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The Wolf in the Cello

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Introduction In the musical world the term 'wolf' is attributed to unpleasant tonal effects, but it is most well known when referred to the cello. The wolfnote occurs in most cellos, to be found about F or F# on the G string, or at the same note on the C string, that is on the two heaviest strings. The wolfnote occurs at the same frequency as that of the main body resonance. It is described as a jarring note, a cyclic stuttering response to the bow, or a cyclic fluctuation of intensity of imperfect quality. There have been previous investigations of the wolfnote in the cello[1,2,3]. The explanation frequently accepted for the physical occurrence is that of Raman[1], that there is a cyclic alternation between vibration at fundamental and octave of the string.

A detailed analysis of the action of instruments of the violin family in terms of elementary circuit theory has been given by Schelleng[4]. Schelleng considered the equivalent circuit for the cello at the wolfnote as a resonant transmission line (the string) coupled through a transformer (the bridge) to a series resonant circuit (the body) with resistive losses, due partly to sound emission. At the wolfnote the two resonant circuits have the same frequency and they are excited by a generator (the bow) placed in the first circuit close to the transformer.

At the wolfnote the circuits present to the bow an impedance for which there are three frequencies having zero reactance. At two of these steady oscillations are possible, each of which is equally forced. It is only by exciting both together, therefore, that the bow can elicit a note from the cello. Schelleng gives a criterion for the occurrence of the wolfnote in the cello.

These investigations into the wolfnote in the cello have been carried out by (a) direct frequency analysis of the wolfnote[5], (b) plate tone testing and (c) string excitation testing. In the latter two, acoustical impedances can be measured directly and related to Schelleng's theory.

Direct Frequency Analysis of Wolfnote The wolfnote on the G string in two cellos was analysed into frequency components. Tape recordings of each wolfnote were made at a particular stopped string length, and the most regular part of the tapes was made into loops and analysed by use of a narrow band filter.

In Cello 1 the analysis showed that vibrations of the string at the fundamental frequency and overtone frequencies up to the third were split into pairs of vibrations separated in frequency by a few hertz. The conclusion is therefore that in this cello the wolf occurs because the normal harmonic series of oscillations of the string alters to become a series of pairs of oscillations, the two components of each pair being equally forced by the bow. Pairs are situated equally on each side of the expected frequency of the relevant harmonic of the string, and the frequency separation of the pairs increases proportionally with harmonic number up to the 4th, Fig. 1.

In Cello 2 the wolfnote is caused by the splitting of the fundamental vibration alone into a pair. No overtones of the string vibration were found to be split. The G string on Cello 2 is heavier than on Cello 1, and its motion appears more simple.

Direct tonal analysis of the splitting of the fundamental vibration of the G string in Cello 1 has been further investigated by ear. With the bridge of this cello loaded with 14 gm the wolf is lowered in frequency and interval of string length over which the wolf could be elicited by the bow was increased to 4 cm. At the extremities of this range the string had frequencies of 152 and 141 Hz. The frequency of each component of the fundamental pair of the wolf was easily measured by listening for zero beating (± 2 Hz) between the wolf and a pure tone produced from a loudspeaker. The frequencies of the fundamental pair of vibrations of the wolfnote were resolved in this way and measured over the range of stopped string length in which the cello wolfed. Outside this range only one vibration was detected, at the fundamental frequency. Fig. 2 shows the frequencies of the vibrations excited by the bow in the range of the wolf. The production of two forced vibrations in the range of wolfing is noted. Such splitting indicated by Fig. 2 is that expected for coupling of two resonant circuits when excited by a wide range non-linear generator[4].

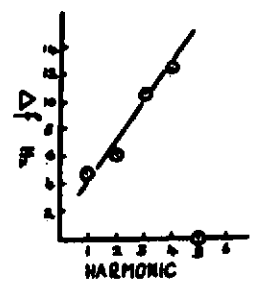

Fig. 1. Frequency separation (Δf) of harmonic pairs at wolfnote. Cello 1, G string.

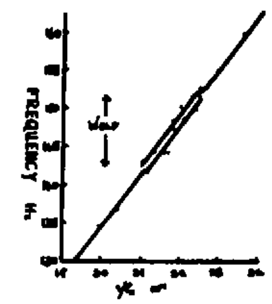

Fig. 2. Frequency versus inverse of string length, $1/\ell_s$, at wolf note. Cello 1, G string, bridge loaded with 14 gm.

<u>Plate Tone Testing</u> The cello is vibrated at the bridge by means of an armature type magnetic transducer with a small disc of mu-metal stuck to the bridge in the conventional method of testing an instrument[6]. The sound pressure level of the sound produced as the transducer is supplied with an a.c. voltage sweeping from 140 - 200 Hz is measured with a microphone placed a plate length in front of the instrument. The length of the G string is altered progressively over the range in which the instrument is known to wolf (160 - 180 Hz, bridge unloaded, other strings open).

Outside the range of the wolf the instrument emits sound mainly at the plate resonance (173 Hz) which produces a single peak with structure. Sound is also produced at the frequency of vibration of the stopped string, a sharp single resonance peak. These two resonances do not overlap and do not couple together.

When the G string is stopped in the range of the wolf the single main resonance of the body alters to become double. The two main peaks are about equal in the middle of the range, and are separated by a small sharp peak. A sequency of traces of SPL versus frequency is shown in Fig. 3, for lengths of the G string through the range of the wolf. The mutation of sound emission from the cello in the range of the main plate resonance when the G string is stopped in the range of the wolf shows the occurrence of extensive coupling between the two resonant systems, string and body. The similarity of the SPL traces, which are related closely to the amplitude of vibration of the front plate, to the response of coupled electrical circuits confirms the suggestion of Schelleng.

Direct measurements of acoustical impedance at the bridge (the transformer of the equivalent electrical circuit) would not be easily interpreted according to Schelleng's theory, but such measurements could be made in a manner similar to Eggers[7]. It would be of greater significance to measure the impedance presented to the bow (the generator) at the point of bowing on the string, for the interpretation of such measurements would be easier in terms of the equivalent electrical circuit. The point of bowing represents the input to the two coupled circuits. The following method of investigation should enable the impedance at the point of bowing to be measured.

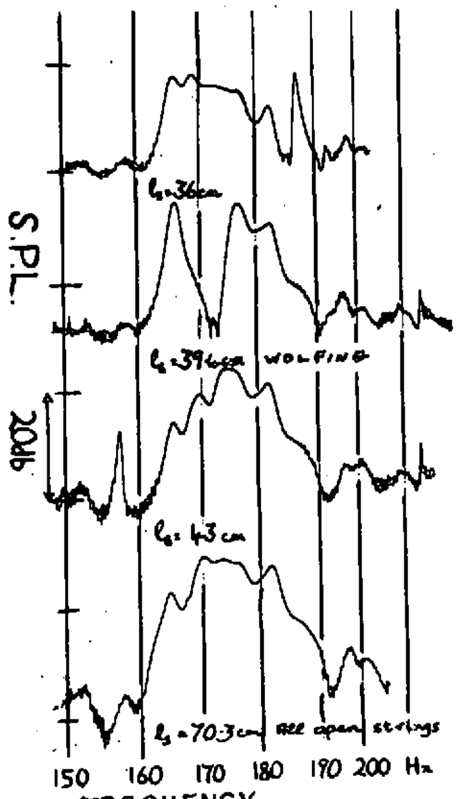

Fig. 3. Plate tone testing. S.P.L. versus frequency of vibration at various stopped G string lengths, ℓ_S. Wolf best elicited by bow at ℓ_S = 39.4 cm. Cello 1.

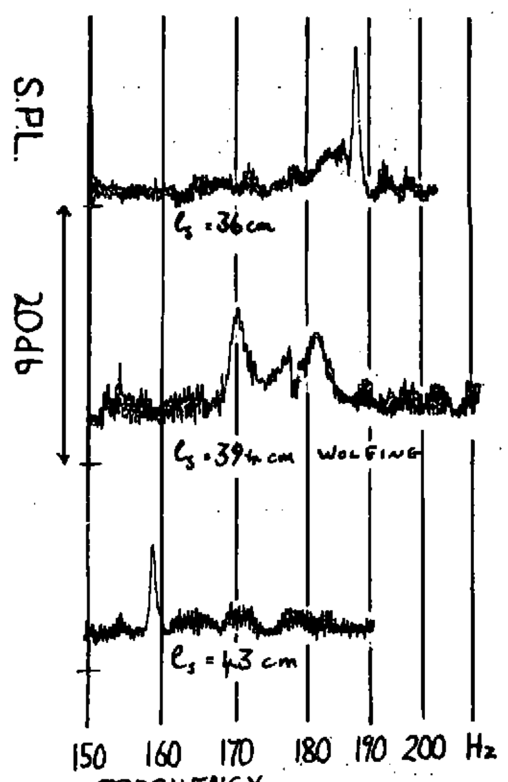

Fig. 4. String excitation testing. S.P.L. versus frequency of a.c. signal to string at various G string lengths, ℓ_S. Magnet placed at 6.5 cm from bridge. Cello 1.

<u>String Excitation Testing</u> The string is vibrated at the point of bowing by placing a horseshoe magnet about the G string at this point and passing an a.c. current, sweeping in frequency, through the metal covered string. The Lorentz force causes the wire to vibrate at the frequency of the current. Sound output from the cello is measured with a microphone placed one plate distance away

when the driving frequency is swept from 140 to 200 Hz for various stopped string lengths. Fig. 4 shows the SPL with string excitation testing for the same stopped lengths of the G string used in plate tone testing.

Outside the range of wolfing sound emission takes place at the frequency of vibration of the string, and is restricted to a narrow frequency band. In the range of the wolf, sound emission takes place over a broader frequency band which contains two main peaks, which are separated by a sharp peak, or step. The sound emission demonstrates the modification to simple sinusoidal motion of the string due to the strong coupling of string and body at the resonant frequency of the body.

Impedance measurements at the point of bowing should follow from a measurement of the voltage induced in the string by its motion in the magnetic field. The voltage across the string will consist of three parts: (a) a resistive voltage drop due to the electrical resistance of the string, (b) an induced voltage due to resistive acoustical losses (e.g. in wood, and in production of sound), and (c) an induced voltage in the string due to the reactive part of the acoustical impedance.

References

1. C.V. Raman, Phil. Mag. 32, 391-395 (1916)
   Nature 97, 363 (1916).
2. G. W. White, Proc. Cambridge Phil. Soc. 18, 85-87, (1915).
3. W. Vollmer, Dissertation Karlsruhe 1936, Uber die Erscheinung des wolftones bei Streichinstrumenten insbesondere beim Cello.
4. J. C. Schelleng, J. Acoust. Soc. Am. 35, 326-338 (1963).
5. I. M. Firth and J. M. Buchanan, The Wolf in the Cello, J. Acoust. Soc. Am. 53, 457, (1973).
6. C. V. Hutchins, Catgut Acoustical Society Newsletter, 15, 15-18, (May 1971).
7. F. Eggers, Acustica, 9, 453-465 (1959).

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