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In Addition

Cover Art

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Please submit tuning and technical articles, Tuner's Life/Tuner's Health stories and queries via e-mail to: editor@ptg.org

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Correction

The March 2015 tuning article on page 20 by Jim Coleman should have read:

6. **Tune F3 to C♯3**. (Tune as a wide major third.)

Set your metronome at 84 (not 104) to establish the beat speed of 5.5 bps on the wide (sharp) side of pure at [F5]. Use wa-wa-wa-wa or Co-Lo-Ra-Do to subdivide each full swing,

An Advanced Method to Analyze Non-Speaking Length Tension and Develop Improved Stability Techniques

By Mark Cerisano, RPT, B.S. (Mechanical Engineering), Montreal QB Chapter

Introduction

"Stability is the first and last tuning skill you will ever learn."

Good stability is a required skill for any tuner, aural or electronic. Without good stability, unisons will sour, and even the most tolerant customer will not call you back. For high-level concert work, it is even more critical that you have rock-solid stability.

By studying the three F's, as I like to call them—Forces, Friction, and Elastic Deformation—one is better able to predict the best technique for stability, and also troubleshoot situations where stability may be elusive.

In this article I will describe stability from a mechanical engineering perspective.

Friction

Friction is all throughout the piano string/tuning pin system, and has a huge effect on how string tensions and tuning pin deformations respond to tuning lever forces.

Wickipedia defines friction as "the force resisting the relative motion of solid surfaces, fluid layers, and material elements sliding against each other."

The amount of that force depends on two things: the materials, and how hard they are pressed together.

Friction presents itself, for our purposes, at two main areas within the pin/string system: between the pin and the pinblock, and between the string and the upper termination point (V-bar or agraffe).

Coefficient of Friction

The coefficient of friction allows us to calculate and imagine the frictional force that is resisting the relative motion of two solid surfaces.

It is simply a number that is multiplied by the force pressing the two surfaces together. When a force is applied to one object (a wooden block, for example) for the purpose of trying to move it relative to another object (across a concrete floor), the frictional force equals the applied force up to a maximum value. The object begins to move once the applied force exceeds the maximum frictional force possible. The coefficient of friction calculates what that maximum frictional force can be.

Example:
A block of wood is resting on concrete. The block weighs 100 lbs. According to the engineeringtoolbox.com website, the coefficient of friction between wood and concrete with clean, dry surfaces, is 0.62. This means one could apply a force of up to 0.62 x 100 lbs = 62 lbs before the wood block begins to move.

Static and Dynamic Coefficients of Friction

In general, friction between two moving objects (dynamic) is less than the friction between two objects that are stationary (static).

According to engineershandbook.com, all objects, except for aluminum on aluminum, have a lower dynamic coefficient of friction than their static coefficient of friction.

What this means is that, in the vast majority of cases, it is harder to get an object to start sliding than it is to keep it sliding. In other words, once an object starts sliding, it is relatively easy to keep it sliding.

This will have obvious application when we start talking about test blows, which are hard blows to a key which basically set the string in motion relative to the upper termination point.

Also, when turning a pin in the pinblock, once the pin starts to move, the friction preventing it from moving drops, and the pin is easier to move.

The reader will keep this idea of reduced friction for moving surfaces in mind as we continue to discuss forces, friction, and elastic deformation in the string/pin system.

Forces on the Tuning Pin

At rest, a tuning pin is under one force, the string tension. This force is causing the tuning pin to bend and twist in the direction of the string force.

What's more, when we apply force to the pin with the tuning lever, the pin will also bend and twist under the application.

It may not be intuitive that the pin bends when we try to turn it, but this is true due to the point of application of the force on the pin being above the pin. It is this bending and twisting during and after tuning that affects the tension of the non-speaking length.

The Non-speaking Length

The non-speaking length (NSL) of a piano string is the part of the string between the tuning pin and the upper termination point. The speaking length (SL) is the length of the piano string that is set in motion by the impact of the hammer, bordered by the upper (V-bar or agraffe) and lower (upper bridge pin) termination points.

Tension Differential (ΔT)

Differential is another word for difference and is often expressed in engineering texts as the Greek letter Delta (Δ).

The tension differential, or ΔT (Delta T) in a piano string system is the difference between the NSL and SL tensions across the upper termination point.

APPLICATION OF FORCE TO TUNING PIN	EFFECT ON TUNING PIN AND NSL TENSION
Tuning lever is placed on tuning pin.	No effect.
Force is initially applied to tuning pin.	Tuning pin begins to deform; it bends and twists. NSL tension changes. SL tension is initially unchanged. Tension differential is still below the frictional threshold and the string has not slipped on the upper termination point.
Force is increased on the tuning lever and hence, on the tuning pin.	The tension differential increases until the frictional force is exceeded. The string begins to slip across the upper termination point. The pitch changes.

APPLICATION OF FORCE TO TUNING PIN	"AFTER TUNING" EFFECT ON TUNING PIN AND NSL TENSION
Tuning lever force is removed from tuning pin.	The tuning pin *unbends*, and *untwists*. The NSL tension changes.

As a tuning pin is turned, the following deformations and tension changes occur:

I call the preceding phase the *During Tuning* phase, because it happens while we are applying force to the pin. But if we want to understand stability, we must look at what happens in the *After Tuning* phase, after the force on the tuning lever is removed.

What happens after we remove the tuning lever force from the tuning pin?

Often it is this final NSL tension change that leaves the NSL tension too close to the tension band limit, and on the first hard blow, the tension band narrows, the NSL tension finds itself outside the tension band, the string slips, and the pitch changes.

The Tension Band

Understanding the concept of a tension band is critical to understanding stability. The tension band is a range of NSL tensions that results in stability. This range exists because of friction between the string and the upper termination point. For any given SL tension, there is a range of NSL tensions that can produce a tension (T) that is less than the friction trying to keep the string from sliding on the upper termination point. Once the NSL tension exceeds the tension band, the string will slip and its pitch will change.

This is the essence of stability. If the string doesn't slip, there is no pitch change, and the string is stable. All concentration for us must be on what is needed to ensure that the NSL tension is left within the dynamic tension band after we are done tuning.

Hard Blows (and the Dynamic Tension Band)

Leaving a string stable after tuning is not enough. On hard playing, the string can slip. So what is happening? Remember our discussion of static and dynamic coefficients of friction above. As the string is set in motion, the upper termination point experiences some movement between it and the string. This creates conditions for the lower dynamic coefficient of friction, and the result is that the tension band narrows; there is less friction holding the string to the upper termination point during a hard blow.

After tuning, if the NSL tension is left near the edge of the static tension band, but still within the band, the string will be stable at rest. But on hard blows, the narrowing of the tension band may be enough to cause the NSL tension to be outside the new narrower dynamic tension band, and the string will slip and the pitch will change.

Why should we try to leave the NSL tension slightly higher than the middle of the tension band, i.e., higher than equalized?

During hard blows, tensions in the speaking length rise slightly due to the stretching induced by the hard blow. The tension band follows the speaking length tension and the whole tension band rises, as well as narrows. The NSL should not be near the bottom of the tension band if possible; the narrowing and rising of the band will put lower NSL tensions at a greater risk of being outside the tension band. It is safer to leave NSL tensions near the top of the tension band. We know this intuitively when we experience that strings rarely go sharp if they are unstable.

What Happens After Tuning

Focusing on the After Tuning phase is where all the work is done to understand stability. Before the tuning lever force is removed from the pin, and while the lever force is at its highest, the tuning pin is bent and twisted in the direction of the lever force. In the After Tuning phase, after the lever force is removed, the tuning pin unbends and untwists.

This unbending and untwisting affects the NSL tension. If we can predict that the new NSL tension will be within the dynamic tension band—which the reader will remember is narrower and slightly higher than the static band—then we will have stability.

Untwisting

Untwisting is the simplest After Tuning effect to imagine. Remember, it reduces the tension differential, i.e., it reduces the difference between the NSL tension and the SL tension produced by the lever force.

Here is what the tuning pin and NSL experience during and after tuning.

The reader will internalize the effect in italics.

Unbending

The bending and unbending of the tuning pin during and after tuning is a little more variable due to the effect of the angle of the tuning lever on the tuning pin.

It may not be obvious that the tuning pin bends when we tune, but no matter how hard we try, with twisting of the handle and other attempts to eliminate this, the tuning pin will always bend under application of a standard tuning lever force. This is because the point of application is above the tuning pin. Instead of trying to eliminate this bending, one can learn to anticipate and control its direction and amount during and after tuning.

Hammer Angle

The 3:00 and 9:00 positions of the tuning lever have the maximum parallel bending and hence maximum effect on NSL tension. Angles less than 3:00 or 9:00 have less of a bending effect and can be used to control the amount of the bending effect in the After Tuning phase.

The After Tuning phase must be the source of our concentration, since the NSL tension is affected by what happens after we remove the tuning lever.

For the purpose of analyzing NSL tension within the tension band after tuning, we will only consider hammer angles 3:00, 9:00, and 12:00. Also, we must consider the two situations of trying to raise pitch, or trying to lower pitch.

The chart below describes what is happening in each of the combinations listed above.

Let's examine some situations where we have the hammer at a given angle and are trying to adjust pitch in one direction, but are not able to achieve a stable tuning.

Example Case: Sharpen a Bit, then Flatten, at 12:00 on an Upright

This is the most often-described stability technique, and the one that I hope will demonstrate the power of NSL Analysis. It was using this very technique and not getting a stable tuning that prompted me to search for a better method that would help me understand what was happening in any piano and alter my hammer technique to achieve a stable tuning.

ACTION	TWISTING	NSL TENSION
At rest, before tuning.	Twisted towards string.	The NSL tensions will definitely be within the static tension band, presumably within the dynamic tension band, and stable.
Force is initially applied.	Pin begins to twist in direction of force.	The NSL tension will initially increase or decrease, depending on direction of force. It will initially be within the tension band.
Force is increased until pitch changes.	Increased twisting.	NSL tension exceeds the static tension band (friction) and the string slips on the upper termination point.
Force is removed from the tuning pin in the After Tuning phase.	Tuning pin untwists.	*If raising pitch, After Tuning untwisting results in a lowering of NSL tension. If lowering pitch, After Tuning untwisting results in a rise in NSL tension.*

Analysis

The final tuning lever motion in this case is to flatten the note. (Even if the pitch doesn't change, the final intentional force on the pin is in this direction.)

We have the following forces and elastic deformation for 12:00 flattening.

What happens when we have an unstable tuning?

By now the reader should be able to answer that question easily. Working back from what we know to be true:

1. The string slipped on the upper termination point.
2. The string slipped on the upper termination point because the tension differential across the termination point exceeded the friction.
3. The tension differential exceeded the friction because the NSL tension went outside the tension band.

Now we have two possible situations: The pitch dropped, or the pitch rose.

But what causes the pin to untwist too much or too little? To answer this, we need to look at elastic deformation as a whole, including unbending as well as untwisting, and analyze what factors can affect how much the NSL tension changes given a constant tuning pin deformation.

The actual amount that the NSL tension changes depends on two factors: the tightness of the pinblock and the actual length of the NSL.

Pinblock Tightness

If the tuning pin is held tightly by the pinblock, the tuner will have to apply more force to the lever before the pin moves. This increased force results in

EFFECT OF HAMMER ANGLE BENDING COMPONENT ON NSL TENSION DURING AND AFTER TUNING

ANGLE	RAISING PITCH		LOWERING PITCH	
	DURING TUNING	AFTER TUNING	DURING TUNING	AFTER TUNING
3:00 Grand 9:00 Upright	Increases	Decreases	Decreases	Increases
9:00 Grand 3:00 Upright	Decreases	Increases	Increases	Decreases

Trying to	With the hammer	During Tuning		At pitch[5]	After tuning	
		The pin twist[1]	The pin bend		The pin untwisting[1]	The pin unbending[6]
Lower Pitch	9:00 Upright 3:00 Grand	Lowers NSL tension[2]	Lowers NSL tension[2]	NSL tension is at the *bottom* of the tension band	Raises NSL tension[3a]	Raises NSL tension
	12:00		Has no effect on NSL tension			Has no effect on NSL tension
	3:00 Upright 9:00 Grand		Raises NSL tension[4]			Lowers NSL tension
Raise Pitch	9:00 Upright 3:00 Grand	Raises NSL tension[2]	Raises NSL tension[2]	NSL tension is at the *top* of the tension band	Lowers NSL tension[3b]	Lowers NSL tension
	12:00		Has no effect on NSL tension			Has no effect on NSL tension
	3:00 Upright 9:00 Grand		Lowers NSL tension[4]			Raises NSL tension

Final tuning lever force	NSL tension during tuning	NSL tension change after tuning (when the lever is removed)
The lever is used to gently settle the pin in the counter-clockwise direction from 12:00.	The NSL tension may or may not reach the tension band limit. If you hear the pitch drop a bit, NSL tension has reached the tension band limit.	Because of untwisting, the NSL tension drops.

increased bending and twisting during tuning, and hence increased unbending and untwisting after tuning. This increased elastic deformation and return to original shape results in increased changes in the NSL tension.

Similarly, a soft pinblock (looser pins, less friction) produces less change in NSL tension due to less elastic deformation occurring during and after tuning.

Newer pianos and older pianos with new pins tend to have tighter pinblocks. Older pianos tend to have softer pinblocks.

NSL Length

Imagine you are tied to a large elastic cord and someone is holding the other end. They begin yanking the cord back and forth. What will happen to you?

Without too much visualization, you should imagine that it depends on the length of the cord. For a shorter cord, you will feel the yanking and your body will move. For a longer length you may not feel anything at all.

This is the same situation with NSL length. When turning a tuning pin, there will be a higher change in NSL tension for a short NSL compared to the same pin movement with a long NSL.

Another way to think of this is to remember that short NSLs are very sensitive to pin movements, includings bending and twisting as well as unbending and untwisting.

Short NSLs are found on small pianos near the tenor break. Long NSLs are found on some old tall uprights, and on medium to large grands.

How to Predict the Sensitivity of NSL Tension to After Tuning

From the chart left, we can easily predict which kinds of piano would cause a problem with the standard "Sharpen a Bit, then Flatten" technique.

Concluding Remarks

I have identified the forces, friction, and elastic deformation that is present in the string/pin system during and after tuning. I have also identified one case

Possible Unstable Situation	Explanation
Pitch Dropped	NSL rise was not enough to put the NSL tension inside the dynamic tension band (which narrows and rises on hard blows).
Pitch Rose	NSL rise was too much and resulted in the NSL tension being left above the dynamic tension band.

Condition	NSL Sensitivity	Notes
Tight Pinblock	High	Newer pianos or older pianos with new tuning pins.
Loose Pinblock	Low	Older pianos with old pins.
Long NSL	Low	Tall older uprights in the treble section where the v-bar descends, but the pins don't. Medium to long grands in the mid section.
Short NSL	High	Small apartment-size spinets at the tenor break.

Instability Problem using "Sharpen a Bit, then Flatten, lever at 12:00"	Cause	Reason	Case
Pitch Drops	NSL tension did not rise enough.	NSL sensitivity was too low.	Can occur in the treble section of older uprights with soft tuning pins, where the tuning pins do not follow the v-bar, but continue high up near the top of the piano (Some Canadian Dominion pianos).
Pitch Rises	NSL tension rose too much after tuning.	High NSL sensitivity.	Occurs in new small pianos with tight pins, in the mid section, just to the right of the tenor break where the NSL is very short.

study where a standard hammer technique can fail, and explained why using NSL analysis.

There are many other situations where the tuning may be unstable and the tuner can figure out how to change the tuning lever angle and get better stability using NSL analysis, but I do not have space in this article to describe them all.

The application of NSL analysis at first glance may appear to only be useful for a slow-pull lever technique, where the tuning pin is moved in a slow consistent motion. However, forces, friction, and elastic deformation are elements of the physical system that are present no matter which technique you are using. Also, the placement of NSL tension must be within the dynamic tension band no matter the lever technique used. In other words, NSL analysis can be enlightening even for impact and impulse lever technique where a jerking or tapping motion is used, but because of space considerations, I am not able to expand on these techniques. Perhaps in a future article. ▢

Endnotes

[1] Pin twist effect on NSL tension does not depend on tuning lever angle.

[2] We turn the pin until the pitch changes. When the pitch changes, that means NSL tension is at the limit of the tension band. As we continue to turn the pin and change pitch more, the NSL tension drags the tension band with it. The tension band is tied to the speaking length tension (pitch).

[3a] When lowering pitch, the NSL tension is at the bottom of the band. The untwist brings NSL tension up off the bottom.

[3b]When raising pitch, the NSL tension is at the top of the band. The untwist brings NSL tension down from the top.

[4]The bending effect on NSL tension counteracts the twisting effect.

[5]"At pitch" means the state when the lever force is still being applied to the pin and the pitch is where you want it. When using the NSL analysis technique, it is important to play the note and listen to the pitch while still applying the lever force. Then we re-listen as the force is removed. This gives us an inside view of where the NSL tension is within the tension band.

[6]Notice how the amount of NSL tension change can be regulated depending on tuning lever angle. For example, when raising pitch, the untwisting lowers NSL tension, but depending on the tuning lever angle, we can add to that lowering (9:00 upright.3:00 grand), not affect NSL tension (12:00), or counteract the lowering NSL tension by increasing it (3:00 upright/9:00 grand).

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