by the FFT. Adjacent peaks are separated by around 32 Hz in the low frequency region. The spectral levels drop, with the exception of around 900 Hz … 1050 Hz, and start rising again after 1400 Hz. This rise culminates at 1978 Hz (B3, ca. 61st partial, a grip of 1,6%), the spectral peak almost at the same level as partials 2, 3, 4, and 5. Around this peak, however, the distance of adjacent peaks has grown to ca. 46 Hz, for some reason that might have to do with the considerable pressure applied on the string. The gradual fall of the peak area ends at 2500 Hz. Steinway D (1.)

Below: FFT analysis.



T02. Advancing to the highest partial that was achieved on the E string. Low node percentages resulting in high partials. Steinway D (1.)

T03. Artificial multiphonics on a bent string (bent at ca. F♯). Bösendorfer.

T04. Artificial multiphonics (or, mostly simple flageolets, due to the greater damping and diminished accuracy) by a plectrum and bending the fundament higher with three wedges from all sides. Bösendorfer.

T05. Playing double multiphonic on a damped dichord F♯1, two to three wedges, one on each dichord string. Bösendorfer.

T06. A double multiphonics on the dichord F♯: one of the dichord strings has a wedge lightly fixed at a multiphonic node, the other is contacted by a plectrum moved by the hand. Bösendorfer.

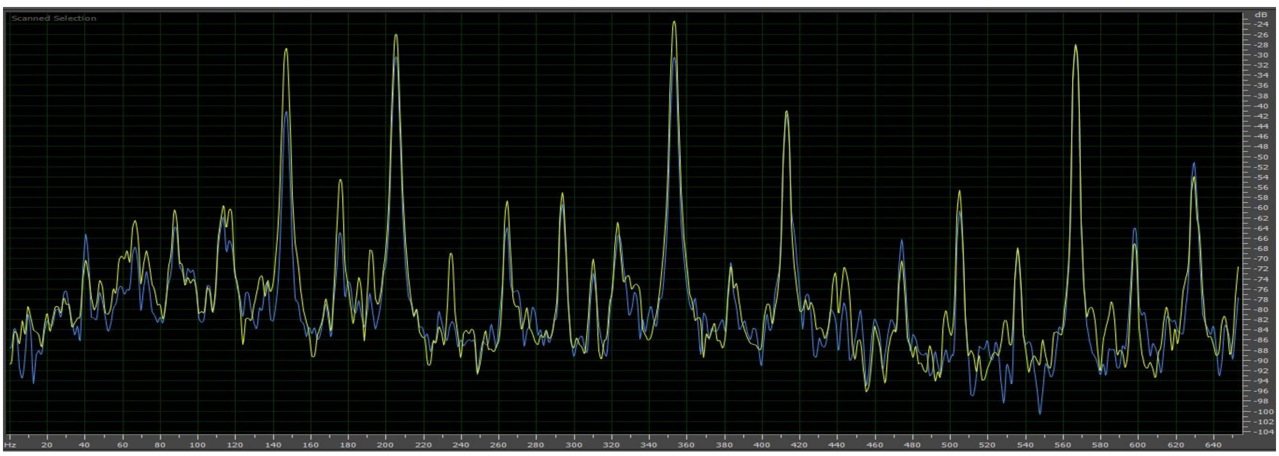
T07. A rather tonal sounding multiphonic on the B♭ string. Steinway D (1.)

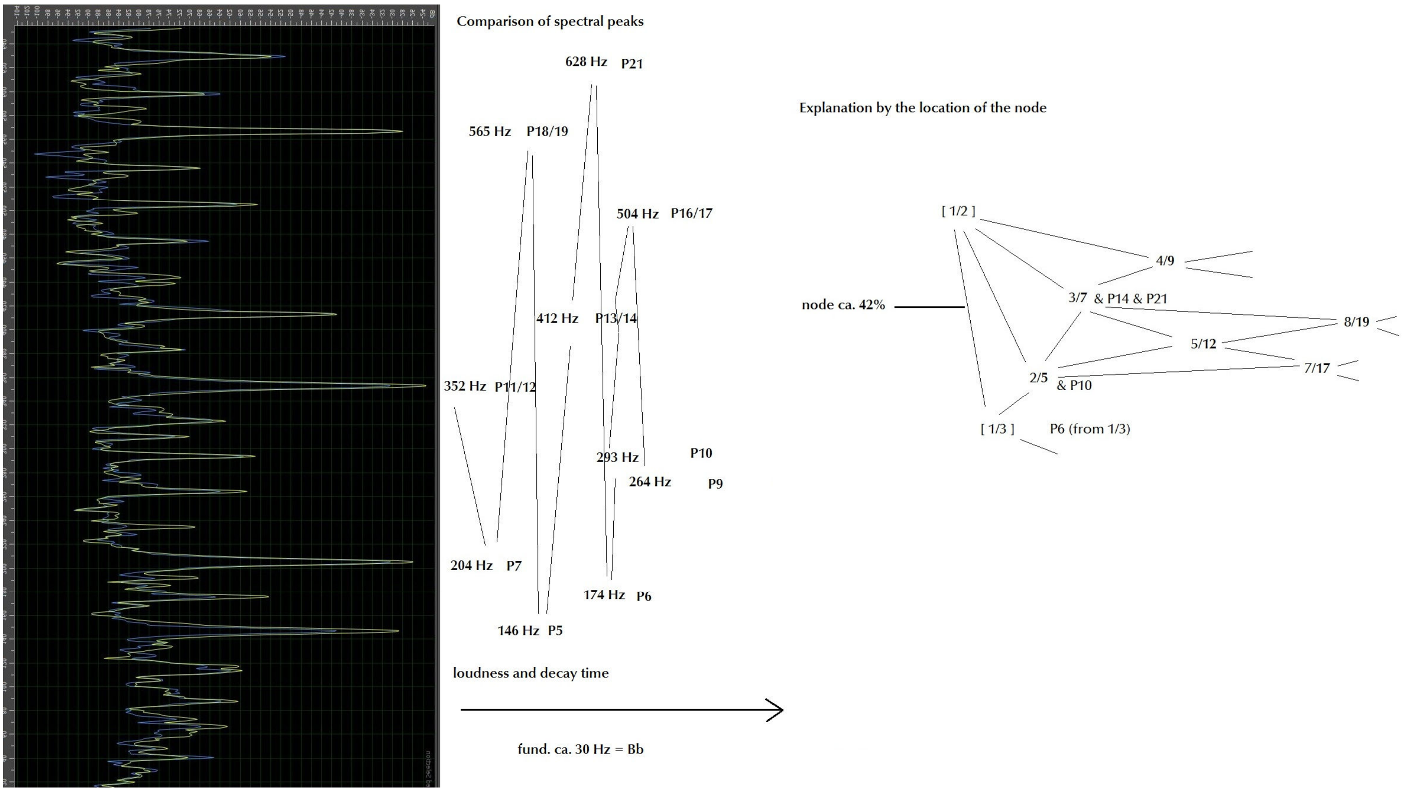
Reduction of the partial content: D3 145Hz, F3 174Hz, G♯3 204, F4 352Hz, G♯1 413Hz, B♮+4 504Hz, C♯+5 567 Hz, E5 662 Hz ... B♭+5 957 Hz.

Partial number ordered by absolute amplitude: 12, 7, 5, 19, 14, 17.

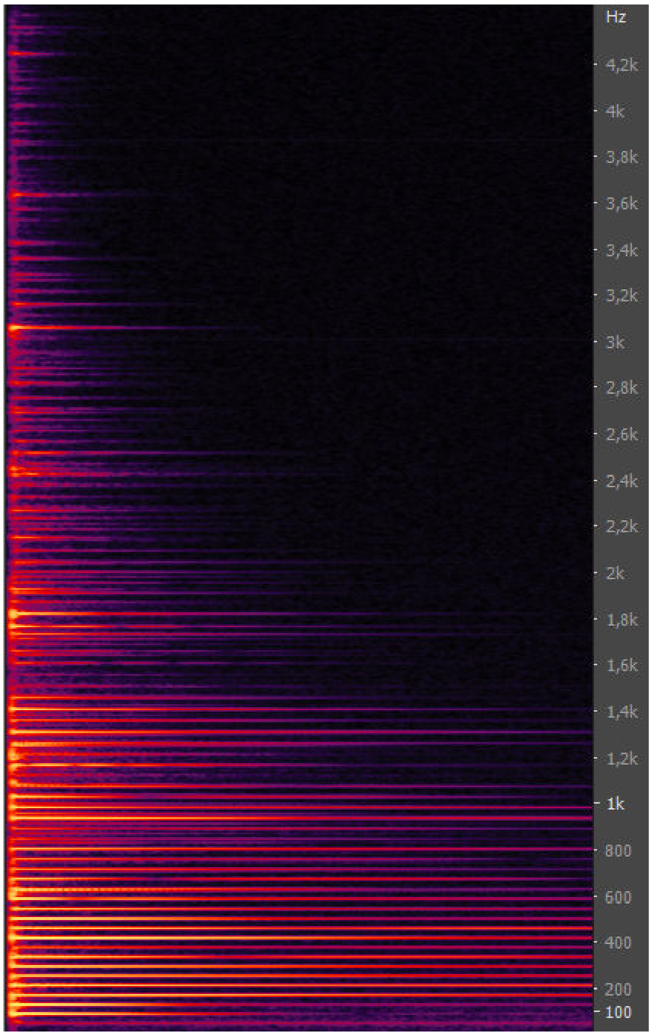
It can sound deceivingly similar to a C♯ chord although the fundament string pitch, B♭, is not related to C♯.

The figures below illustrate this. The second figure replicates the first, being turned to align with the frequency domain used in conventional notation. This direction also eases comparisons with notation where relative dynamic levels can be transferred rapidly to correspond to decay times or individual lines of instruments.





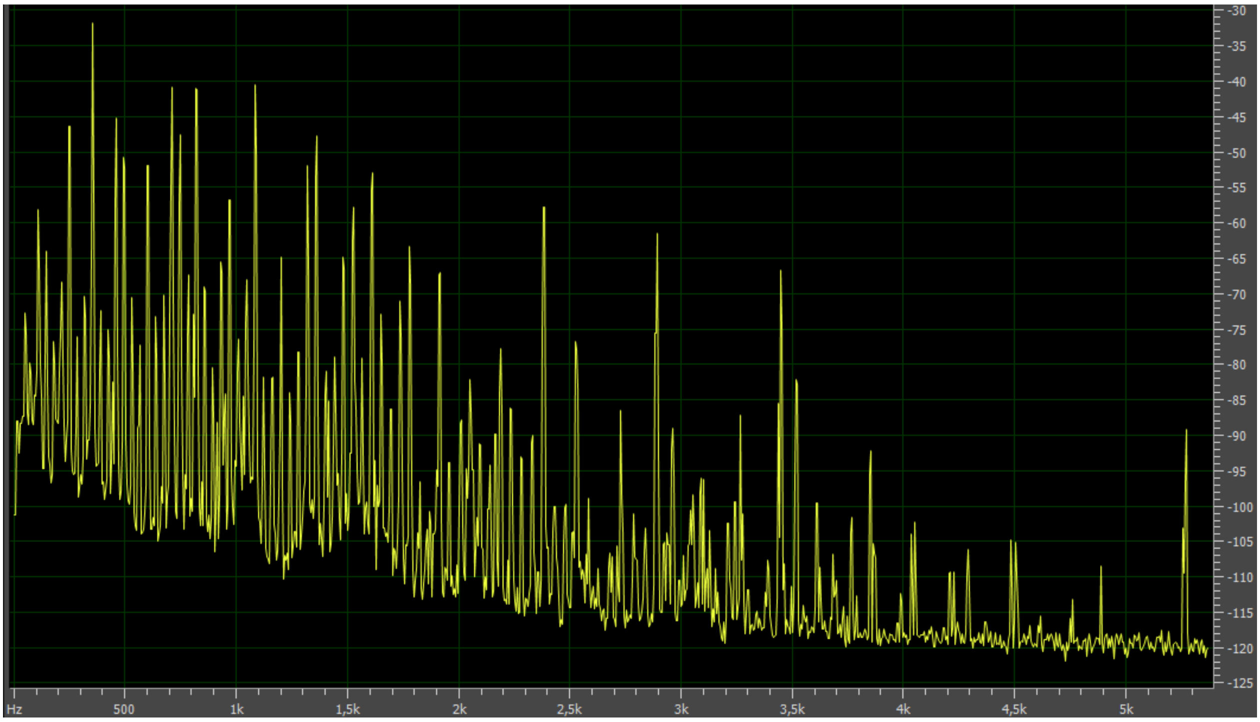
T08. Open strings C♯ and E. Steinway B.
Right: Onset and decay of the E string sound during 10 seconds on the left channel.



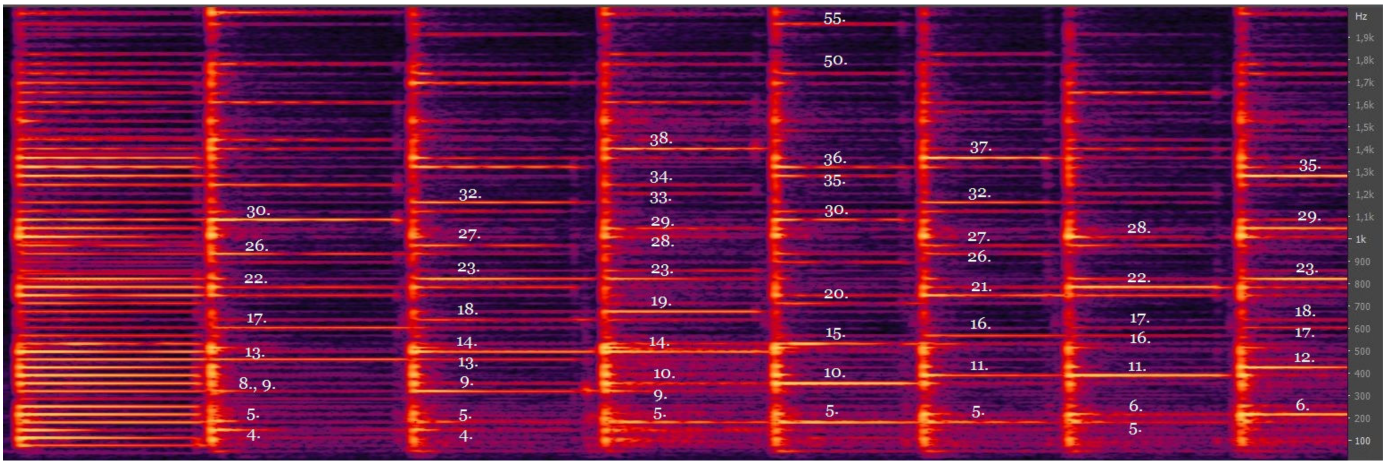
T09. Lab recording. Estonia to audio recording device.

T10. Lab camera recording, converted. Estonia to camera to MATLAB.

T11. C♯ 30% (P10, P7, P13). Below: FFT analysis. A SuperCollider –synthesised version with 15 strongest peaks from the FFT graph above, set at uniform loudness level.



T12. Open sting C# followed by seven different multiphonics on the C# string, leaps in progression 23% ... 17%.
A spectrogram of the sample in linear frequency view, which clearly shows the additive principle of partials and the partials as a filtered-out open string sound. The hammer placement must have been around the 7th partial as it is the faintest of the low harmonics in the open string.
Steinway D (2.).



T13. A fast progression from ca. 28% to damper at 15%, with considerable plectrum noise. Steinway D (1.).
T14. Example of careless handling of the plectrum on the C string. These sounds can be detrimental to live electronic processing. Steinway D (1.).

T15. Wedge-prepared instrument, with the lid closed. Keys A-B♭, B♮-C, D-E♭ played. Steinway D (2.).

T16. Wedge node progression on C and C♯, moving wedge by hand – the plectrum does not move. Steinway B.
T17. Attackless, buzz multiphonic on F0 and A0. Bösendorfer.

T18. Attackless, smooth multiphonic on C♯1. Bösendorfer .

T19. Attackless multiphonics on A, E, C♯, and D♯ strings. Fazioli.

T20. Scratch multiphonics, A string. Fazioli.

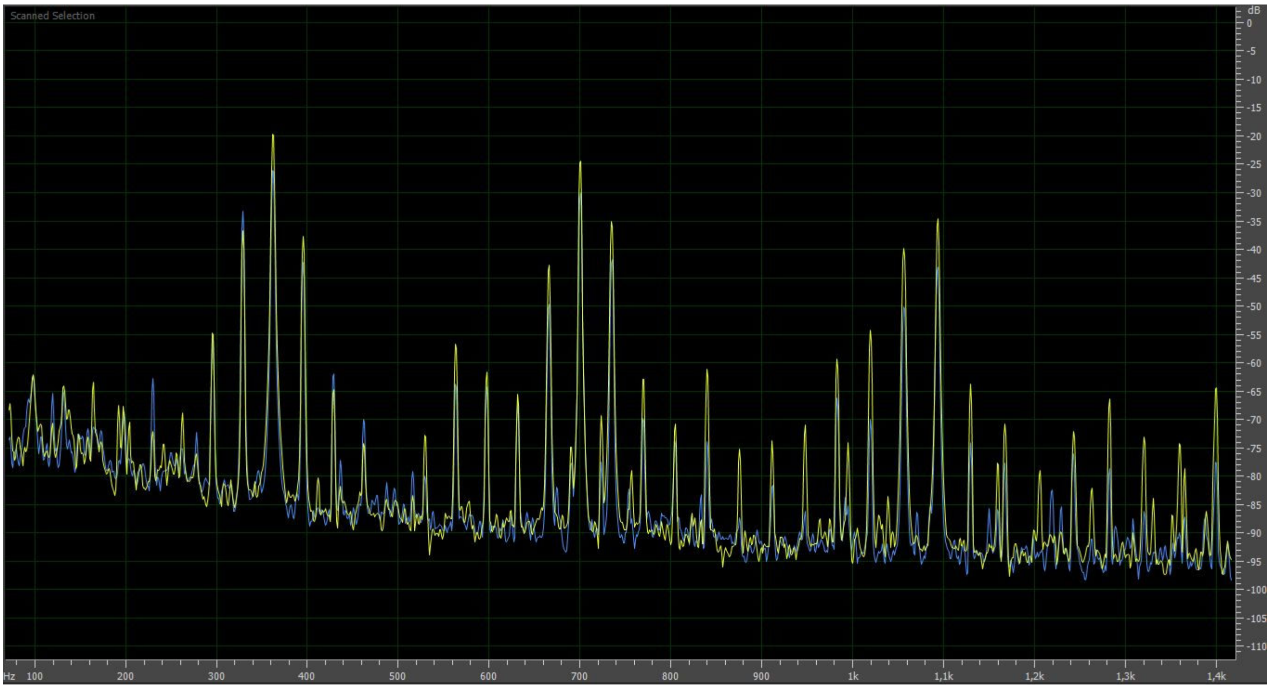
T21. Scratch multiphonics on A0, F1, F♯1 strings. Bösendorfer.

T22. A friction multiphonic with a bicyle rubber tube, on E and C# strings. Hardly possible on such low strings. Fazioli.

T23. A spectral cluster on C string. Partials 9, 10, 11, 12, and 13 have rather melted into one cluster, being near to each other: 294 Hz, 328 Hz, 362 Hz, 394 Hz, and 428 Hz. The spectral peak is at 362 Hz and the other peaks are gradually smaller at symmetrical distances from it.

Similar local peaks and mirroring partial constellations can be found with each multiple of 362 Hz, constituting the harmonic series – although these constellations blurred by difference tones and harmonic upwards warping. The grip is around 9,1%. Steinway D (1.)

Below: FFT analysis.



T24. The multiphonic node also mentioned in Walter's study, 2_5_7_12 (41,7%). One take on C♯1 string and two takes on C1 string on another instrument, both Steinway D's.

T25. E string ca. 42% 5_7_12_19. Explained by the sum of 12 + 19, a bit of the 31st partial (13/31 at 41,9%) can even be heard, warped upward to E6 to sound like a 32nd partial. Fazioli.

T26. A node progression on the A string. Steinway D (1.).

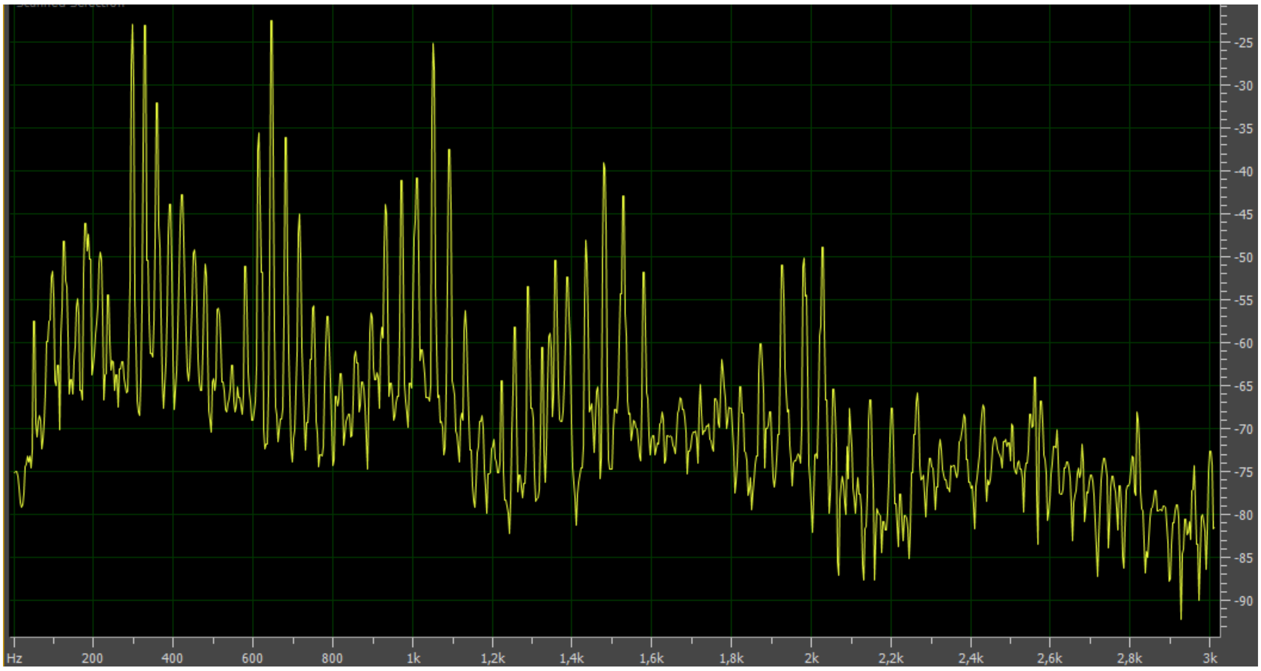
T27. A fast node progression of adjacent slots on the A string. Bösendorfer.

T28. A progression of nearby but non-adjacent slots on the E string, from 3/8 to 3/7. The first two attacks include the 5/13 whereas the remaining three include 5/12. Similarly, 3/8 gives way to 3/7. Steinway D (1.).

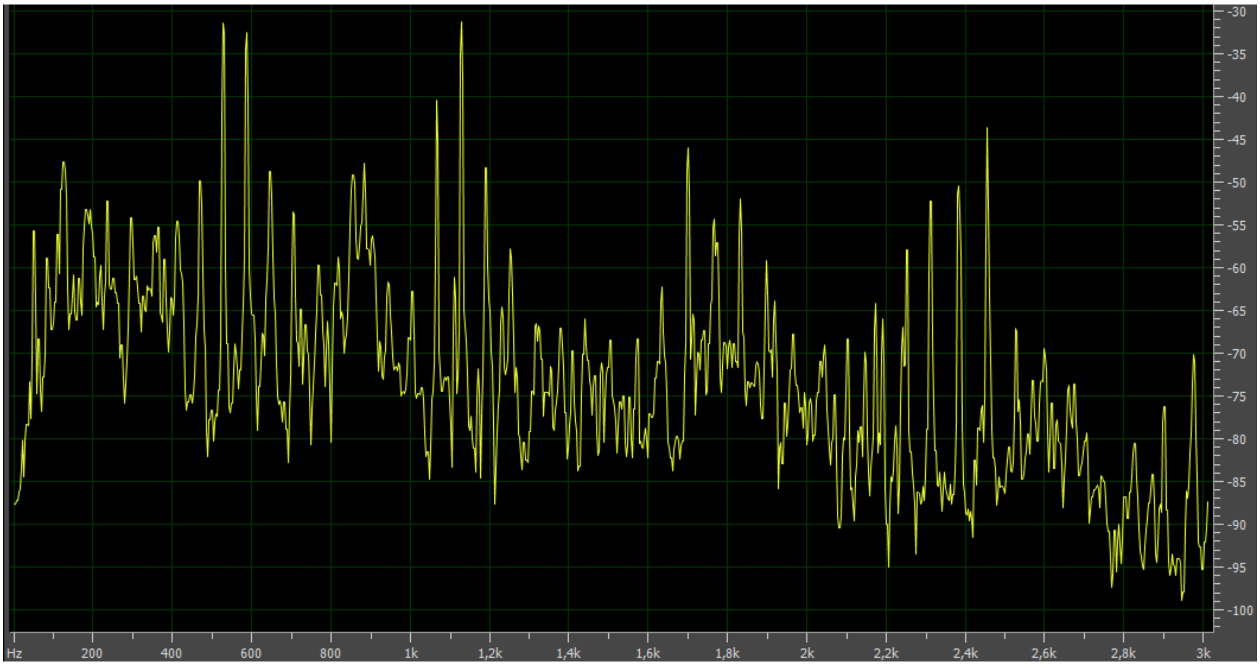
T29. Searching for practical restrictions:

B♭0 (monochord) and B♭1 (dichord), almost the same multiphonic (not exactly the same node since on the higher string the node is below the damper. Steinway B.

B♭0:



B♭ 1:



A SuperCollider –synthesised version with 15 strongest peaks from the FFT graph above, set at uniform loudness level.

T30. A node glissando, trying to maintain the same distance (around 35,7% 3_14) on adjacent strings but not succeeding. E to B♭. Steinway D (1.).

T31. A node glissando, Trying to maintain the same distance (35,7%) on adjacent strings. The prominent partials are 5/14th and 1/3rd. Even 7/20th can be heard occasionally. Steinway D (1.).

T32. Pencil inside a rubber tube, different strings. Fazioli.

T33. Rubber tyre multiphonics. Bösendorfer.

T34. Rubber tyre multiphonics. Fazioli & Steinway B.

Further listening: T35 ... T40.

T35. Different multiphonics on the E string, small plectrum. Steinway B.

T36. Combinations of multiphonics on several strings.

T37. Repetitions of the same multiphonic around 46% of string partials on C and E. The strings are prepared with wedges at nodes similar to each other. Steinway B.

T38. B♮ string at 3/13. (23%) as cleanly as possible. The lid is closed and the fundament frequency region of the recording has been filtered out afterwards. Steinway D (2.).

T39. Multiphonic improvisation using the pedal and one plectrum. Steinway D (1.).

T40. Listening to frequency regions. Partials 9 to 15 fading in one at a time.