PTG Physics Class Outline

Anthony Willey & Roger Gable
Stage 7 Pianos
1/19/2015

Part 1

Introduction
Roger on why physics is important for the piano technician
Poster: Art and science
Anthony on the spherical cow
We will only solve simple problems here
Math Review (Anthony mostly)
Algebra in 5 minutes
Equations and unknowns
Rules of equations: do the same thing to both sides of the equals sign
Example: Invoice amount for hourly work
Graphing
Solve a simple equation
Geometry in 2 minutes
Pythagorean theorem a^2 + b^2 = c^2
Trigonometry in 5 minutes
Triangles, Sin Cos Tan, Oscar Had A Heap Of Acorns
Illustration of trig functions and sine wave
Solve a simple triangle problem (white board)
Basic concepts in Physics
Vectors (Direction and magnitude) (Anthony)
Show “Vector” video
Velocity and acceleration are vectors
Force definition (Anthony)
Force also a vector
Newton’s second law: F=ma or Force causes Acceleration
Demonstration of Force: Gravity on air track
Torque definition: it’s like force but rotational.
Torque = Force times Distance
Free body diagram
Sum of forces = 0 and sum of torques = 0, otherwise object will move or rotate
Tuning lever example
Torque, lever length, and flagpoling
Do half lever on whiteboard
Skip Hanging body demo? (solve for two unknown forces)
Combines concepts of forces (gravity, tension), torque, trigonometry, and algebra
First choice to skip if we’re running short on time
Moment of inertia

Demo: rolling cylinder and sphere?
Lead placement in keys
Center of percussion (Roger)
Need to fill out
Illustration: Bell ringer
Friction
Static and Kinetic
Coefficient of Friction demo (sliding block)
Ask participants to provide examples of when static and kinetic friction is important in piano industry
Tuning pin (jerk tuning vs. smooth pull)
Setting the string (friction across bearing bar)
Touchweight (getting the key to start moving)
Measuring center pin friction
Downweight and upweight (diagram on powerpoint, solve on whiteboard)
Collisions
Elastic and inelastic
Air track demo
Most collisions (eg. piano hammer) are neither perfectly elastic or inelastic, but somewhere in between.

Part 2

Energy: Potential vs. Kinetic (roll a ball down a slope demo)
Different kinds of energy: chemical, electric, gravitational, mechanical/rotational, kinetic
Energy can change forms but can't be created or destroyed
Burn a potato chip
Heat on the atomic scale:
Talk about thermal expansion
Demo: Ball and ring
Application: How temperature affects tuning (strings expand/loosen with heat)
Demo: bi-metallic junction
Application: Why laminated keys are a bad thing
Oscillators: simple pendulum, mass on a spring.
Show how energy moves between kinetic and potential
Frequency depends on mass and restoring force
Wave motion (transverse, longitudinal, mass and tension alter speed)
Demo: Slinky to show longitudinal and transverse
Application: transverse waves on piano strings
Principle: wave speed depends on tension and linear mass density
Frequency and standing waves
Modes for a string fixed at both ends
Demo: Jig saw jig
Adding individual frequencies to make a wave (Fourier series)
Any wave can be described as the sum of multiple harmonic frequencies
Illustration: standing waves on a plucked string
Video: plucked strings and struck piano string
Discussion: tone and timbre in the frequency spectrum

Impedance and driven oscillators
Driving frequency matters
Demo: Driven mass on spring demo
Illustration: graph of frequency response curve
Demo and discussion: frequency response of soundboard with/without crown

Piano Physics

Roger Gable and Anthony Willey
1/9/2015

Roger has been tuning pianos for 50 years. Anthony is a new RPT but has a Masters Degree in Physics from BYU. This class will be taught at the regional conference in Ontario next month, which currently has the best turn-out this far in advance ever. Roger came up with this idea about a year ago realizing that there are few technicians who have much science education. A lot of people went through high school without physics or math classes. Much of this information will be very primary.

In Arts and Sciences there is an overlap; it is in this section where the piano industry falls. The science is in the action, stringing the piano, the belly work, etc, while the art is in the tuning and design. If a circle represents all information in the piano technology, what this presentation covers will be all the information surrounding that circle. In order to advance in piano technology it is important to have a little knowledge outside the field.

The format for this class is to begin with basic Newtonian physics and then to relate that to the piano industry. With a broader spectral knowledge, the piano technician can better explain how the piano and the world work. Physics includes a lot of math.

Math

A theoretical physicist visits a friend in the country who is having trouble with his cows. The physicist goes home and spends hours with math and returns to the farmer, stating, "I can solve your problem, but it only works for spherical cows." To calculate all the issues in a soundboard would be extremely complex, but it might be much easier to solve the problems for a circular soundboard.

- A piano technician working for 2.5 hours at a rate of $50/hour should bill how much?
  Y=50xt, where y is a dependent variable, and t is time
  Whatever you do to the left side of the equation must be done the same on the right side in order to keep them equal.
- Graphing: y=5-xt, with amount charged up the left and time in hours along the bottom.
  - Points, line
  - Add a $25 service charge raises the slope up
  - Y=x2 (squared) creates a parabolic curve. This is a polynomial
- Geometry
  - Area (circle pie r squared, and other formulae)
  - Volume (length times width times height): cylinder=pie r squared times height
  - Pythagorean Theorem: a squared + b squared = c squared (3-4-5 triangle)
- Trigonometry is all about triangles
  - Right triangle: hypotenuse, opposite and adjacent
  - Sin, cosine, tangent

        - Sin=opposite over hypotenuse
        - Cos=adjacent over hypotenuse
        - Tan=opposite over adjacent
        - Oscar Had a Heap of Acorns
    - Plots of trig functions
        - Tangent: repetitive
        - Sin wave
            - The circle is like a generator, and as it turns it produces an AC output
            - The sin is the key to the Steinway design
            - A simple harmonic oscillator makes a sin wave
    - Ratios
        - It is 3pm and a man is standing by a tree. The sun casts a shadow. If your shadow ends at the end of the tree shadow. His shadow is 6' long, the person is 3' tall, and it is 12' from the end of the shadow to the tree trunk.
        - Ratio: 3/6 = X/12
        - 6xX=3x12, 36/6=6

Physics

Vectors

- Vectors have direction and magnitude and are symbolized by an arrow.
- Speed is a magnitude
- Acceleration is change in velocity

Force

- Force causes acceleration
- Force is mass times acceleration
- Forces on an object
    - Gravity exerts a forces on the mass of an object
    - Normal force (perpendicular to the surface
    - Friction (opposes motion)
    - The objects will move as a sum of these forces. Reposition these vectors and a triangle is created.
- Remove friction. The net force will cause acceleration in the direction that is missing.

Torque

- Torque is rotational force
    - Torque=Force time Distance
    - Put a rotational force of 10 lb. on a 2 foot long rod = 2o foot pounds clockwise
    - F=10lbs at d=2ft clockwise, f=20lbs with d=1ft counterclockwise: 0 torque
- Sums
    - The sum of the forces and the sum of the torques need to be zero

- The Tuning Lever Problem
    - F(hand)=10lb, d=1ft, tip pin=10ft-lbs: sum of the forces is zero
    - The tuning pin also exerts force on the tuning lever.

- If you flagpole the tuning pin, you have to adjust for this motion.
- If you have a tuning hammer half as long, and add 20 pounds at the hand, 10 ft-lbs at pin, you will flagpole the pin more.
- The shorter the hammer, the more flag-poling (bending the pin in the wood)
- Change tuning lever length and your style has to change

Moment of Inertia

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Center of Percussion

- Swing a baseball bat. Where is the best place on the bat to hit the ball? At the tip, in the middle, or by the hands?
- The sweet spot is when 33% of the mass is on one side, and 66% of the mass on the other side. There is more inertia on the shorter section than on the longer. There will be no sting felt in the hands on a bat when the ball is hit at this point. All the energy is instantly transferred to the ball.
  - In reality, the bat is not uniform, and the arm becomes part of the equation.
- Roger has an idea for a new hammer.
  - When a hammer hits the string, the center of percussion is actually in the air between the tip of the hammer and the shank.
  - We need to make a hammer with molding like just the upper half of a normal molding. If we bring the center of percussion closer to the tip of the hammer the impact will be more efficient.
  - Bell clappers have an extension of metal rod below the clapper for wrapping rope to mute the sound during practice. Roger believes that extension is also to balance the center of percussion.

Friction

- Static friction (the initial push to get it started)
- Kinetic friction

Down-Weight and Up-Weight

Roger made a giant wooden key pivoting in the center on a pedal pivot pin. He set weights on one end and then set weight on the other end to find out how much weight it takes to make that end go down. If it takes 5 grams to move it down and another 5 grams to move it back, that means there is no friction.

Add friction by tightening the screws on the pivot pin. Now add 12 grams to go down, then take how many off to make it go up. How do we know how much is friction and how much is down-weight? Usually down-weight is 50 grams and maybe 35 grams up. If we subtract 15 pounds each way, we are adding friction twice.

We don't know the weight of the action and we don't know the friction. What we do know is the down-weight and the up-weight.

F-action + F-friction = F-down

F-action – F-friction = F-up

Subtract the second from the first, and we get

2F minus friction/2 = F-down – F-up/2

Elastic collision means that they bounce off each other.
Inelastic collision means that they will stick together, and may continue onward with less speed.

Tenor Section

- Why does the tenor section of a piano always rise and fall more than the rest of the piano? Pianos are scaled between 40 and 60 % of the breaking point. Down at the tenor section most pianos are scaled around 40%. For pianos with wrapped wires on the tenor section, those will also rise and fall but not quite as much. Why does the plain wire rise and fall? This may give us an idea why the bass wound wires rise and fall.
- Yamaha U1 pianos are notorious for drifting. These pianos are Yamaha's #1 selling pianos.
- Soundboards expand and contract due to humidity.

Demonstration:
18-guage wire, 3' long on demonstration jig, tuned to F3
With this device we are going to simulate the rise of the bridge due to humidity.
By raising the bridge we can increase the down-bearing. The agraffe is located right where the bridge would be on a U1 piano.

- Raise the bridge
    - This made it 2000th and 5 cents
    - We raised the bridge a little more and the pitch increased more.
- Now move the lifting device to the center of the string and tune it to F again.
    - Move the device up and read the change in pitch
    - It raises half as much as it did at the end of the string

Why is it that with a longer waste area there is less pitch change? Near the termination of the string we are adding more tension on the short section of the wire. Draw a triangle from between the two termination points and the bridge. As the hypotenuse on the waste end stretches longer – almost to the same length of the height of the triangle, the pitch goes up. At higher string tensions, the change at the waste is reduced. It is the proportion of the waste at the speaking length that causes the tenor section to go up and down more than the rest of the piano. The Waste end on a U1 is very short. If you can lengthen the waste end of the tenor strings, the pitch will remain more constant. If you raise the tension of strings too much, the tone will become worse.

Energy Weight at the Key

A roller coaster takes you up to the top, which converts to potential energy. As you go down it turns into speed. Energy can change forms but cannot be created or destroyed. Physics teachers will hold a bowling ball on a pendulum , in front of a student's face, and let go; it will not hit their face when it returns.

Heat on the atomic scale

- Atoms vibrate faster, and take up a little more space than before: expansion
- Thermal expansion
    - Demonstration: heat brass ball & won't fit through brass ring; heat the ring and it fits again

        - Two pieces of metal on each side of a metal strip. As it is heated it curls because one type of metal expands faster than the other

Mass and Restoring Force

- *Wave* speed on a string
    - Transverse wave (shake)
    - Longitudinal wave (push)
    - To make the wave travel faster, increase the tension
- *Period* is the time it takes for a wave to travel down and back again
    - Total length – 2L
    - Period is length over velocity
    - Fundamental frequency of a string fixed at both ends
    - Standing waves on a string
        - Rubber band attached to a jig saw to create wave patterns
- *Impedence* is the resistance to friction
    - Demonstration
        - When the energy of a string increases or decreases, impedence comes into play
        - The demonstration weight vibrates at about one herz naturally
        - The driver now causes the weight (mass) to go up and down slower than normal: we get out what we put in
        - On the Frequency Response Curve there is a resonance at 100 Hz
        - Increase the frequency and we get more bounce
        - At resonance speed the weight bounces all the way
        - Drive the wheel very much faster than the frequency response and there is very little motion of the weight.
    - In a piano
        - The weight represents the soundboard, and the spring represents the string.
        - Do we want the string to vibrate slower, the same, or faster than the resonant frequency?
        - We want the string to be below the resonant frequency.
        - If the string is resonating really strongly with the soundboard, there will be very quick decay.
        - When a soundboard loses its crown, and the resonant frequency of the board goes down. If the soundboard were absolutely flat, the soundboard and the string frequency are matched and the soundboard will follow the string. Pianos with really loud banging noises, especially where they notch out the bridge to accommodate the strut, the soundboard is so flexible there because the stiffness is gone, the soundboard sucks all the energy and there is no sustain.
        - Whatever the string does, the soundboard will follow it. Driving below the resonance frequency is ideal.
        - To increase the resonant frequency of the soundboard:
            - Decrease its mass and make the soundboard lighter
            - Increase the stiffness of the soundboard
            - Spruce is the stiffest, lightest wood we can find
        - False beats

- Kink in string cause internal reflection
- Weak bridge pin connection causes the return wave to be out of phase
- A twisted plain wire