Soundanalyse Violin making

Finding Tap tones in music fragments: a new approach in finding tap tones of existing violins

Grant: do the tap tones of Guarneri del Gesù violins differ with that of Stradivarius?

Rob van der Haar

Version 1.3 dd. 6 oktober '20 Sneek

Table of Contents:

Chapter 1 Summary

The research

When you knock on a violin, these so called tap tones are emitted. These are own frequencies of the sound box and are used in the construction and tuning of a bowed instrument. In this research I show that the sounds can also be deduced from the sound fragments of a violin that is being played. This makes it possible to determine the tap tones (eigenfrequencies) of a violin by means of suitable sound fragments. These turn out to be fragments in which single tones from about 1000 Hz are present (e.g. the 'b' on the e-string). These may be one or more notes of the same frequency, as well as, for example, a part of a scale on the e-band.

Grant

Using the above knowledge the eigenfrequencies of six Stradivarius violins(a) have been compared with those of 5 Guarneri del Gesù violins(b). It turns out that the five Guarneri violins have an average, as well as each instrument separately, about 20 Hz higher tap tones than the Stradivari violins. On average the Guarneri came out at 288 Hz and the Stradivari at 270 Hz.

(a) The Spanish 1677, The Ernst 1709, The Joachim 1714, The Monasterio 1719, The Madrileno 1720 en The Rode 1623

(b) The Gibson 1734, The Lafont 1735, The Plowden 1735, The ex-Vieuwtemps 1739 en The Beriot uit 1744

Chapter 2 Introduction and purpose

2.1 What is a tap tone and how do you determine it?

Whether it is a table, a window or a violin, every object you knock on gives knocks. Because the pitch of such knocks is always the same for a certain object, you speak of eigenfrequencies. For example, most violins give a knock with a frequency of between 260 and 300 Hz when you knock on the front, back or curl. These frequencies form the sound base of a violin, as it were, and are therefore used by the violin maker, during the construction of the individual blades, at the completion of the instrument as a whole and when optimizing the sound of an existing instrument.
The tones are easy to determine when you have the instrument in your hand. Tap it, record the tones and analyse them.

2.2 A new way to determine tap tones

I would also like to determine the tap tones from approved top instruments of the Cremonese violin makers. Unfortunately I do not have the possibility to measure several Del Gesù and Stradivari instruments, but I do have sound recordings of, among others, eleven violins of these two violin makers. In this research I am going to see if the tap tones of a violin can be determined without having the instrument at my disposal.

2.3 Approach of the research

In the case of violins I had in my workshop, I determined the eigen frequencies and then searched for those frequencies during sound emission while bowing the violin and found that those eigen frequencies appear in the higher tones during bowing. With these data I have come to a positive answer to the question of whether I can determine the harmonics of a violin without actually having the instrument at my disposal and with that I have reached the goal of my research.

From thirteen violins I have compared the directly measured tap tone with the read-off tap tone from the graphs of bowed tones. These frequencies appeared to correspond with each violin. On the basis of induction I drew up the general rule that the directly measured eigen frequencies correspond with the played eigen frequencies.

2.4 Structure of this report

In acoustic research the terms 'pitch', 'frequency', 'tonal strength' and 'loudness' are used. Also the decomposition of tones into fundamentals (key-notes) and overtones is discussed. In chapter 3 I will further explain these and a number of other concepts, including the audiogram. It is the basic knowledge the reader needs in the following chapters.
In chapter 4 the working method is discussed and the results are discussed. In chapter 5 the conclusions are drawn from the measurements of chapter 4. Chapter 6 discusses the accuracy of the experiment and the choice of the beating tone. In addition, we look ahead to further research.

The Grant discusses an application of the new measurement method. The eigenfrequencies of a number of Guarneri del Gesù instruments are compared with those of Stradivarius.

Chapter 3 Acoustic frame

3.1 Eigenfrequencies or resonant frequencies

Each instrument has its own specific eigenfrequencies, also called 'resonance frequencies'. A distinction is made between on the one hand the resonances of the sound box, neck, strings and the like and on the other hand the resonances of the enclosed air.

3.1.1 Body frequencies

If you tap the instrument with a finger, the violin emits a tone with a certain frequency, or in practice a combination of some strong frequencies. For example, you can tap the front page, back page, curl and bridge.

An example of the body frequency is the A0 (pronounced A-zero): you hear this when you hold the instrument vertically, with the curl up and then tap the curl. Meanwhile you keep the strings muffled with your hand. As shown in the picture on the right. The microphone registers the sound and with the help of the computer you can read the pitch in the audiograms.

Free Plate modes; Frequently used body frequencies are the top and bottom tones. By tapping the blade with a knuckle of your finger, you can determine the M2 (length blade) and M5 (width blade) frequencies. I use these frequencies especially when building the instrument when the blades are not yet glued to the wreath. When the blades are on the wreath, the stack is placed, the bridge is set and the strings are attached, I use the A0 mode.

Another way to determine the natural frequency of an instrument that is ready to play is by means of the comb-knock. I hold the instrument horizontally (see picture left) and tap the bridge with a wooden hammer. The hammer has a mass of about two grams and is made of a satay pin (see picture on the right).

When comparing the audiogram of the bridge beat with that of the A0 mode of the same violin, it appears that the lowest peak in the audiogram of the bridge beat corresponds to the A0 mode.

3.1.2. Air frequencies

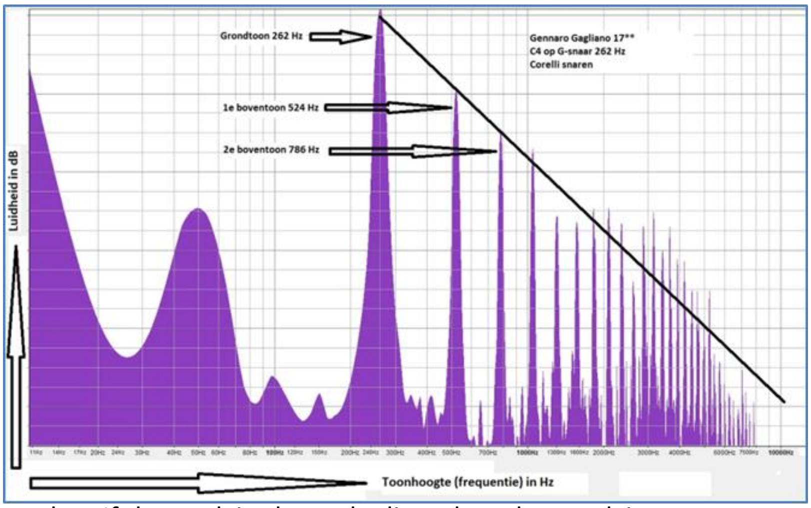
We speak of air frequencies when the air in the violin is vibrated. When playing, this happens by moving away from each other and towards each other from the top and bottom of the violin.
An example is the A0 (read A-zero) mode. This is the natural frequency you hear when you blow over the neck of a bottle, for example. The smaller the volume of the bottle, the higher the tone. By putting more or less water in the bottle, you can vary the volume of the enclosed air and thus the frequency (pitch) of the tone. In a similar way you can also blow over the f-holes of the sound box and determine the pitch of the sound box. This frequency is also called 'Helmholtz frequency', after the physics researcher. This

frequency often lies between 260 and 280 Hz for a violin. With a larger instrument, such as a viola and cello, this value is obviously lower.
Next to the A0 mode also the A1 mode is used. This is created when the air in the soundbox is vibrated and the wavelength of that vibration fits the dimensions of the soundbox. The average value of this frequency in my measurements is around 470 Hz.

Because in this research I compare instruments ready to play with each other I have used the eigenfrequencies which are best to determine. Both the knock on the scroll and the bridge knock are suitable for this. As mentioned before, these methods give the same value of the eigenfrequency. Because I have always measured the A0 of the 65 violins I have measured and only in the last few years I determined the bridge knock, I have chosen for the A0 determination by a knock on the curl. The amount of measurement data I then have at my disposal is larger. This increases the validity of the research. Although there are more air and body modes to determine, such as tapping the front and back, I leave them out of this study.

3.2 Fourier analysis and software
A tone, produced by a musical instrument, consists of the keynote and a range of overtones. The mix of these fundamental and overtones determines the sound color of the instrument. The mathematician Fourier has developed a method to dissect (sound) waves. Computer programs that are made to decompose a tone into ground- and overtones are therefore called Fast Fourier Transform programs. Often abbreviated to FFT. I use the computer program Audacity to decompose a tone. The reason I chose Audacity is twofold. First, the program is freely available so that my experiments can be repeated by others. Secondly, in my opinion it scores high on the line of continuity. The program has been maintained for 20 years by a group of enthusiasts. The output of that program I call an audiogram. In the next piece it is briefly shown how an Audiogram should be read.

3.3 Audiogram
The figure on the right is an audiogram. The purple colored peaks form the graph. I added the black straight, descending line and the texts and arrows.
Along the vertical axis the loudness is shown in decibels (dB). The higher the peak in the graph, the louder the tone. Along the horizontal axis the frequency is indicated. The higher the frequency in Hertz (Hz), the higher the tone sounds. In this example a C4 (262 Hz) is played on the g-string of a violin. In the graph the highest peak is the root tone. To the right we see a number of overtones, of which the first and second overtones are indicated by a black arrow. The overtones gradually decrease in loudness (loudness). The black line drawn here connects the peaks as much as possible. If the peak remains below the black line, the overtone is weaker. If the peak is above the line, then that peak is proportionally stronger (louder). The part to the left of the root is not important for the violin, and should therefore not be interpreted in that context. These are the sounds of the computer, including the 50Hz tone caused by the frequency of the mains.

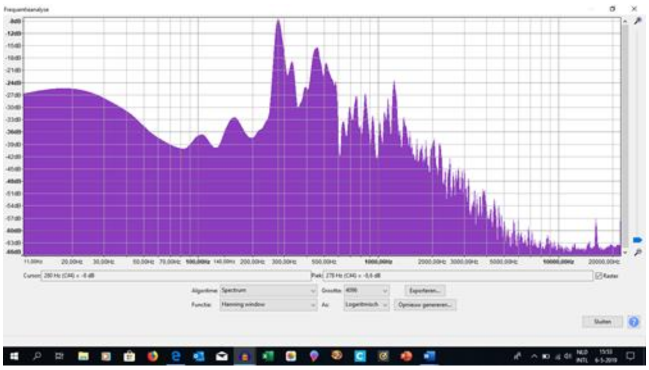


Chapter 4 Determining Tap Tones: Methods and Results

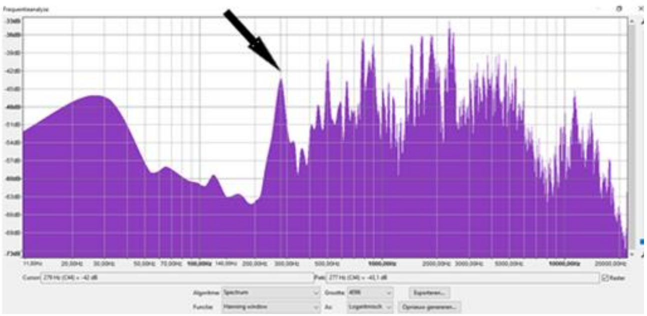
In order to determine the harmonics, or rather the corresponding eigenfrequencies of the harmonics, of an instrument, without having the instrument in our hands, we take a number of steps:
1) We determine the directly measured knock tone of an instrument. Suppose it has a frequency of 280 Hz.
2) We search in the audiograms of played tones of the violin used at 1 for a peak of 280 Hz.
3) When the corresponding peak is found, we will check if this is a coincidence or if other violins also reveal their beats in the audiograms.
4) Next we look if we can find these peaks also in audio recordings of old Cremonese violins.

The research:

4.1 The keynote of a violin measured directly

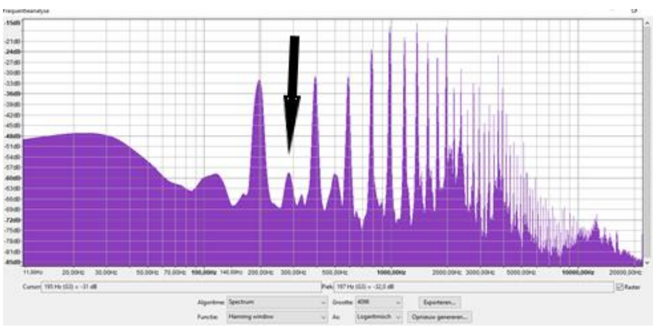


B0 beep (see page 5)
We start our search with a Stradivarius 1713 copy. An atelier violin from around 1900. The B0 beating tone is at 278 Hz (highest peak in the figure on the right). The B0 is determined by tapping the curl with the knuckle of your finger, while keeping the strings muffled.



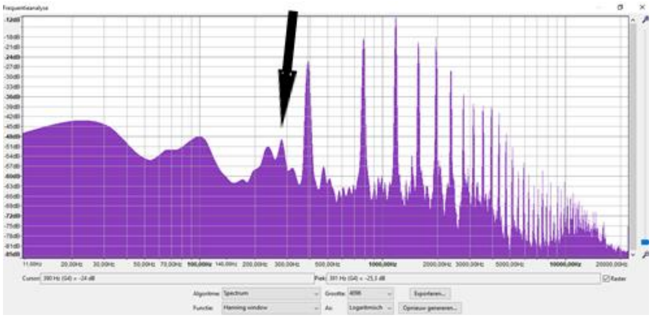
Bridge knock (see page 5)
Tap the side of the comb with a wooden hammer (NB about two grams!!!). The audiogram on the right shows the beating of the comb. The characteristic peak is at 277 Hz (see arrow in picture on the right).

4.2 Search for the eigenfrequency of a violin in played tones.
If we know the eigenfrequency of an instrument, we can search in the audiograms of played tones for peaks at this known frequency. As an example we take the audiograms of four played tones on the String copy with a beating tone of approx. 280 Hz. We will search in the audiograms of the ironed tones G3, G4, A#5 and C#6.
In the 4 graphs below, the beating peak is always indicated with a black arrow.



Keynote G3 197 Hz Knock-to-peak 282 Hz.

In G3, the keynote is below the knock sound.

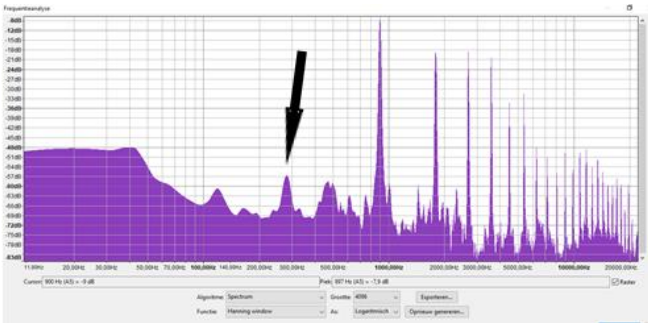


Ground tone G4 390 Hz Knock-to-peak 281 Hz.

In G4, the root is above the beat, but we still see a number of peaks near the beat.

Ground tone A5 897 Hz tap tone peak is at 281Hz.

On A5, the peak is clearly visible and recognisable.



Ground tone C#6 1135 Hz tap tone peak 281 Hz.

Also with C#6 the peak is clearly visible and recognizable.

The tapping tone (B0) directly measured in this case is 280 Hz. The readings from the strings are 282 Hz for the G3, 281 for the G4, 281 for the G5 and 281 for the C#6. The deviation lies within the measurement accuracy of two to three Hz. We can say that for this violin **the thesis that the beating tone can be read from the coated notes is correct.**

In general, the peak can best be recognised with a tone with a frequency greater than 1000 Hz. This does not have to be a single tone, it may also be a group of tones, as long as all tones are above 1000 Hz. **This way of determining the beating tone I call the indirect method.**

4.3 Does the agreement between in and -directly measured fundamental tones apply to more violins?

The next step is to compare the directly measured knock from about thirteen violins with the readout from one or more trebles. The results are shown in the table below.

Divers violins:	**Tap tone read from bowed sound**		
Violin	**Tap tones frequency (in Hz) (Direct)**	**Tap tone frequency (Hz) (Indirect)**	**Mind**
Petrus Guarneri 1725	272	272	Tap tone read from backside knock
Louis Blits 1971	272	268	
Max Millant 1973	271	274 (269-285)	
Kopie Strad 1713	270	268/274	
Lambert Houniet opus 145	269	271	Tap tone read from bridge knock
Lambert Houniet opus 146	276	279	
Bas Maas 2011	268	271	
Bas Maas 2011 Splendor	278	277	
Italiaans 18e eeuw	285	284	Tap tone read from backside knock
Rob van der Haar 2017	262	264	
Rob van der Haar 2013	278	278	
Italiaanse restauration	284	285	
Giulio Degani ca 1900 copy	279	279	

Also with these thirteen violins, the directly measured knocks and the knocks derived from the played tone are always within four Hz of each other. On this basis, we can conclude that the beating of a violin can be deduced from the graph of a played tone. On the basis of Induction we conclude that the results that apply to these fourteen violins (one elaborated and thirteen in the table) apply to all violins.

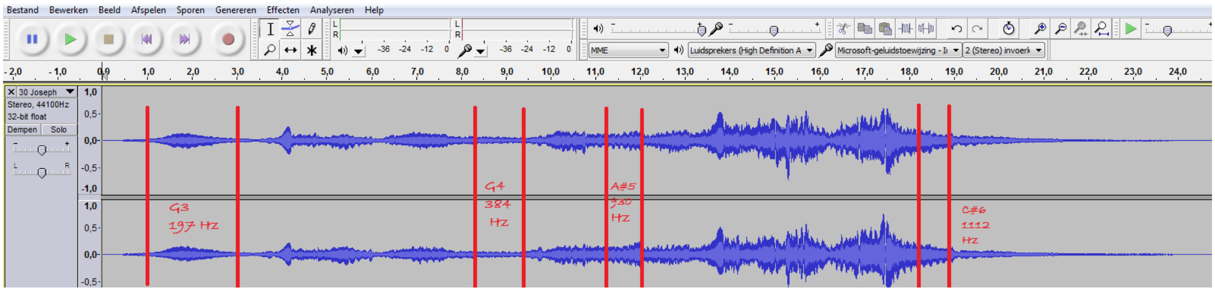
4.4 Searching for fundamental tones in the audiograms of played Cremonese violins

4.4.1 Procedure

Glory of Cremona
In 1989 the CD 'Glory of Cremona' was released. It includes the following fragment of Max Bruch's violin concerto on about twenty different -Cremonese- violins, played by Ruggiero Ricci.

Here the intro in question, first in music notation.

Then the sound fragment of Bruch from the place where the solo starts, shown as a screenshot in Audacity. Between the red lines the different tones G3, G4, A#5 and C#6. I used the analyses of these four tones in my first research. (1)

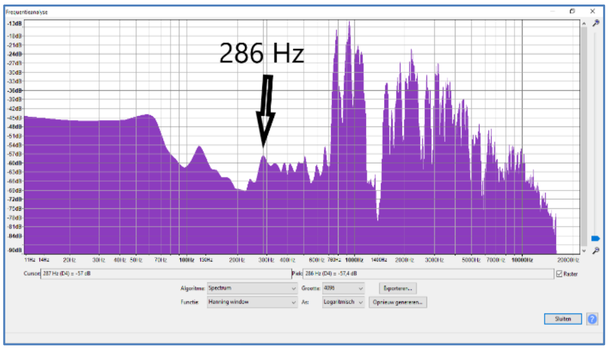


On the next page are the graphs of the trebles of two Guarneri instruments, the "Gibson" and the "Lafont" and of two Stradivarius violins, the "Ernst" and the "Joachim".

N.B. The Glory of Cremona shots were made in New York. With a power frequency of 60 Hz. The graphs therefore always show peaks at 60 HZ and some 'overtones' of these (120, 180 and 240 Hz) which decrease in strength as the frequency increases. My own recordings with a fixed computer were made with the 50 Hz frequency of the Dutch mains. In recent years I have been registering with a laptop and no longer register with the mains. These mains peaks will not be taken into account in any further discussions.

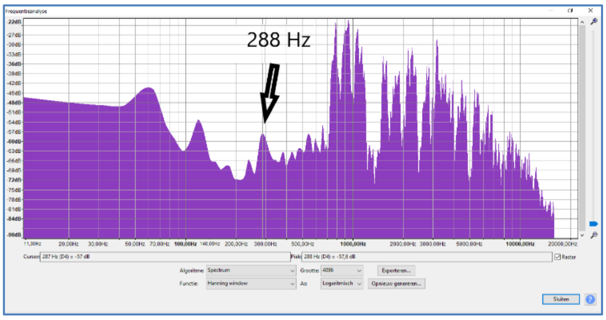
1) Klankanalyse vioolbouw; Een onderzoek naar de klank van de viool door middel van analyse van de akoestische 'vingerafdruk' Mei 2014

4.4.2. Results of 2 del Gesù and 2 Stradivarius instruments



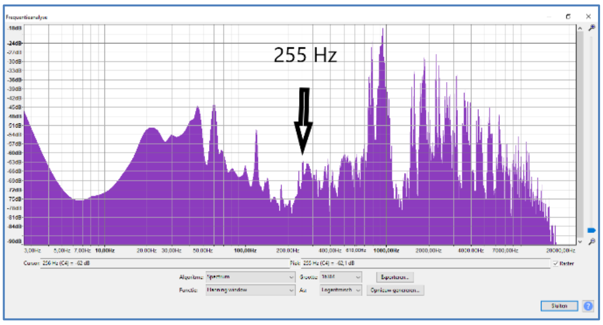
Joseph Guarneri del Gesù

The “Gibson” 1734 286 Hz



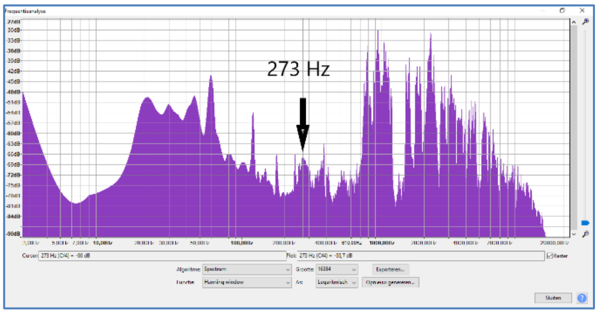
Joseph Guarneri del Gesù

The “Lafont” 1735 288 Hz



Antonius Stradivari

The “Ernst” 1709 255 Hz



Antonius Stradivari

The “Joachim” 1714 273 Hz

In all four cases, the strongest peak was read. Multiple analyses of a single treble or groups of trebles played on one instrument lead to the same value for each individual violin.

We can say that each violin reveals its characteristic value: the eigenfrequency of the instrument.

4.4.3 Results of a larger group Cremonese violins

In a similar way, the beats were read from a number of other Cremonese violins. This leads to the following table:

Viool	Tap tone (read from audiogram) In Hz
Nicolo Amati 1656	285
Carlo Bergonzi "The Constable" 1731	282
Joseph Guarneri del Gesù "The Plowden" 1735	289
Joseph Guarneri del Gesù "The Gibson" 1734	286
Joseph Guarneri del Gesù "The Lafont" 1735	289
Joseph Guarneri del Gesù "The Ex-vieuwtemps" 1739	286
Joseph Guarneri del Gesù "The Beriot" 1744	290
Gasparo da Salo 1570-1580	284
Antonio Stradivari "The Ernst" 1709	255
Antonio Stradivari "The Joachim" 1714	273
Antonio Stradivari "The Madrileno" 1720	269
Antonio Stradivari "The Monasterio" 1719	274
Antonio Stradivari "The Rode" 1723	269
Antonio Stradivari "The Spanish" 1677	283

Chapter 5 Conclusion

In this study I measured the beating tone of about fourteen violins directly by tapping the curl, recording the beating tone and analyzing it with appropriate software. I then read the tap tones from the audiograms of the same violins.

1) For the Strad-copy, the directly measured beats (B0) have a frequency of 280 Hz (par 4.1). The readings from the strings are 282 Hz for the G3, 281 for the G4, 281 for the G5 and 281 for the C#6. (section 4.2) The deviation is within the measurement accuracy of 2 to 3 Hz. We can say that for this violin the thesis that the beating tone can be read from the stringed notes is correct.

2) Also for the other thirteen violins studied, the directly measured knocks and the knock sounds derived from the stringed notes are always within 4 Hz of each other. (par 4.3)

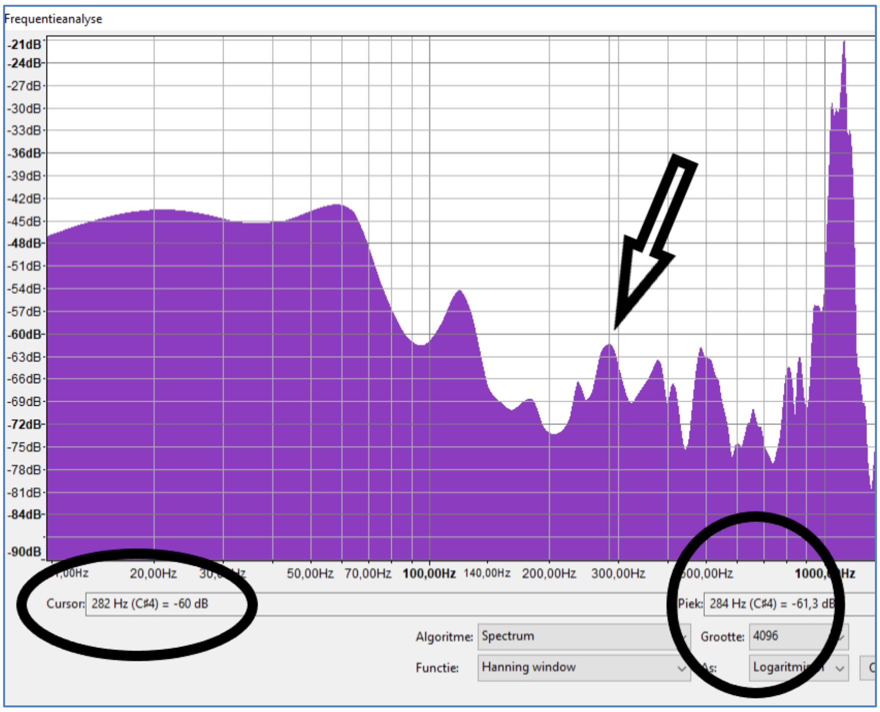
On this basis, I come to the conclusion that the beating of a violin can be deduced from the graph of a played tone.

Based on Induction, I conclude that the results that apply to these 14 violins (1 elaborated and 13 in the table) apply to all violins.
This answers the central question of this research: 'Can I determine the beat tones of an instrument without having the instrument in my hands?' positively.

Chapter 6 Discussion and Follow-up Study

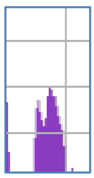
6.1 Accuracy

First of all the question: how accurate is a measurement with an FFT program, such as Audacity?
A measurement of a single peak is accurate within one Hertz. This can be seen, for example, in the display of a tone generator and when comparing it with digital tuners. The measurements are endlessly reproducible and always come out within a margin of error of one Hz.
When reading an audiogram, practice can sometimes be more unruly, because it can happen that there is a peak composed of two other peaks that differ in loudness. As an example -a part of- the audiogram of the Gaspar da Salo violin. We look at the peak of 284 Hz, to which the arrow points.



In the oval at the bottom left of the image we read that the cursor, shown as a white vertical line just to the left of the black arrow, is at 282 Hz and in the circle at the bottom right that the peak is at 284 Hz. In the same circle we read that the resolution (Size) is at 4096. It is clearly visible in the audiogram near the black arrow that the peak is not really peaked, as with the next peak to the left.

If we apply a resolution four times as large to the black arrow at the same peak (see small image on the right), it is clearly visible that the peak is made up of two peaks.



In this case, the automatic reading of the peak is influenced by the size of the resolution and one or more values of the frequency may differ.

In practice I read the frequency in such a case a few times at a different place in the measurements and then in practice it is always clear what the eigenfrequency peak is. If that is not clear, I will mention it.

On the basis of this reading of compound peaks, I come to the conclusion that it is possible to work with an accuracy of two to three Hertz.

6.1 Choice of tap tone

In addition to accuracy, I would like to dwell on the choice of tapping tone. As mentioned in paragraph 3.1.1, there are several ways to determine the natural frequency of the 'body' of the violin. These include the sound box, neck, curl, tuning screws, fingerboard, comb, pile, strings and string holder. Also the chin support falls under this because it can also influence the sound. When measuring a violin I always determine the B0 with the help of a knock on the curl. In addition, I knock on the front and back of the violin. In recent years I have added the comb knock and the CBR knock. In general the values of the BO and the comb beat are close to each other. As an average of 34 instruments, I find 274.5 Hz for the B0, while the average of the camp beat is 273.1 (fifteen measurements of the camp beat were from this group of 34 violins).
On this basis, I draw the conclusion that both the values from the curl knock and the values from the bridge knock can be used as a means of determining the A0, the violin's own frequency.

> It appears that the lowest peak in the audiogram of the camp knock corresponds to the A0 mode.

6.1 Follow-up study

The core of current research is the ability to determine the tones from sound recordings. Follow-up research will have to focus on two directions. Firstly, the further verification of the current research. Measuring more instruments, both directly and indirectly, to determine the sound tones and thus further legitimise the approach. In short, measuring more -old instruments. Secondly, applying the method is a good direction for follow-up research. In what way can this approach help to fathom the sound formation in the violin and thus further advance the violin making?
As an advance on this application I have included an encore in which the own frequencies of Del Gesù violins are compared with some Stradivari violins.

Grant: Taptones Guarneri del Gesù en Stradivarius

Question: Do the frequencies of the tap tones of Guarneri del Gesù instruments differ from those of Stradivarius violins?

As an example of the possibilities offered by the new way of working, we are going to compare the tap tones - obtained in the new way - of six Stradivari violins with five Guarneri del Gesù instruments. For this we used recordings of Cremonese violins on the CD 'Glory of Cremona'.
This leads to the following table:

Violen Joseph Guarneri del Gesù		**Average Guarneri A0**
"The Plowden" 1735	289	288
"The Gibson" 1734	286	
"The Lafont" 1735	289	
"The Ex-vieuwtemps" 1739	286	
"The Beriot" 1744	290	
Violen Antonio Stradivari		**Average Stradivarius A0**
"The Ernst" 1709	255	271
"The Joachim" 1714	273	
"The Madrileno" 1720	269	
"The Monasterio" 1719	274	
"The Rode" 1723	269	
"The Spanish" 1677	283	

From this series of measurements it can be deduced that the eigenfrequencies (A0) of the Del Gesù instruments have a higher frequency than the Stradivarius violins. This applies to each instrument individually as well as to the group averages. The average of the del Gesù instruments is 288.0 Hz, that of the Stradivari violins at 270.5 Hz.

Whether or not this difference in eigenfrequencies has consequences for the sound formation, both in terms of loudness and timbre, I will leave this research outside the scope of this study.

Recommended sources

Below you will find a small selection of the many digital sources that contain more information on the own frequencies of violins:

The documents and websites can be reached via a search engine.

Digital sources:

- Acoustics for violin and guitar makers — Erik Jansson editie 4 2002
- Mode tuning for the violin maker — Carleen Hutchins & Duane Voskuil. nov 95 CAS Journal 2, No. 4
- Violin Acoustics-Overview — D.Noon Artikel

De volgende sites vormen een bron van kennis met betrekking tot de geluidsproductie door een viool.

- Martin Schleske — http://www.schleske.de Kies 'vibration analyses'
- The University New South Wales (Australië) — http://www.newt.phys.unsw.edu.au
- American Physical Society Site — http://www.physicscentral.com/ Zoek op violin
  of volg: http://www.physicscentral.com/explore/action/fiddle.cfm