On The Accuracy Of Calculation Of The Impedance Spectra Of Woodwind Instruments

Conference or Workshop Item

On the accuracy of calculation of the impedance spectra of woodwind instruments

Keith Bowen (Royal College of Music), Kurijn Buys and David Sharp (Open University)

Most woodwind instruments in museums may not be played, because of the risk of damage. However, if the acoustic impedance spectra (tube resonances) can be measured or calculated, many conclusions may be drawn about, for example, pitch, timbre, intonation, utility of alternative fingerings and effects of bore shrinkage.

Impedance measurement methods may sometimes be applied to instruments in museums, but are only meaningful if the instrument is in good playing condition, free from leaks. However, the overwhelming contribution to the acoustic properties of a woodwind is made by the shape of its air column. If the bore shape and tone holes are measured sufficiently accurately, we may compute the acoustic impedance of the instrument for all fingerings using standard equations of linear acoustics.

This methodology has been thoroughly tested by applying it to a Heckel bass clarinet in A (German system) from 1910. This working instrument has been kept continuously in good playing condition but has seen relatively light use. Measurements were made using a calibrated tape measure and (plastic) Vernier calipers, which minimized bore damage. The results were compared with experimental measurement of acoustic impedances using a BIAS system at the Open University. Impedance calculation software was written in MatLab™ following the scheme of Plitnik and Strong[1], using the later developments by Keefe[2], Cronin[3] and Dalmont et al.[4] For all fingerings the impedance peaks agreed with the calculations, on average to better than 10 cents in frequency for the peak forming the basis of the sounding note. This could be empirically corrected by an end correction of 3 mm (on a 1350 mm instrument). The reed/embouchure impedance was semi-empirically corrected by an end correction of 17 mm, which is consistent with the theory and experiments of Dalmont et al.[4] on soprano clarinets.

Playing tests were in good agreement. The playing frequencies agreed well with the calculations using the above end corrections, both when the mouthpiece was fully pushed in and when it was pulled out by 10.8 mm to correct overall intonation. The calculations also correctly predicted the excellent tuning and timbre of the fork fingering for written B♭2, the "patent C#" fingering for C#3 and the unsuitability of the fork fingering for E♭2, which was about a quarter-tone sharp.

The 'impedance mapping' method of Jeltsch et al.[5] has been further developed into a powerful tool for summarizing the acoustical behavior of a complete instrument and comparing it with other instruments. A new method of determining the cut-off phenomenon in woodwind instruments, utilizing the higher resonances in the tube, has shown that there is a cut-off band rather than a single frequency. In the case of the Heckel, the Benade approximation gives a cut-off frequency of 1000 Hz, whereas there is actually a range of 920 - 1320 Hz, dependent on the fingering.

These methods are being applied to the study of non-playable bass clarinets in museum collections, in an attempt to elucidate musical differences between instruments of different designs.

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[1] G. R. Plitnik and W. J. Strong, "Numerical Method for Calculating Input Impedances of the Oboe," *Journal of the Acoustical Society of America* 65 (1979): 816–25.
[2] D. H. Keefe, "Woodwind Air Column Models," *Journal of the Acoustical Society of America* 88 (1990): 35–51.
[3] Robert H. Cronin, "Understanding the Operation of Auxiliary Fingerings on the Modern Bassoon'," *Journal of the International Double Reed Society* 24 (1996): 13–30.
[4] J.P. Dalmont et al., "Some Aspects of Tuning and Clean Intonation in Reed Instruments," *Applied Acoustics* 46, no. 1 (1995): 19–60, https://doi.org/10.1016/0003-682X(95)93950-M.
[5] Jean Jeltsch, Vincent Gibiat, and I. Forest, "Acoustical Study of a Set of Six Key Baumann's Clarinets ≈," in *Proc. International Symposium on Musical Instruments* (International Symposium on Musical Instruments, Dourdan, 1995), 134–40.