Evasive manoeuvres of bowed-string instruments: The effect of wolf suppressors on wolf tones

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In this study, different designs of wolf suppressors for bowed-string instruments are compared and assessed with respect to their efficiency to reduce the wolf-tone liability of violins and cellos. The common type of wolf suppressor is considered which consists of a mass that is fixed on the string section between the bridge and the tailpiece. It is found that not only the damping and the mass of the wolf suppressors play an important role, but also that their geometry can be decisive for the resonances that they add to the instrument and by which wolf tones can be tackled. On the one hand, this is shown by acoustic measurements of the tunable wolf-suppressor subsystem: The additional resonances are identified for different positions of the investigated suppressors on the string section. On the other hand, recordings of the motion of the wolf suppressors by means of a high-speed camera exhibit complex vibrations of the wolf-suppressor masses. Distinct motion patterns can thus be observed after plucking or bowing of the considered string section as well as when the main string section is bowed at a resonance frequency of the wolf-suppressor subsystem. In view of these findings, for some exemplary wolf tones on a cello, the supposed working principle of tunable vibration absorber is examined by tuning the resonance of the wolf-suppressor subsystem to match the wolf tone. As is well known, this cure is not always successful and in many cases the wolf tone is rather modified than eliminated.

1 Introduction

While wolf tones are an annoyance for the producer of aesthetic sounds on violin-family instruments, they provide the researcher in musical acoustics with a welcome opportunity to unravel the mechanisms of interaction between bowed string and instrument body. For other notes, the desired Helmholtz motion of the bowed string can be produced with reasonable ease. But at wolf tones his usual skills fail the player and a howling or beating sound is elicited, instead. In so far, wolf tones add a striking aspect to the idea of playability which is a property that results from the string-body coupling. Wolf tones, in particular, occur at strong body resonances, at which the Helmholtz motion on the string can become unstable because of the associated bridge motions.

The explanation of the beating sound that results from this instability has different facets. In one conception [10], the howling results from a cyclic and continuous change between Helmholtz motion and the second harmonic regime, which is also associated with a cyclic variation of the usable bow-force interval, in which Helmholtz motion is induced [13]. From a second perspective [4, 6], the beating results from the simultaneous excitation of the two resonances that are created around the actual body-resonance frequency by a strong coupling of a body and a string resonance. Other accounts [1, 11] add further details. But it is not in the scope of this paper to give a satisfying account of this involved phenomenon.

It is the common experience of players and also an observation made during this study that wolf tones are very volatile. At one instance, the wolf tone on an instrument may be strong, a day later it may be all gone and cannot be reproduced. This is presumably due to the atmospheric conditions, most of all humidity and temperature, that influence the behaviour of the instrument and the frictional properties. Moreover, once a wolf tone is spotted, it is very hard to make it sound the same twice, which is noticeably due to variations in bow force and pitch, adjusted by right and left hand, respectively.

Apart from the volatility of the wolf tone itself, it is hard to predict which countermeasure may prevent the wolf tone best: In some cases it suffices to adjust the playing technique, in others only the installation of a wolf suppressor may lead to an amendment. Wolf suppressors of different kinds are commonly installed either on the instrument's top plate or on the afterlength of the lowest string, that is, on the string section between the bridge and the tailpiece. This study is concerned with the latter design: These wolf suppressors are small masses, that vary in shape, material and fixture to the strings.

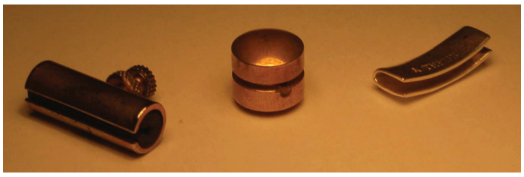

Figure 1: Different wolf suppressors, from left to right: Standard wolf suppressor, ”LupX” and ”Wolf Tuner”.

The present investigation includes three different kinds of wolf suppressors (*cf.* Fig. 1)

- A standard wolf suppressor consisting of a hard rubber that is fixed to the string by a brass hull with a screw (m=7.00 g),
- The ”LupX” wolf eliminator: two disc-shaped brass elements between which the string is clamped by a screw mechanism (m=7.77 g),
- The ”Wolf Tuner” by violin maker André Theunis – a folded silver sheet with a slight curvature (m=2.72 g).

Schelleng [12] has given some instructions on how to adjust a wolf suppressor on the afterlength: The resonance of the subsystem is supposed to match the wolf tone frequency, which is achieved by relocating the device on the afterlength. That is to say, the supposed working principle is that of a tunable vibration absorber. The nature of the resulting subsystem resonances is the main topic of the present investigations. The effect of these additional resonances on wolf tones differs from instrument to instrument and is also found to undergo changes with time, on a specific instrument. In a previous study of wolf tones, Debut et al. [2] have investigated the degrees of modification of a wolf tone on a cello under the influence of the ”New Harmony” wolf, amongst others. In contrast, the characteristics of a tunable absorber can reliably be shown for the wolf suppressor on the afterlength if bowed notes other than the wolf tone are regarded. One example thereof will be given below.

2 Resonances of the wolf-suppressor subsystem

2.1 Fundamental modes

In order to identify resonances that are added to the musical instrument by the application of the different wolf suppressors, the afterlength of a cello C string loaded with a wolf suppressor was plucked with a plectrum. The radiated sound was recorded with a microphone; experiments were conducted in an anechoic chamber. The position x_m of the wolf suppressor was varied along the afterlength of l =12.8 cm. To achieve this comfortably, the silk wrapping of the string had to be removed. The position x_m is measured from the edge of the bridge to the centre of the mass. The studied cello had a wolf around 175 Hz, which was strongest when played on the C string, as is common.

In Figure 2 the results for the three different wolf suppressors are represented. The spectra recorded at different relative positions (x_m/l) are plotted using a colour coding for the sound pressure level. Resonances of the wolf-suppressor subsystem can be identified as follows. Any spectral peaks that are constant with x_m can be regarded as inherent to the instrument without wolf suppressor. Such resonances of the cello can be identified at 93 Hz (A_0), 162 Hz and 175 Hz (probably B_1^+ and B_1^-, respectively) in Figure 2.

Thus, for each wolf-suppressor design, a similar, approximately parabolic trend of resonance peaks with respect to x_m is found, with the centre of symmetry located at the centre of the afterlength. The major difference between the three wolf suppressors with respect to this lowest resonance can be attributed to the difference in mass, as listed above – lower mass yielding higher frequencies. Consequently, the ”Wolf Tuner” resonances approach the relevant body resonances from above, with an approximate matching at the centre, whereas the standard suppressor and the ”LupX” have resonances mostly below the body resonances. They match the latter for positions close to the terminations of the string section.

As for effectiveness, each suppressor has generally been able to prevent the wolf tone, provided the correct mounting position. But this could not be reproducibly shown: With the change of the wolf-tone strength or nature, the effectiveness of the devices changed. A common side-effect of the application of a wolf suppressor (also documented in [2]) is the shift of the frequency at which the wolf tone is found – that is what one might call an ”evasive manoeuvre”. The underlying complex coupling mechanisms of string, body and wolf-suppressor subsystem lead to the creation of additional resonances that can provide the conditions for a shifted wolf tone. For a careful analysis, see [7].

2.2 Higher modes

In a lecture, Helmholtz [8] derived an equation for the resonances of a string of length l loaded with a mass m at position x_m:

$$mkc^2 = T \cdot (\cot kx_m + \cot k(l - x_m)), \qquad (1)$$

where k is the angular wavenumber related to the frequency and wave velocity by $\omega = k \cdot c$; T is the tension of the string. This equation can be solved for the wavenumber k numerically, results of which are shown in Fig. 3. It can be seen that, for a given position, the resonances of the loaded string are not in a rational (harmonic) relation. That is exactly what Helmholtz wanted to stress in his lecture, describing the resulting sound as ”kettle-like”. Indeed, the afterlength loaded with a wolf suppressor – especially on the cello – sounds much like a bell or kettle.

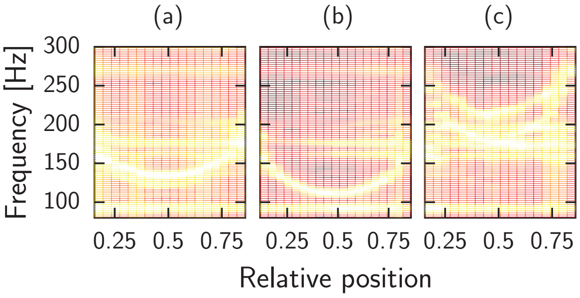

Figure 2: Radiated-sound spectra of three different wolf suppressors at different positions on the afterlength of a cello C string which was plucked for the experiment; sound pressure level increases in the progression black-red-yellow.

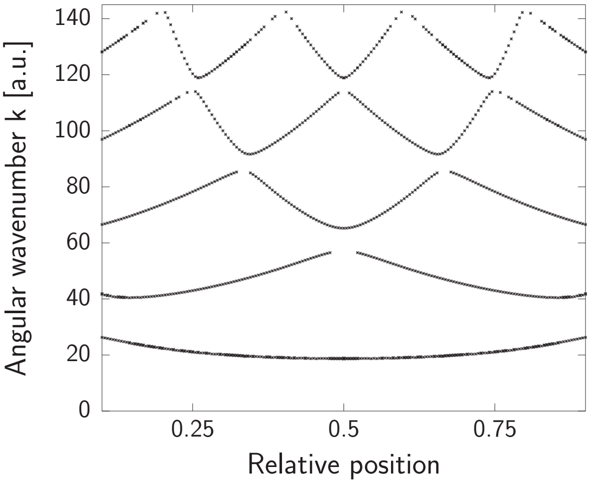

Figure 3: Theoretical resonances of a string loaded with one mass at different relative positions of the mass (x_m/l) on the string of length l.

The frequency interval presented in Figure 2, in the vicinity of wolf tone, exhibits the lowest or fundamental resonances of the respective wolf-suppressor subsystems and their dependence on position. However, higher modes were also present in the radiated sound of the plucked afterlength with each wolf suppressor. In Figure 4, this is illustrated for the standard wolf suppressor with frequencies up to 2 kHz. Continuously falling resonances can be perceived with increasing bridge-suppressor distance if the afterlength is excited at the section adjacent to the bridge. In contrast, a rising of pitch can be detected during this relocation of the mass when the section adjacent to the tailpiece is plucked. Both trends can be found in the plot of the theoretical solutions shown in Fig. 3.

As the higher harmonics are sufficiently dominant, this effect can be irritating when one tries to tune the fundamental resonances of the wolf-suppressor subsystem to the wolf tone. Such difficulties adjusting resonances are particularly encountered with the ”Wolf Tuner”. This becomes clear by inspecting Fig. 5 which shows a second-resonance trend between 500 and 600 Hz that has a maximum at the centre

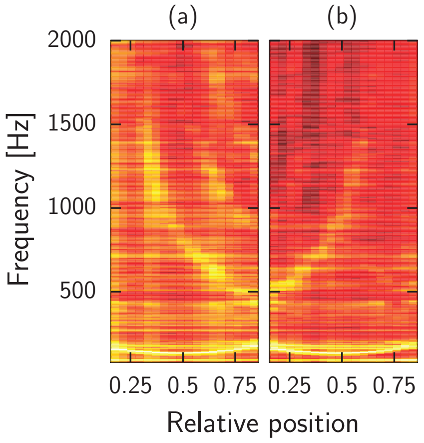

Figure 4: Higher resonances of standard wolf suppressor; (a): afterlength plucked next to the bridge; (b): afterlength plucked next to the tailpiece.

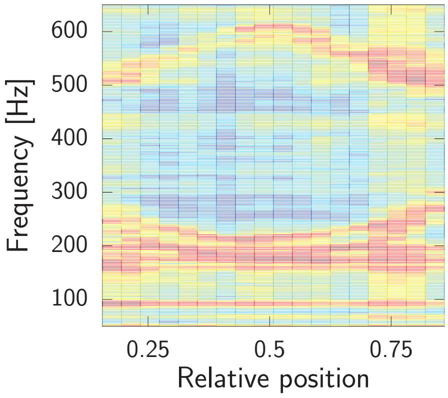

Figure 5: Higher resonances of the "Wolf Tuner": Converse trends of the fundamental and the higher resonances.

position — as opposed to the two fundamentals in the range of 180 ~ 300 Hz which exhibit a minimum at the centre.

3 Additional degrees of freedom of wolf suppressors on a string

In this section, it will be argued briefly that for arbitrarily shaped wolf suppressors, there exist more than those resonances that can be accounted for by the model of a mass on a string, that is to say, by equation 1 and Figure 3. A paradigm of this are the resonances created by the "Wolf Tuner". It has been mentioned casually that there are two fundamental resonances. This can be read from Figure 2 and 5 where we see two closely spaced resonance trends that consequently can be referred to the same mode with regard to the mass-string model.

By high-speed camera recordings and measurements with different string polarisations, it could be shown that these two resonances stem from different directions of mass-string vibrations, or polarisations (*cf.* Fig. 6 (a)). The phenomenon was investigated with a "Wolf Tuner" for the violin: On the violin, the spacing between the two fundamental resonances is larger and thus the effect can be analysed more easily. For example, the lower resonance could be excited separately by bowing at the curved side of the "Wolf Tuner", see Fig. 6 (c). The higher resonance could be elicited by bowing at the crease of the "Wolf Tuner" (Fig. 6 (b)). The difference in frequency presumably results from a difference of the effective mass for the respective type of vibration. These dynamics are to be discussed in more detail in a follow-up paper.

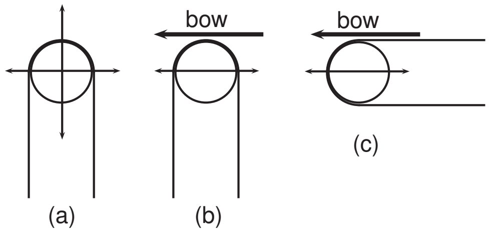

Figure 6: Different polarisations of a string with the "Wolf Tuner". These polarisations can be excited separately by bowing and yield a sound of different frequency.

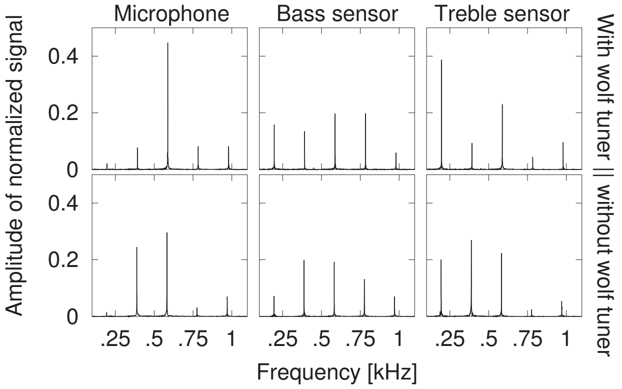

Figure 7: Bowed open G string of a violin with attached "Wolf Tuner"; recorded with a microphone (left) and with sensors under the bridge feet (center and right). The subsystem with the "Wolf Tuner" is tuned to the second harmonic, which it absorbs to some extent.

4 Influence on notes other than wolf tones: vibration absorption

The effect of selectively absorbing some of the vibrational content of the bowed string by judiciously installing a wolf suppressor on the afterlength could be reliably shown for all investigated specimen, on a cello as well as on a violin. For the measurements represented in Figure 7, a "Wolf Tuner" was installed on a violin, on the afterlength of the G string, and tuned to its second harmonic at approximately 400 Hz. The radiated sound was recorded with a microphone. Additionally, the vibrations of the two bridge feet could be detected with minimally-invasive film sensors as described in [5]. It becomes obvious that the second harmonic is much weaker in the presence of the tuned wolf-suppressor subsystem (upper row of Fig. 7), at all recording locations, than without the "Wolf Tuner". A similar absorption can be found on instruments with sympathetic strings, on the Indian sarangi [3], for example, or the Steinway grand piano with duplex strings [9].

5 Conclusion

The working principle of wolf suppressors against wolf tones on bowed-string instruments has been investigated.

The resonances of the wolf-suppressor subsystem were measured with different designs of suppressors for installation on the afterlength of the string. It was shown that the mass as well as the geometric shape of the device can influence the resonances. The possibility of tuning the subsystem by relocating the suppressor on the afterlength turns it into a tunable vibration absorber, which could be shown for all investigated specimen.

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