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Fabrication of Chinese Transverse Flute, Dízi: An Acoustic Impedance Analysis

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亚洲音乐科技
Asian Music Technology

Dízi (笛子): Introduction

The Chinese transverse flute Dízi (笛子)

- long documented history, first mentioned in Han Dynasty (206 BC - 220 AD)
- Simple construction using "found material": natural bamboo
- Drilled simply with with series of holes (no keys used)
- *6 finger holes + a embouchure hole + a 'membrane-hole' + a pair of foot holes.*
- Distinct sound and timbre, allowing for *complex musical expression*
- Principal instrument of Traditional and Classical Chinese Music

Modern (top) and traditional (bottom) Dízi in the key of C, compared alongside the embouchure hole (first hole on the left). Note the superficial similarities of hole placements and external dimensions.

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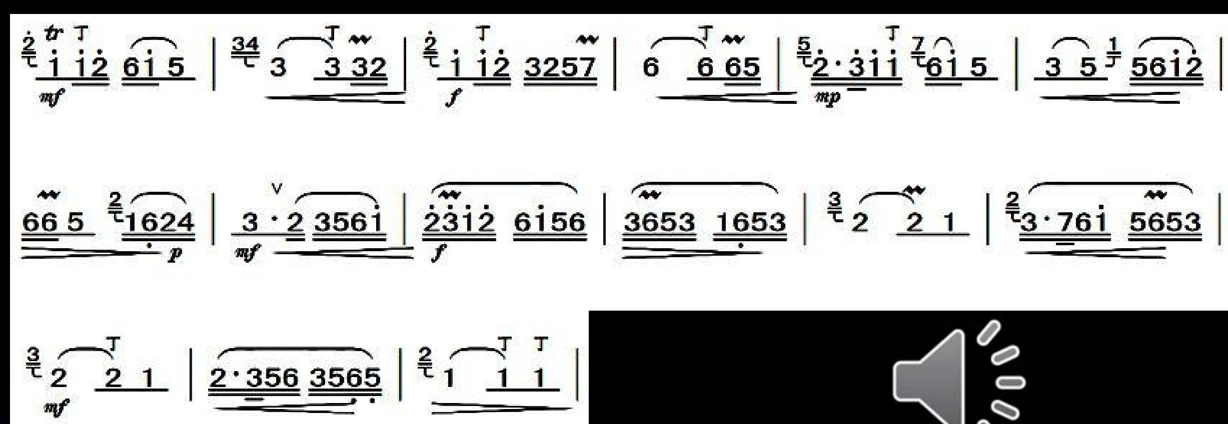
Musical Example: “Gusu Xing” 姑苏行, solo Dízi excerpt…

- Traditional Dízi tune popularized by master Dízi player and composer Jiang Xianyu in 1962.
- Classical “travel poetry” music evoking the beautiful scenery and traditional gardens of the ancient city of *Suzhou*
- *Intimate and elegant, this tune has relaxed and bright rhythm and a simple but complete structure
- one of the representative pieces of the “Southern School” of Dízi repertoire
- *Ng Hsien Han* (SUTD PhD Student): performs on C-key Dízi, known as a “QǔDí” (“lyrical” Dízi), long & mellow
- www.dicapella.com



Dízi (笛子): Constraints/Challenges

The Chinese transverse flute Dízi (笛子)

- *Despite* (or because?) long history, traditional design, not systematically rationalised
- Literature shows minimal acoustic understanding of design/fabrication & innovation
- "found material": geometry is limited by the *natural state* of the bamboo blank!
- Design parameters: int/external dimensions, taper, surface conditions, uniformity
- Holes: optimal position, dimensions and shape, wall angle and edges?
- *Difficult* to achieve good intonation, uniform timbre, pitch range & playing response
- Cultural expectation that Dízi (笛子) must look (and be) natural!
- Master makers can combine *experience* and '*intuition*' to produce top instrument

Mr Ng Teck Seng, Dízi master-maker, Singapore

- Western classical-music trained: musician + orchestral conductor (Shanghai Conservatory)
- Makes Dízi >25 years; actively & systematically innovates on Dízi design & fabrication
- His 'modern' innovations result in excellent intonation, uniform timbre, wide pitch range (3-8*ves*), climate-stable, responsive and expressive instruments
- His Dízi are highly sought-after by international professional and expert players
- Now consults at China Conservatory of Music (Beijing) as instructor (Music Technology)
- Actively seeks to systematize and innovate traditional musical instruments
- Opportunity arose to collaborate: **investigate the acoustics of Dízi and its fabrication**!

By Lam Shushan
@ShuShanCNA

19 Jun 2016 06:26PM

Bookmark

Singapore

In China, this Singaporean flute-maker is a 'sifu'

Master craftsman Ng Teck Seng's lifelong devotion to fixing a century-old discord in chinese orchestral music has gained the attention of China's leading music school.

Dízi (笛子): Study Objectives

1. Characterize Fabrication Process in terms of Acoustic Behaviour

- Transformation from bamboo blanks to Dízi
- While the maker *knows* what geometric transformation is desired
- We wish to discover what acoustic behaviour accompany these geometric transformation
- Characterize the evolution from bamboo blank to world-class instrument

2. Identify Factors and Predictors of Dízi Quality

- What makes a good Dízi good? (and a poor Dízi poor?)
- What objective factors contribute (material, geometric, fabrication, acoustics)
- What are some clues? Can these be quantified?
- What can be revealed by studying acoustic properties accompanying the fabrication process?

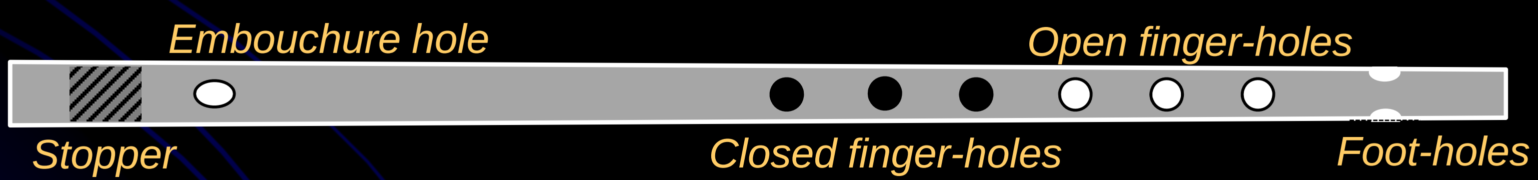
3. What broad lessons can be learnt about traditional instrument making?

- What *acoustical* clues are already known by traditional instrument makers?
- What contributions and innovations does a systematic acoustic study of traditional making processes provide to the preservation and improvement of such traditions?

Materials & Methods

Tracking the Fabrication Process

- produce Dízi in “High G” (i.e. sounds ‘*doh*’ = G5 – 784 Hz – for the fingering xxx ooo)
- 9 similar blanks chosen, *Pleioblastus amarus* bamboo (common Chinese name: 苦竹)
- Seasoned several years in a climate controlled environment for stability
- Cut to a nominal length of 366 mm, with characteristic dimensions:
  - ‘upstream’ end, internal and external diameters: 14.5 and 21.5 mm respectively
  - ‘downstream’ end, internal and external diameters: 12.5 and 19.5 mm
  - gentle internal taper of −0.08°.
- Broadly, the fabrication process involves the following sequence



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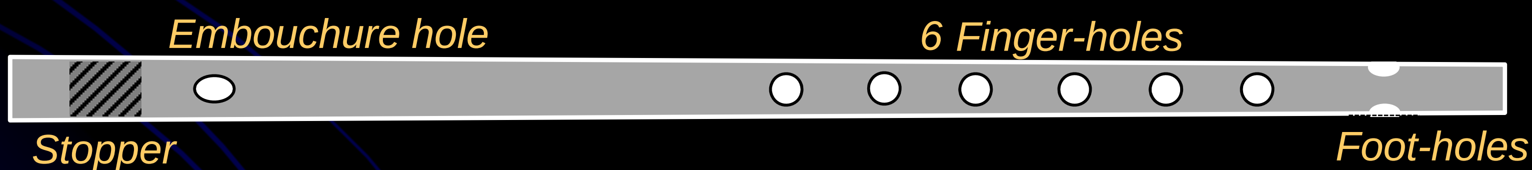
  - gentle internal taper of −0.08°.
- Broadly, the fabrication process involves the following sequence (+ *Z*-measurement)

  0. ***Blank*** (cut to size)
  1. **Embouchure hole** cut and dressed
  2. "upstream" **stopper** positioned, and downstream end of tube trimmed to length
  3. **Foot-holes** cut and dressed
  4. **Finger-holes** cut and dressed, *beginning at the downstream end*

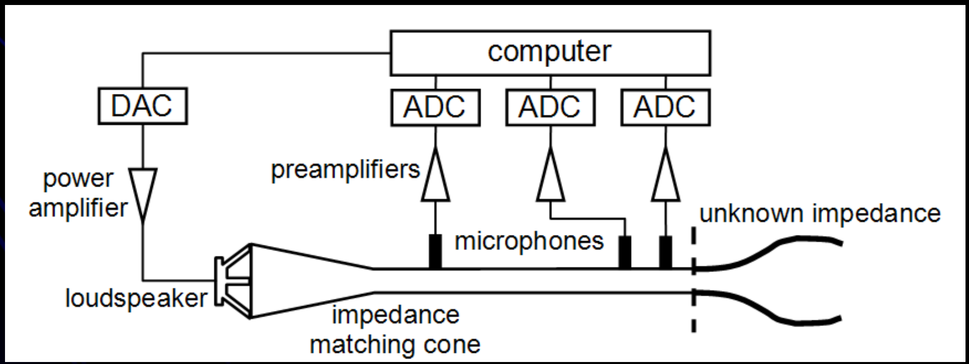


- Note: because of the *organic nature* of bamboo, no 'fixed' dimensions per se are used
- The maker has to judge – *for every bamboo blank in hand* – the optimal position, size and wall/edge angle of each hole by iteratively playing ⇌ adjusting /correcting
- **A false step cannot be undone!**

Materials & Methods

Acoustic Impedance (*Z*) Spectrometry

- Acoustic Impedance associated with *each step* of Dízi Fabrication Process is measured
- Three-Microphone Two-Calibration (3M2C) technique is used
- Well-established: 3M2C previously used on western classical flutes, sax, clarinets, brass
- Method achieves *high precision* over *wide dynamic range* by
  1. using 3 pressure transducers (↑ frequency range over which precision available)
  2. calibrates using non-resonant reference impedance loads (removes singularities in spectrum)
  3. iteratively reduces sensitivity to system noise at particular frequencies
  4. measures *Z* at the reference plane
- B&K 4944A ¼-inch mics + B&K Nexus + MOTU interface + MATLAB
- Frequency range collected: 100-4000 Hz @Δf = 2.7 Hz resolution
- Ambient conditions 25 ± 0.5°C; 55 ± 5% RH (both lower than playing conditions, so it may be expected that features observed may deviate very slightly in frequency by ~2%; ~30¢)



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- Radiation impedance of embouchure hole: accounted for using a short 'correction' spacer (4 mm) between the reference plane and the embouchure hole, and sealed using gasket of adhesive putty ('blu-tack'). (This gasket is necessary, because exterior surface is natural and unfinished, so each bamboo blank is neither the same external diameter nor perfectly cylindrical)
- At every measurement, gasket is checked for consistency and sealing

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Materials & Methods

Study on Fabrication Process

- 9 identical bamboo blanks chosen
- Acoustic Impedance associated with *each step* of Dízi Fabrication Process is measured

Predictions on Dízi Quality

- Interestingly, upon initial steps (embouchure hole cut-and-dressed + stopper fixed), our Dízi master-maker was able to rank the blanks intuitively, right away
- Two best and two poorest Dízi yielded from these 9 blanks were predicted by the maker

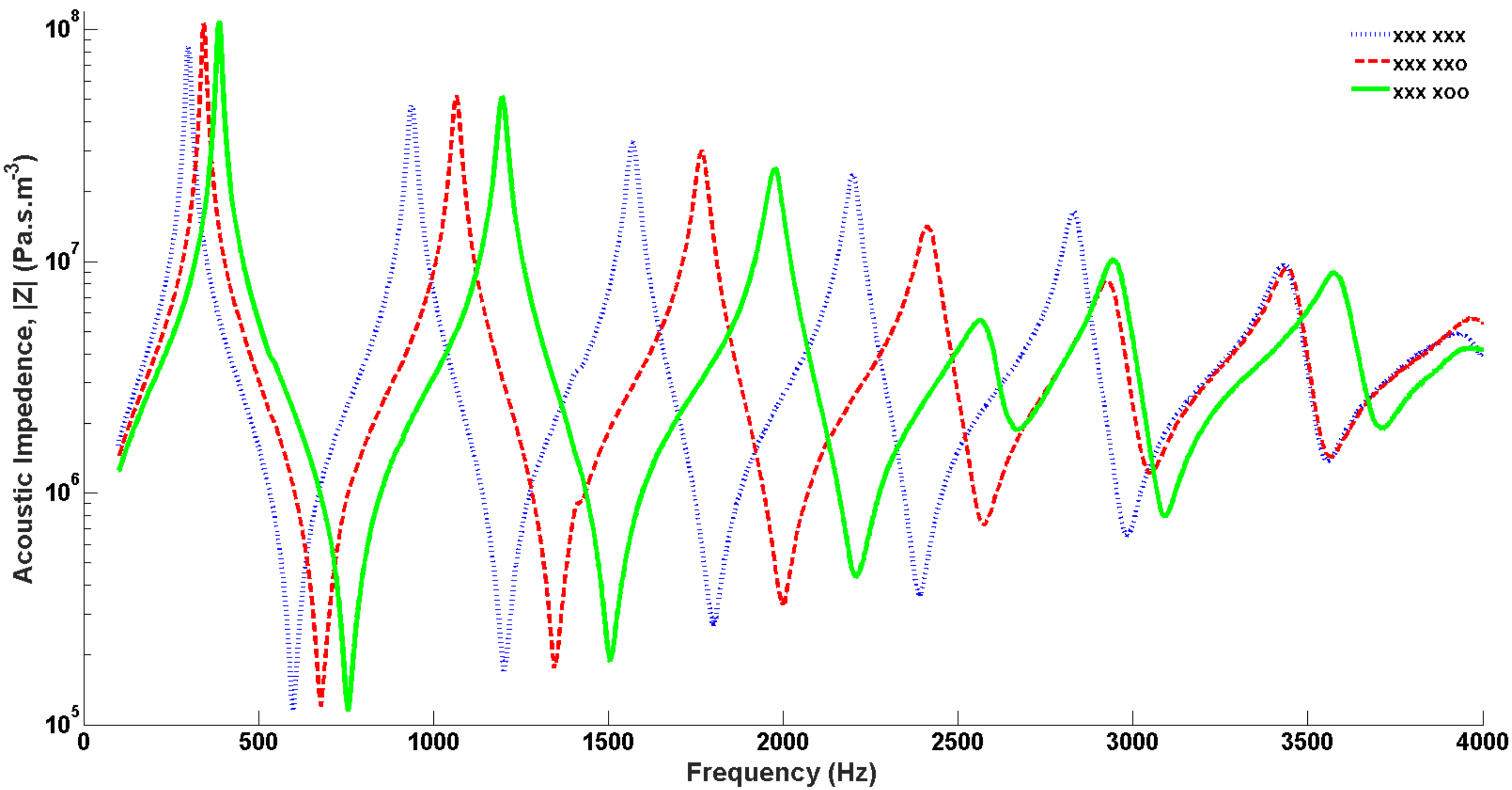
Effects on Varnishing

- One of the ‘average’ blanks (ranked as above) was set aside for separate study: Examine the effect of *varnishing the inner surface* (varnishing Dízi interior is integral to imparting protection and stability against moisture and condensation from player’s breath)
- Varnish applied on days 3, 4 and 6
- Impedance measurements taken just *before* and *after* a fresh coat is applied, and also when allowed to cure

Results and Discussion

Step-by-Step Fabrication & Dízi Impedance Spectra (*good quality blank*)

- *Z*(*f*) for fingerings : xxx xxx, (*soh*, D5, 599 Hz); xxx xxo, (*la*, E5, 674 Hz); xxx xoo (*ti*, F#5, 756 Hz)
- Minima indicate operating resonances (open-open pipe): sharp, regularly spaced (converge ~3 MΩ, ↑*f*)
- E.g. xxx xxx Fingering: 599 (D5+34¢), 1202 (D6+40¢), 1979 (A6+36¢), 2390 (D7+30¢) and 2984 (F#7+14¢) Hz
- This indicates uniformity of geometry, texture and material quality (efficient tone generation achieved when resonance frequencies approximate the harmonic series, allowing harmonics generated by the non-linear jet to be reinforced!)
- Implications on playing responsiveness, control and stability of tone. (consistent with classical flute studies)



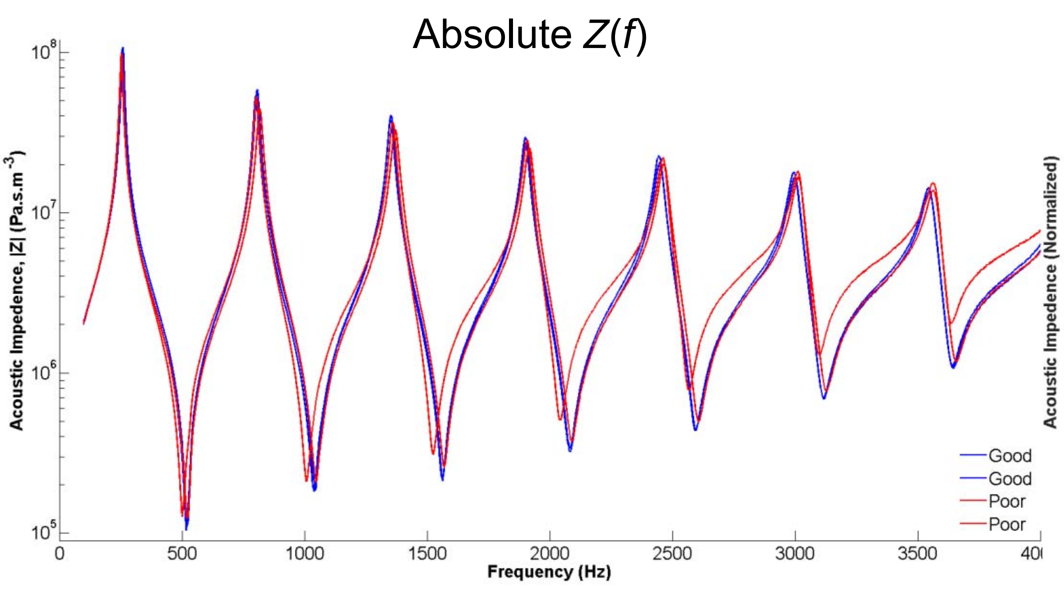
Results and Discussion

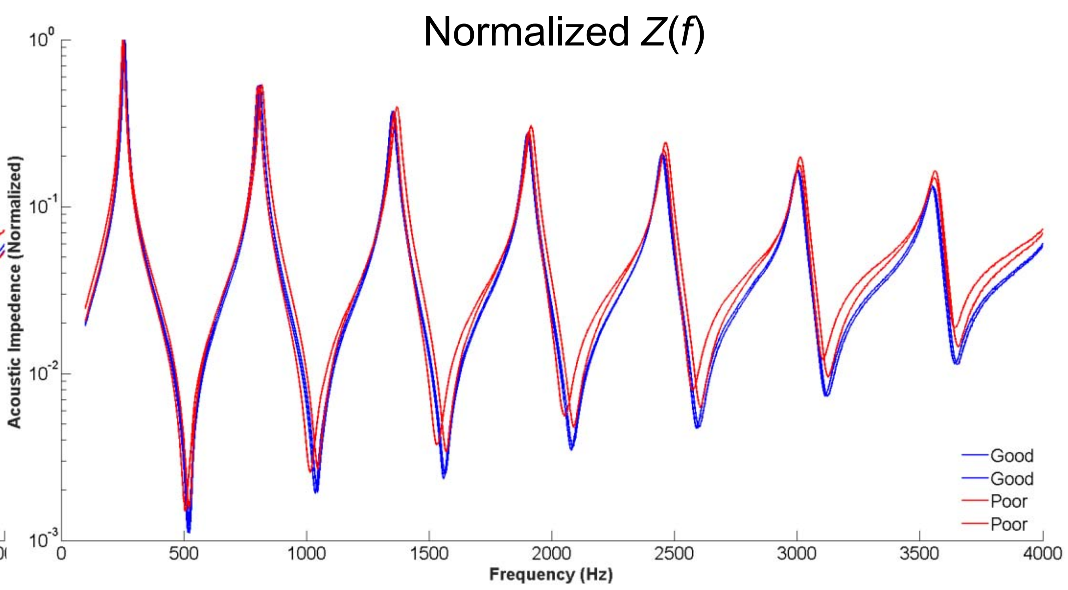
Predictions of Dízi Quality

- We compare 2 good *vs* poor quality blanks (measured in Step 0), by overlaying their *Z*(*f*)
- Master-maker had already intuitively and independently assess and ranked them(!) (he is naïve to *Z*(*f*))

- Simply overlaying *Z*(*f*):
- Good blanks = good agreement (tight & consistent “target” Z-structure!);
- Poor blanks = vague agreement but yields no immediately discernible trends (some inkling)
- (is master-maker mistaken?)

- What if we normalized *Z*(*f*), scaled to the first *Z*(*f*) maximum?
- (This will reveal the Q-factor of resonances)

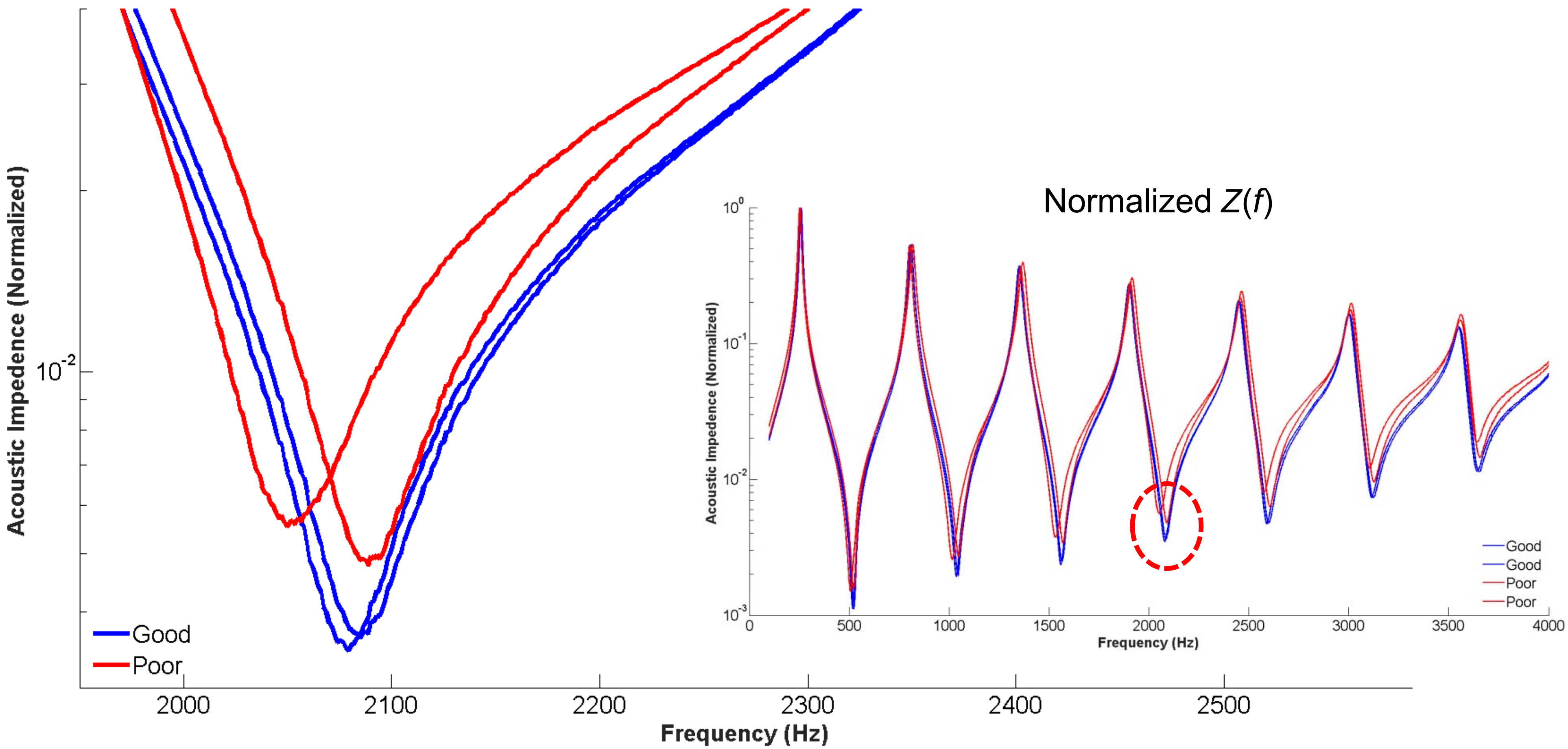




Results and Discussion

Predictions of Dízi Quality

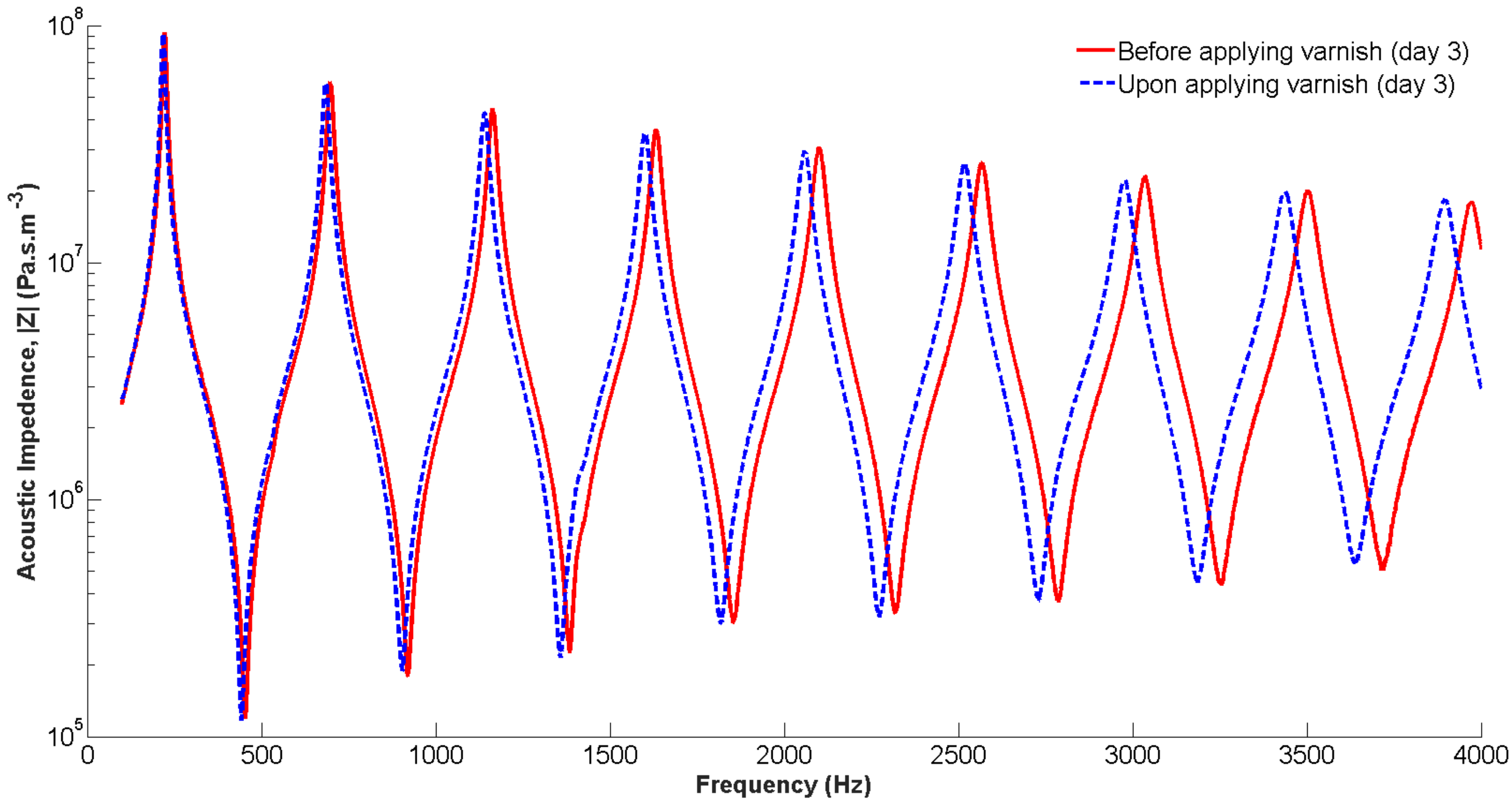
- We compare 2 good *vs* poor quality blanks (measured in Step 0), by overlaying their *normalized Z*(*f*)
- Master-maker had already intuitively and independently assess and ranked them(!) (he is naïve to *Z*(*f*))
- Good blanks: resonances show consistent (harmonic) distribution, very similar structure!
- Poor blanks: somewhat agreement in overall structure, but not consistent!
- *Minima* (normalized): good blanks show deep, sharp, consistent minima (High Q-factor); poor blanks don't!
- Tight consistency indicates ↑ dimensional uniformity (eg taper), ↓ surface losses: desirable qualities.



Results and Discussion

Effects of Varnishing (average quality blank)

- Daily measurements (Day 1, 2, 3) of *unvarnish* blank demonstrate excellent consistency in *Z*(*f*): stability
- Day 3: varnish is applied, and Z(f) measured just *before* and *upon* application
- Dramatic downshift in frequency of Z(f) structure, upon varnishing! (similar for subsequent coats)
- This indicates a change in internal wall losses! (reported previously in wooden flutes by Dickens, 2007)
- *Remarkably*, when allowed to cure, resonances recover to original (within limits of meas. uncertainty, ± 2.6 Hz)



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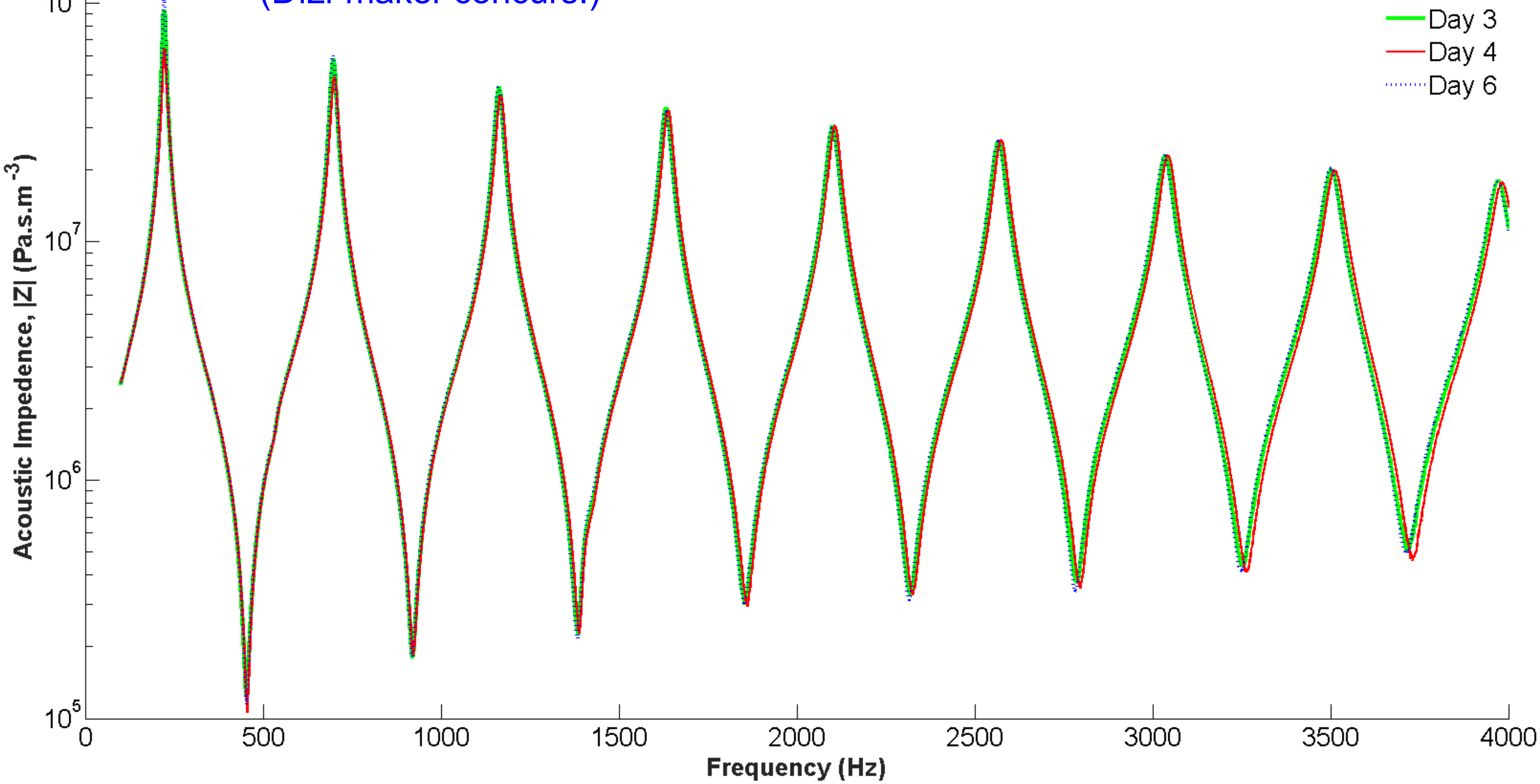
- *Remarkably*, when allowed to cure, resonances recover to original (*within limits of meas. uncertainty*, ± 2.6 Hz)
- Varnishing (imparts moisture-proofing but) does not transform [redeem?] original acoustic performance!
- Choice of raw material (including geometric/dimensional stability, surface texture) is critical at the outset. (Dízi-maker concurs!)



Conclusions

By Accompanying Each Step of Dízi Fabrication with Acoustic-*Z* Measurements

- Insights into acoustic implication + design consideration of high performance Dízi
- Requires careful selection of appropriate bamboo blanks with optimal geometry, material characteristics, surface quality, and then matched with careful fabrication judgements
- Dízi quality (e.g. good intonation across registers) depend on uniformity of bore taper, and also on finger-hole position/geometry (foothole and stopper positions also contribute)
- Varnishing (imparts moisture-proofing qualities for stability) but does not offer redemption for poor/mediocre material quality
- Best performing Dízi observed are associated with
  - Blank shows acoustic resonance associated with *Z*(*f*) minima with high Q-factor
  - Well-defined acoustic resonances which are regularly spaced in frequency
  - (efficient tone generation achieved when resonance frequencies of the resonator approximate the harmonic series, allowing harmonics generated by the non-linear jet to be reinforced!)
  - This indicates uniformity of geometry, texture and material quality
- Makers of traditional instruments may seem to follow artisanal traditional methods, but with the right combination of curiosity, intuition and experience, they are often "on the right track" and can offer profound scientific and technological insight (even when the effects are seemingly subtle).

Thank you!

Acknowledgement

- The impedance measurements were conducted at the Acoustics Lab, School of Physics, University of New South Wales, Sydney Australia.
- We are grateful to John Smith and Joe Wolfe for kindly hosting us.

Question & Answers?