IMPROVING MUSICAL INSTRUMENT STRING LONGEVITY WITH ORGANOSILANES

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Organosilanes in Product Development Applications

Hydrophobic Coatings for Inorganic Powders
(*U. S. Patents 7,387,795; 5,543,173 ; 5,348,760*)

Safety Glass
(*U.S. Patent 5,747,617*)

Floors
(*U.S. Patent 6,413,618*)

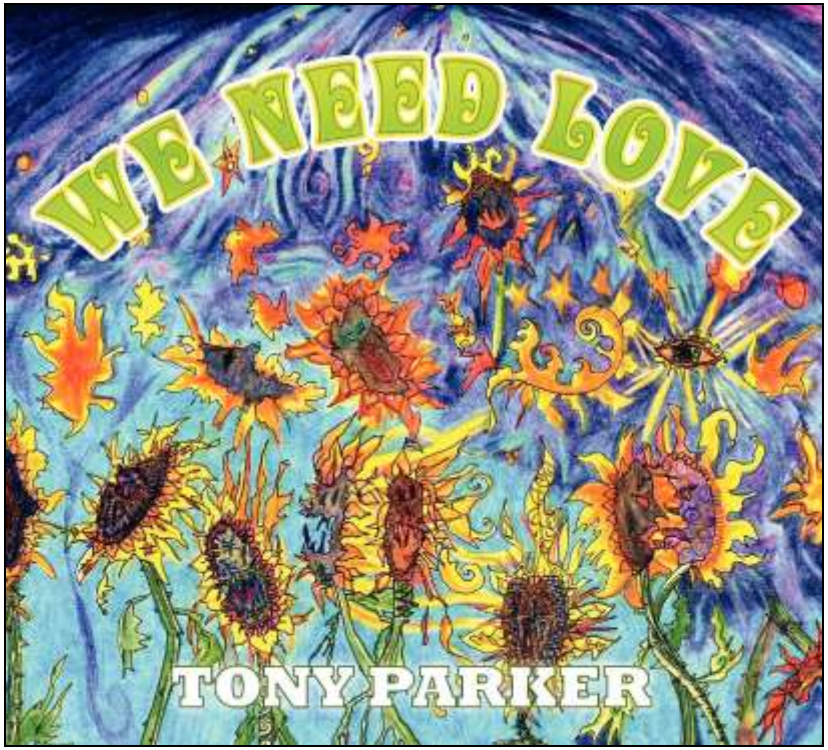
Coatings
(*U.S. Patent 6,759,096*)

***Musical Instrument Strings**
(*U. S. Patent 7,476,791*)

Protein-based Adhesives (Patents Pending)

Self-assembled Monolayers

Silane Treated Strings



ORGANOSILANE TREATED STRINGS
(*U. S. Patents 7,476,791 & 6,348,646*) →

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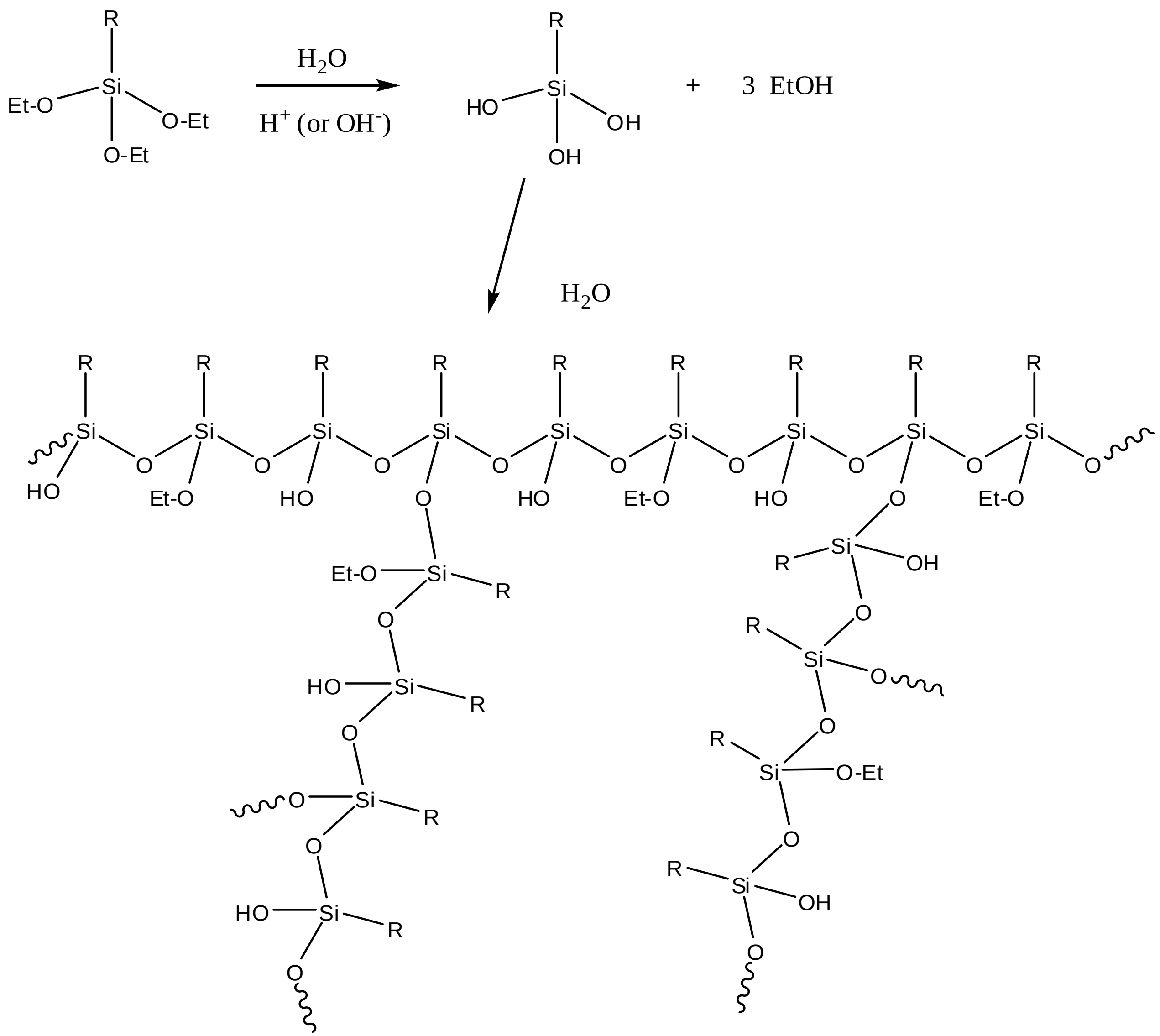
GENERAL CHEMISTRY



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MUSICAL INSTRUMENT STRINGS AND CORROSION

Background

The corrosion of metallic musical instrument strings has been a problem for more than 100 years

Analytically, the vibration of an ideal string can be expressed as follows:
$f(n) = n/2L\ (T/m)^{1/2}$

f is the vibration frequency
n represents the overtone vibration (n = 1 for the fundamental tone)
L is the speaking length between end-points (25.5" for a typical guitar)
T is the tension on the string (higher tension produces higher frequencies)
m is the mass per unit length (heavier strings vibrate at lower frequencies)

Sir James Jeans, Science and Music, Dover Publications, Inc., New York (1968).

Corrosion byproducts lead to vibrational damping

Overtones are the most sensitive (overtones affect “brightness”)

Polymer coatings have been employed – damping is a problem

MUSICAL INSTRUMENT STRINGS AND CORROSION

The Advantages of Organosilane Surface-Treated Strings

(*U. S. Patent 7,476,791*)

Enhanced Longevity – Strings resist corrosion (salt & moisture from hands)

Improved Sound Quality – No damping (< 0.1 % mass by string wt. vs. 3.5 % for conventional polymer-coated strings)

Better mechanical integrity than thicker polymeric coatings

Longer Resonance Times (slower vibrational decay)

Versatile Chemistry – Works on Steel-Core & Titanium-Core Strings (Ti is always the best)

MUSICAL INSTRUMENT STRINGS AND CORROSION

Surface-Treatment Process Steps

(*U. S. Patent 7,476,791*)

1. Prehydrolyze Foundation Layer (e.g., aminosilane) & Optional Top-Coat Solutions

→

2. Deposit Foundation Layer from dilute solution & flash dry (continuous or batch)

→

3. Deposit optional top-coat from dilute solution & flash dry (continuous or batch)

↓

4. Bake/Cure

Critical Process Parameters:

- **Hydrolysis**
- **Solution concentrations**
- **Net deposition mass**
- **Cure t & T**

MUSICAL INSTRUMENT STRINGS AND CORROSION

Organosilane Surface-Treated Strings

(*U. S. Patent 7,476,791*)

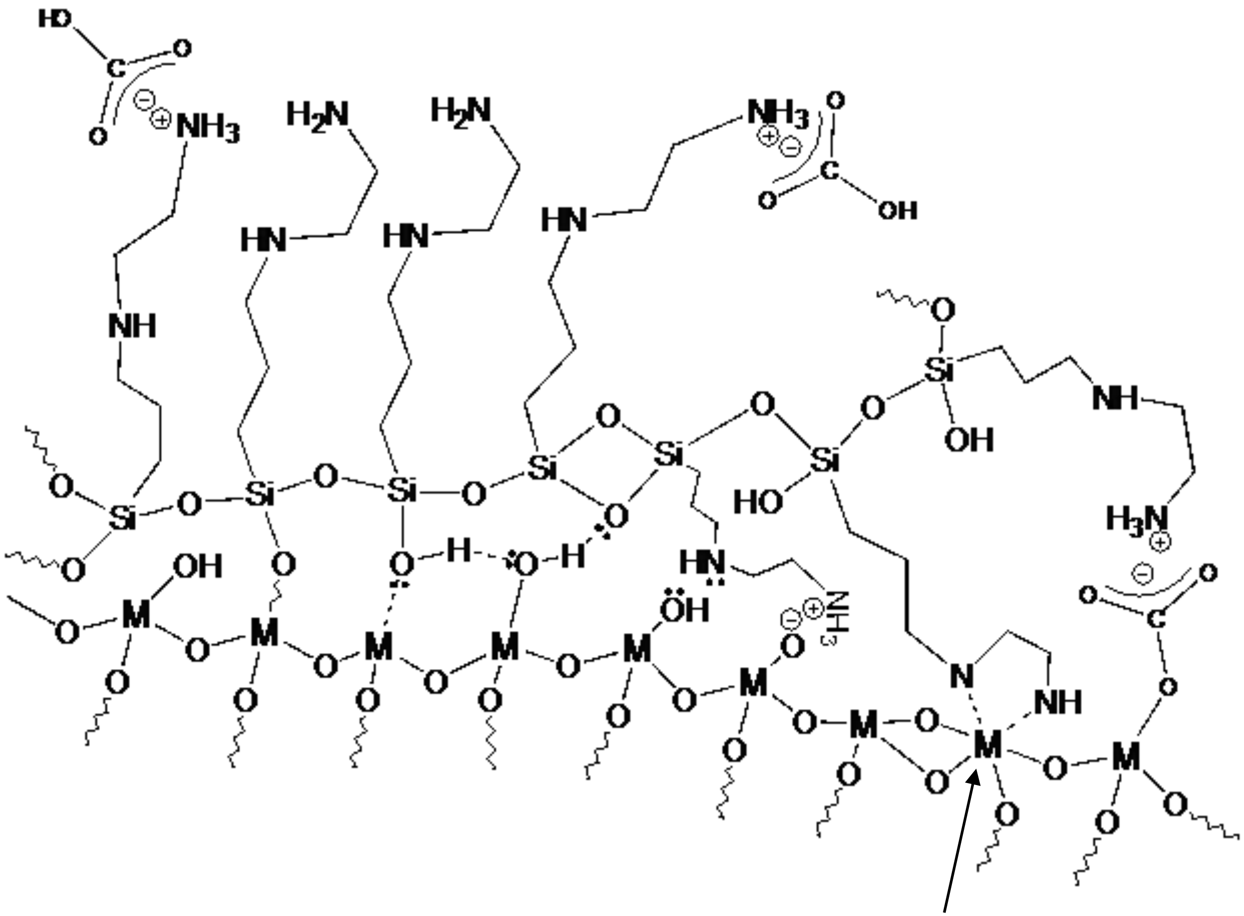
Surface FTIR (ATR) studies show that the deposition of thick films favor the formation of amine salts, whereas the deposition of thin films favor the formation of coordination complexes

Dynamic Mechanical Analysis (DMA) studies show that thick films are thermally and mechanically unstable, while thin films maintain their mechanical and acoustic integrity (i.e., they are durable)

Sound Enhancement - Acoustic studies reveal that the free-vibration decay rate is actually decreased in the presence of surface treatment (they vibrate for longer times)

The Foundation Layer – AAPS

N-(2-aminoethyl)-3-aminopropylpropyltrimethoxysilane



FTIR data provide evidence for the existence of chelated amines near the metal interface – this is the desirable bonding condition

AAPS treated Ti-core strings after 21 days in Brine Solution

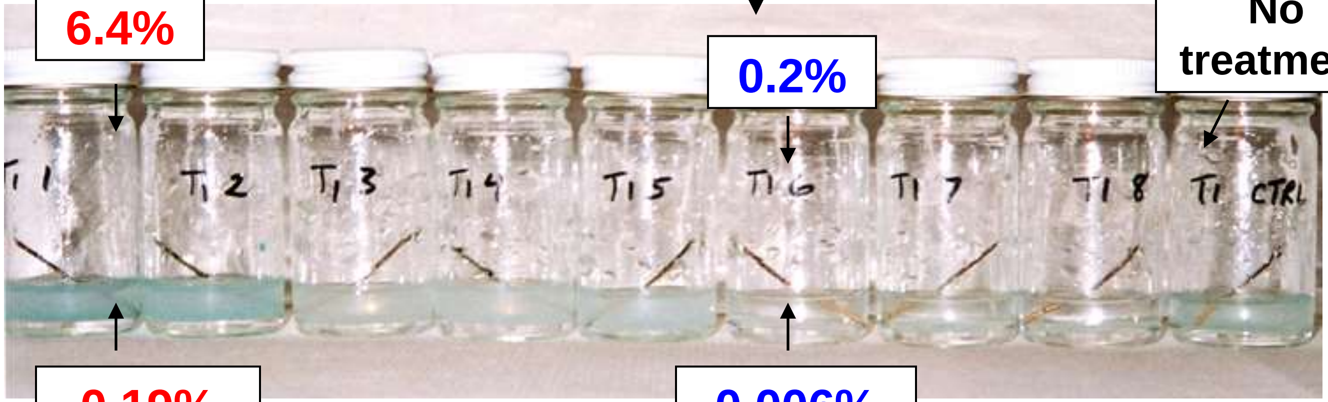
- **High levels of AAPS accelerate corrosion**
- **Low levels provide excellent corrosion protection**

Solution Concentrations

6.4%

0.2%

No treatment



0.19%

0.006%

Mass of treatment (% of total string mass)

$7.8x10^{-3}$ moles/m^2

$2.4x10^{-4}$ moles/m^2

Steel-core Strings in Brine Solution

Differences start to appear within hours of exposure

No Treatment

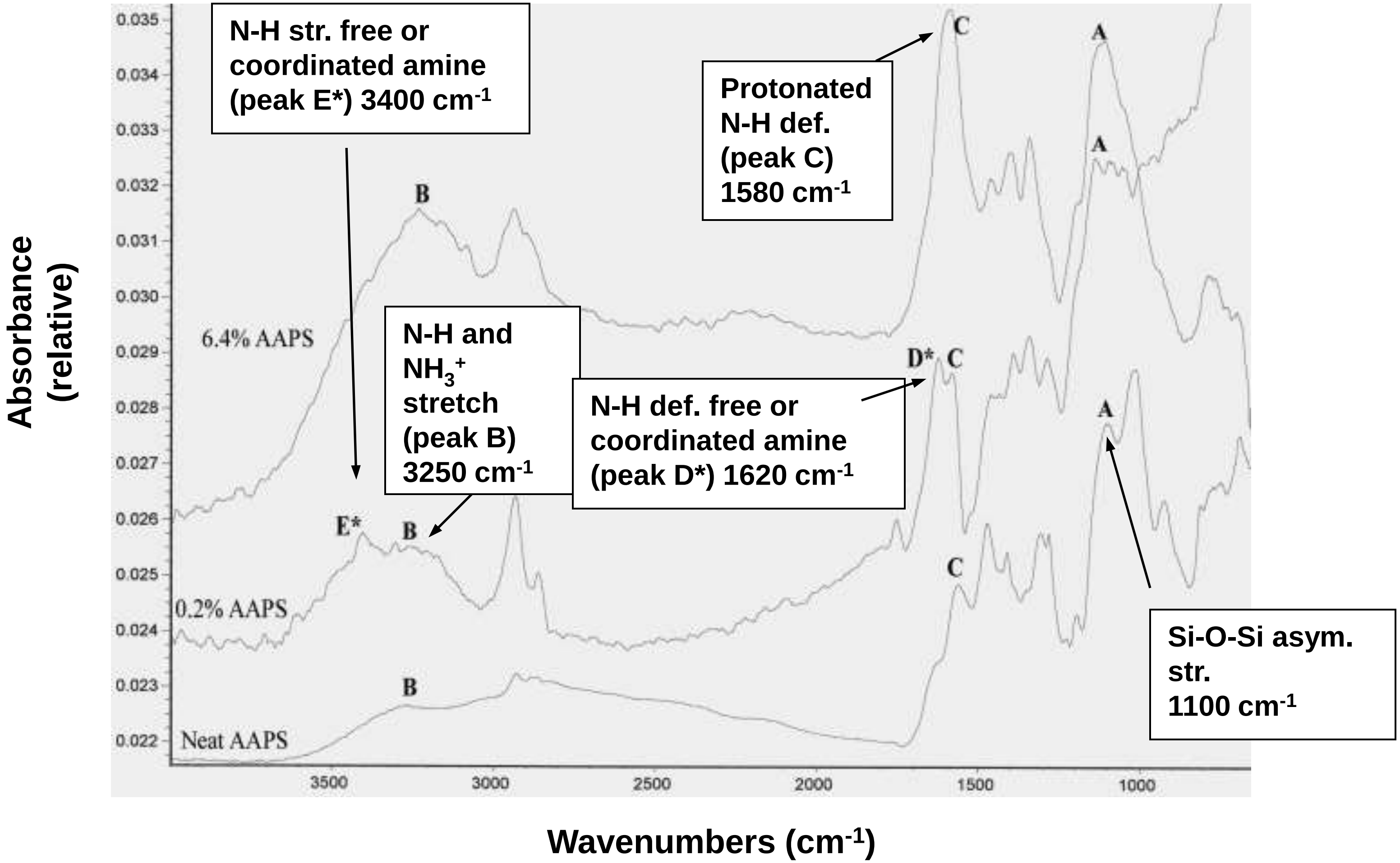
Treated

Typical difference between non-treated Ti and steel after 24 hours in NaCl solution

Trends among steel-core strings can be seen within only a few hours, whereas trends among titanium-core strings take several days to appear

FTIR Surface Spectra (SATR)

High levels of AAPS → protonated amines → accelerated corrosion
Low levels of AAPS → chelated amines → corrosion protection



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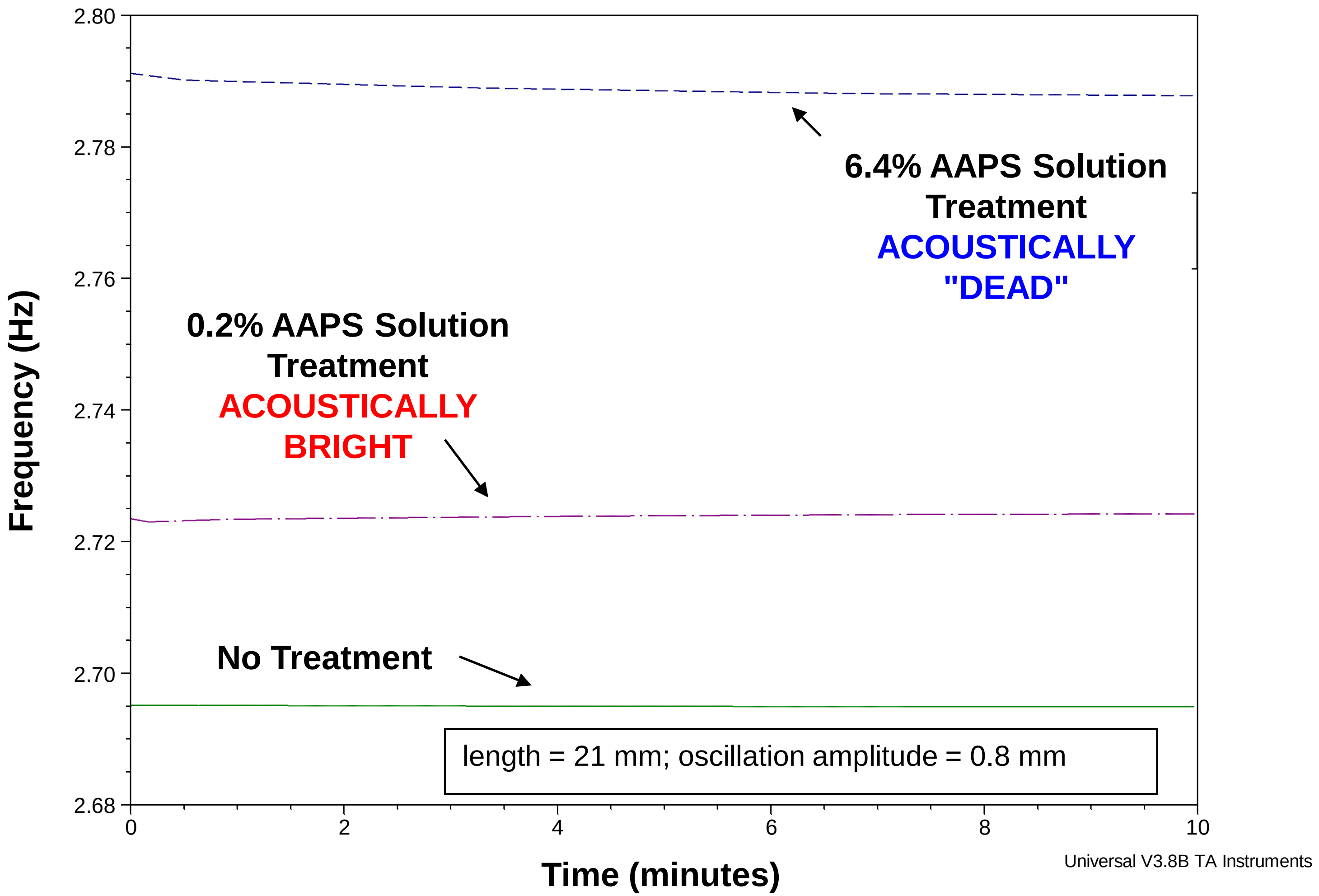
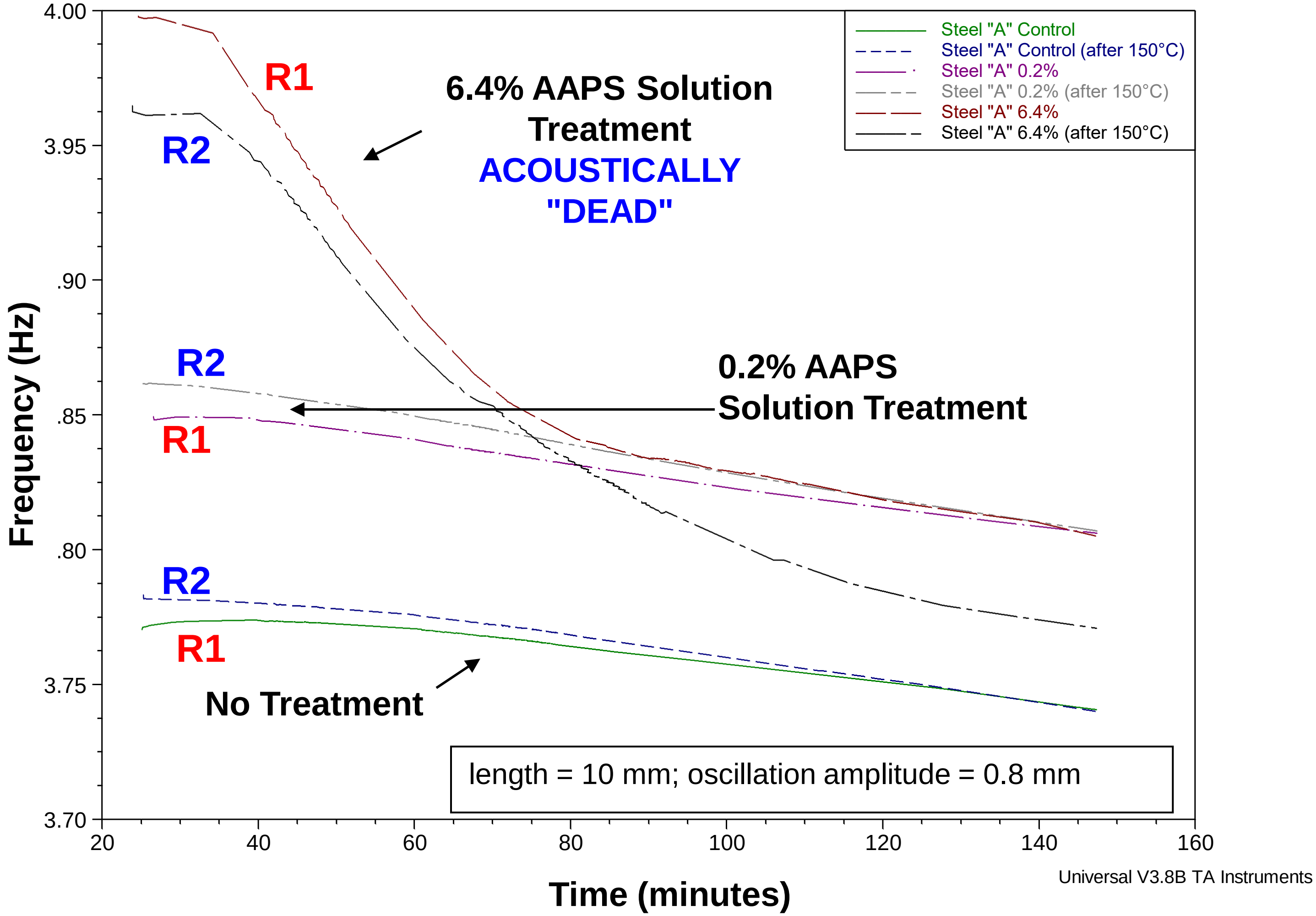
Resonant Mode DMA

Phosphor Bronze Wound Steel Core "A" Strings with and without AAPS Treatment



Resonant Mode DMA - EFFECT OF THERMAL HISTORY
Phosphor Bronze Wound Steel Core "A" Strings with and without AAPS Treatment

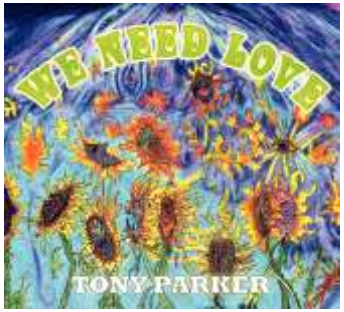


String Vibration – Acoustic Measurements

500g weight was tied & suspended from the mid-point of an A-string (tuned to 110 Hz) – sensitive to the fundamental tone

The weight was released to impart vibration

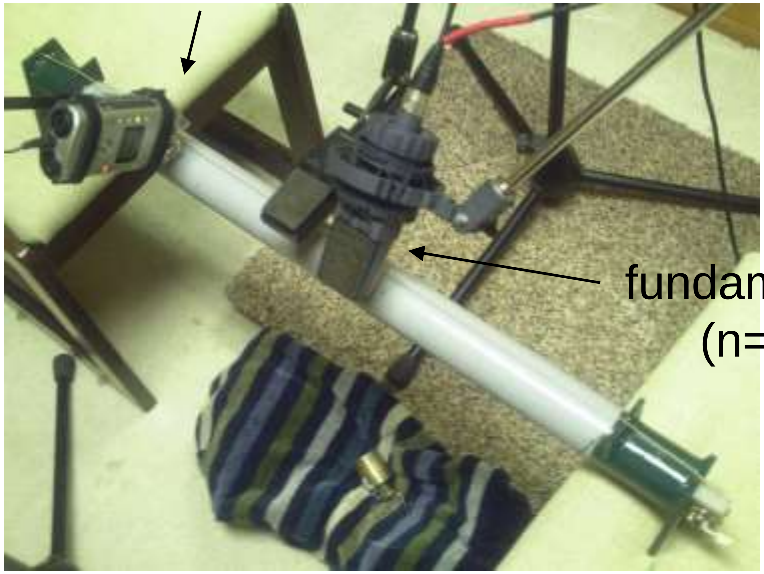
Sound pressure measurements were made after several vocal takes for "We Need Love"



Data were collected (recorded) at a 44.1 kHz sample rate (24 bit depth)

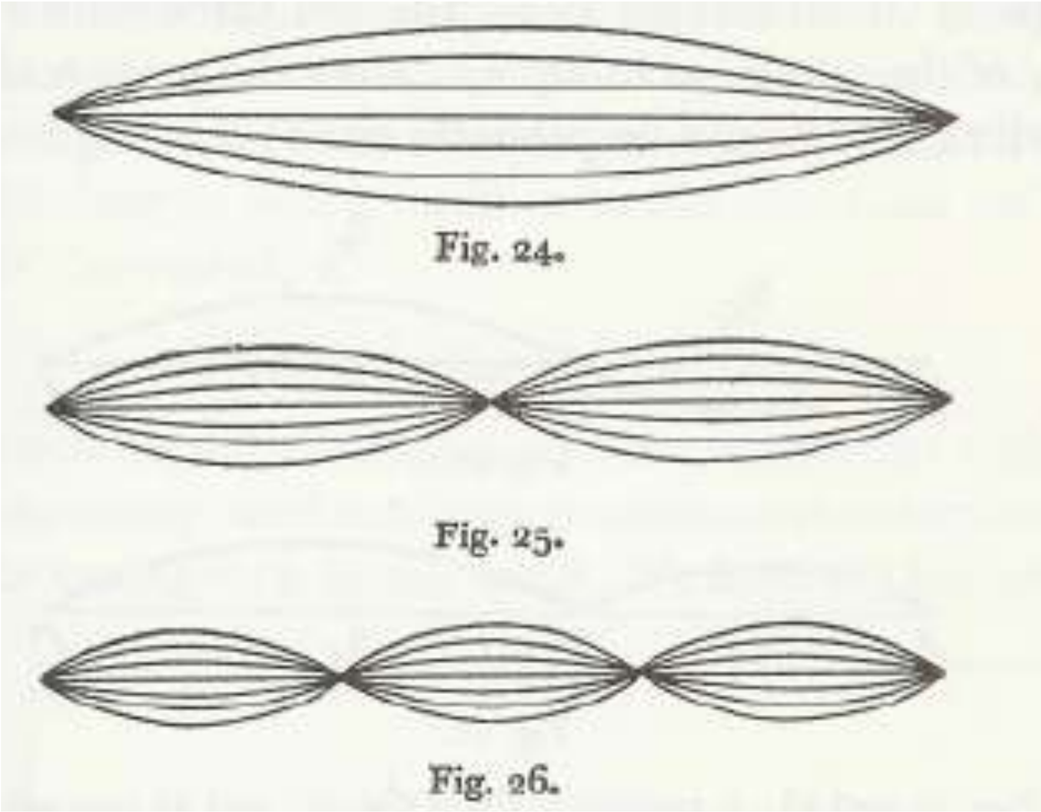
(producer / electrical engineer)

1st overtone (n=2)



fundamental (n=1)

String Vibration



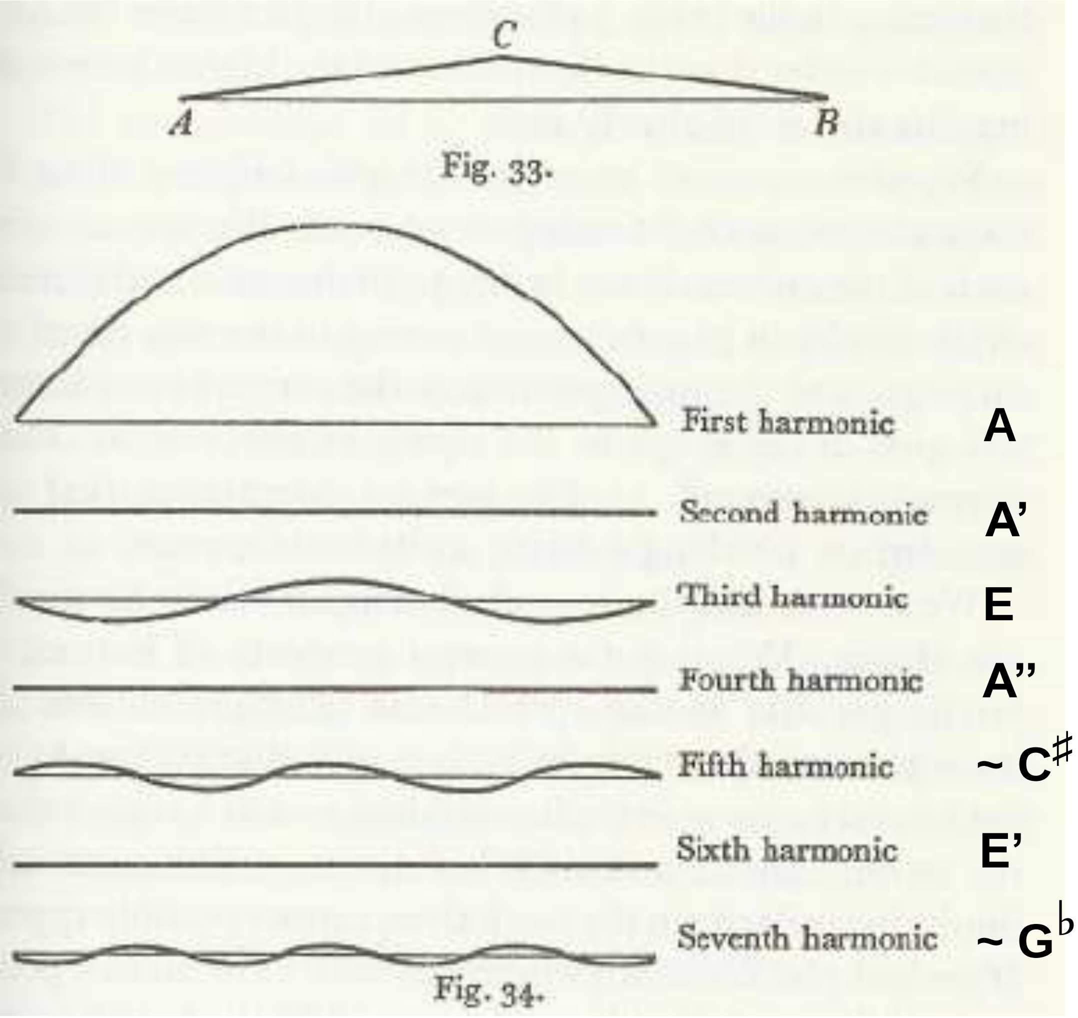
n = 1, 110 Hz (A)

n = 2, 220 Hz (A')

n = 3, 330 Hz (E)

n = 4, 440 Hz (A''); n = 5, 550 Hz (C♯); n = 6, 660 Hz (E'); n = 7, 770 Hz (G♭); n = 8, 880 Hz (A''')

Sir James Jeans, Science and Music, Dover Publications, Inc., New York (1968).

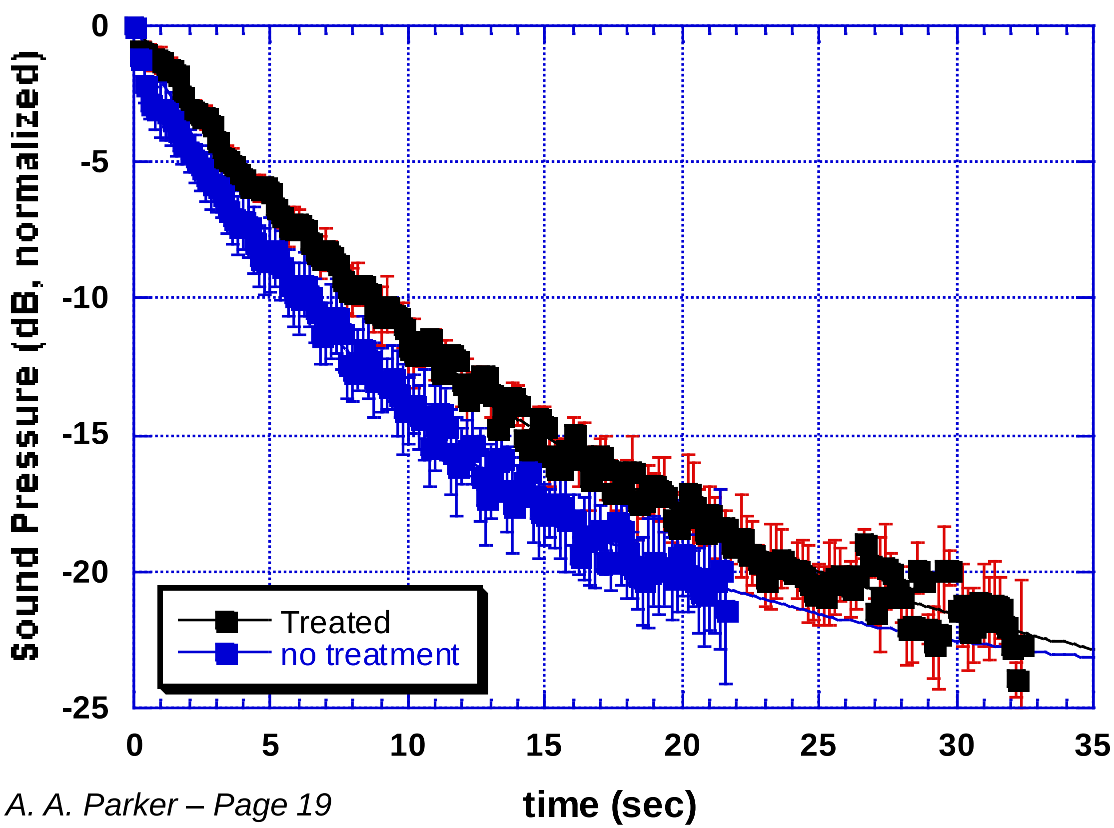


Sir James Jeans, <u>Science and Music</u>, Dover Publications, Inc., New York (1968).

String Vibration: Decay of the Fundamental Tone

Data were analyzed with EQ band pass filters; over the range 107-113 Hz, which corresponds to about 50 cents above and below the target 'A' 110 Hz. In musical terms, 50 cents refers to half the distance between a note and its closest semitone neighbor

Effect of Surface Treatment on Sound Pressure Level Decay at 110 Hz (A-note) Medium Tension PB-Wound Ti-Core A-String



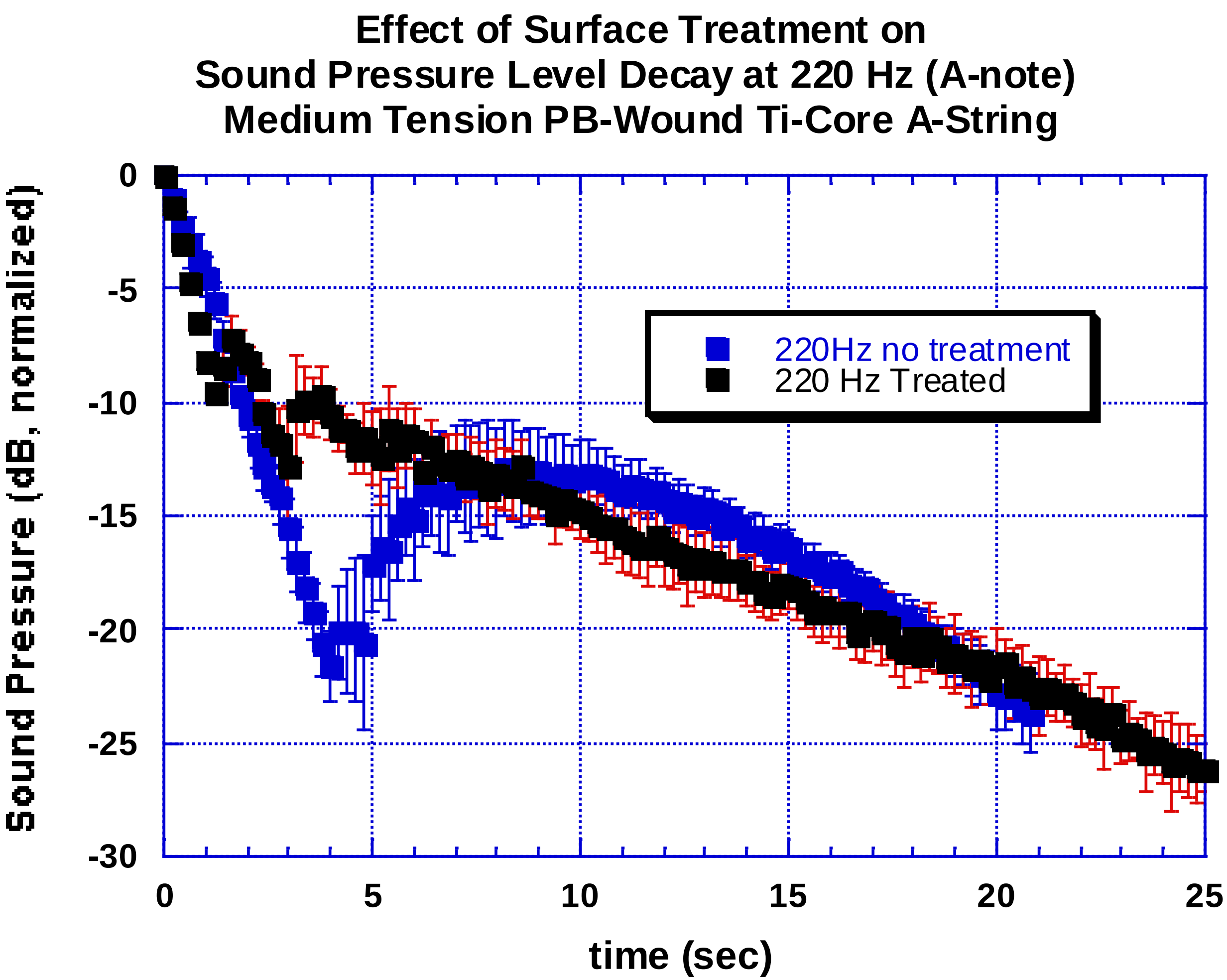
SPL = A*(exp(-t/tc)-1) (Treated)

	Value	Error
tc (sec)	18.1	0.4
A	26.7	0.3
Chisq	47.9	NA
R	0.99	NA

SPL = A*(exp(-t/tc)-1) (no treatment)

	Value	Error
tc (sec)	11.5	0.3
A	24.3	0.3
Chisq	33.6	NA
R	0.99	NA

String Vibration: Decay of the 2nd Harmonic (n=2)



Acoustic Measurements - Advantages & Limitations

Advantages:

- **Simplicity – great for testing relative effects of controlled variables (e.g., presence or absence of a surface treatment) - simple plots of sound pressure (dB) vs. time**

- **EQ filters were used to qualitatively separate the fundamental (110 Hz) and the 2nd harmonic (220 Hz) from other frequencies**

Limitations:

- **Even-numbered harmonics are suppressed by center-plucking**

- **Although simple, the EQ filtering technique leads to "bleed-through" of multiple frequencies**

Future Work

- **Off-center plucking**
- **Frequency Analyses – more accurate effect of surface treatment on overtone intensities & decay rates**
- **Effect of aging on vibration properties**
- **Effect of extended play on vibration properties**
- **Titanium vs. Steel**
- **Next album in progress**
- **Official release of "We Need Love"**

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Conclusions

Organosilanes are ubiquitous in product development applications (at least in my developments)

Musical instrument strings can be improved with silane surface treatments - corrosion protection and enhanced acoustic properties

Processing factors are important (e.g., hydrolysis, method of deposition)

Low-concentration ingredients can have an impact on the performance properties of surface treatments

Acknowledgements

Calen Bruce

Dave “Magic” Mariasy

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