VIBRATION REDUCING PEN FOR PEOPLE WITH TREMORS

Tyrone Tracy

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PROJECT

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VIBRATION REDUCING PEN FOR PEOPLE WITH TREMORS

A Project

By

Tyrone Tracy

Approved by: Akihiko Kumagai, Committee Chair

Date: 7/29/2009
Student: Tyrone Tracy

I certify that this student has met the requirements for the format contained in the University format manual, and that this project is suitable for shelving in the Library and credit is to be awarded for the Project.

Kenneth Sprott

Department of Mechanical Engineering
Abstract of

VIBRATION REDUCING PEN FOR PEOPLE WITH TREMORS

by

Tyrone Tracy

Statement of Problem

Most people, at some time in their life, will have to deal with medical complications that occur in themselves or their family. Many underlying health problems exhibit shared physical symptoms. One physical symptom that originates from a variety of health problems is tremors. Patients experiencing sudden movements in the arms and hands find life difficult in terms of performing daily tasks such as using a utensil or writing. To help patients cope with problematic tremors in their daily lives, my project will contribute toward making one daily task easier to perform; being able to write legibly using a pen.

Sources of Data

Vibration theory concepts were gathered and learned through studying literature on force transmission and isolation. The calculations presented in this project were
made based on equations derived in the past by many experts. Modeling and simulation of the writing utensil were created by the author using 3-D modeling software.

Conclusions Reached

The scope of this project is to essentially prove a concept. The concept is making a writing utensil, a pen, which will damp vibrations when an individual with hand tremors uses it. This project made several assumptions about the input vibration from tremors. The simulations show that the vibrations were successfully dampened using four springs built between the pen shell and pen core.

Committee Chair

Akihiko Kumagai

2/9/2009

Date
DEDICATION

This project is dedicated to my parents who advised me to further my education.

To my father, thanks for all the support.
I want to thank Professor Akihiko Kumagai for technical guidance during this project. Also I would like to thank Professor Suh and Professor Granda whose classes taught me how to use SolidWorks and Visual Nastran 4D respectively.
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WORKSTATION SPECIFICATIONS

Hardware used:

- Computer specifications: Intel Xeon, 1.86GHz, 11.5GB RAM

Software used:

- SolidWorks 2008
- MSC.visualNastran 4D 2003
Chapter 1

INTRODUCTION

Statement of Collaboration:

Key resources at California State University, Sacramento were needed to complete this Project; lab time, software simulation packages and Professor Akihiiko Kumagai’s technical guidance. It is in agreement, between student and University, that in order to fulfill the Project requirement for a Master’s of Science at Sacramento State its resources are available for use.

Purpose:

Most humans, at some point in their life, will have to deal with medical complications that occur in themselves or their family. Many underlying health problems exhibit shared physical symptoms. One physical symptom that originates from a variety of health problems is tremors. To help patients cope with tremors in their daily lives, my project will contribute toward making one daily task easier to perform; being able to write legibly using a pen.
Problem:

Tremors are a sign of possible severe neurological disorders like Parkinson’s disease and Essential tremors (Prinsloo, Claude P., and Pierre J. Cilliers, Measurement and Analysis Of Muscle Tremor Using a Digitizing Tablet. IEEE Explore, 1998.) A tremor is an unintentional, sudden, jerky movement by one or more muscles occurring anywhere in the body. Commonly amongst tremor patients tremors can be seen in the arms and hands. Patients experiencing sudden movements in the arms and hands find life difficult in terms of performing daily tasks such as using eating utensils or writing on paper. The goal of this project is to minimize vibrations when an individual with hand tremors writes on paper.
Chapter 2

THE STUDY

Design of Experiment:

Some tremors are unpredictable in nature and cause severe jerky movements, yet some are predictable in terms of frequency and amplitude. In reality tremors can move in all three dimensions, x, y, z, but the scope of this project is limited and simplifications have to be made. The following list is the fundamental assumptions this project will adhere to.

1) Tremors around the 4Hz range (which encompasses Essential and Parkinson’s tremor)
2) Tremor amplitude around one half of one inch
3) Tremor only occurs in one direction

The purpose of this project is to verify that a pen built with four springs between the pen shell and pen core will damp vibration while writing letters of the alphabet. The letter “o” was chosen to run simulations around. The reasons the letter “o” was chosen are:

1) Is relatively easy to simulate with our software resources
2) It’s a letter than encompasses x and y direction movement
3) Results between a normal pen and a vibration reducing pen can be clearly seen

After the assumptions and project scope definition were made the next step is to simulate writing the letter “o.”
3-D Model Construction:

SolidWorks was used to create several three dimensional objects. All the pieces were constructed with Aluminum 2024-T3. After the pieces were created they were imported into Visual Nastran 4D and assembled using a variety of joints and constraints. This assembly simulates writing the letter “o.” Additionally the Wheel and Rod assembly were created in Nastran in order to control vibration amplitude and diameter of the “o.” SolidWorks was used to create the pieces of the modeled pen shown in Figure 1 and the entire simulation model shown in Figure 2. Part drawings of all these components are available in Appendix.

- Pen Shell
  - Mass: .074lbs
  - Length: 6"
  - Diameter: 1.3"

- Pen Core
  - Mass: .047lbs
  - Length: 7"

- Inner Ring
  - Diameter: 4"
  - Thickness: .472"
- Outer Ring
  - Diameter: 5"
  - Thickness: .472"

- Wheel
  - Mass: .00132kg
  - Diameter: .01206m, 0.475 inches
  - Rotation: 1440 deg/s

- Rod
  - Length: .0636m

The pen is designed with four coil springs connecting the pen shell and the pen core. The coil springs will be referenced in the simulations and calculations.

![Pen Design](image)

**Figure 1.** Pen Design. The coils are labeled.
The overall setup includes all the pieces described previously connected with joints and constraints defined in Visual Nastran 4D software. The idea is that the outer ring rotates in one direction and the inner ring rotates in the opposite direction; this keeps the orientation of the pen steady. This double rotation of the rings is needed so that the combination of the rings can be rotated in the “o” figure. Below is an image of the setup:

Figure 2. 3-D Pen Movement Simulation Setup
Figure 3. 3-D Pen Movement Simulation Setup with Angled View.

Simulations:

To begin simulations several reference parameters must be defined.

- "o" diameter without vibration = 6.29"
- Input amplitude from vibration = ~0.475"
- 12 seconds to complete one circle
- Pen wheel: 1440 deg/s, 2 oscillations in .5 seconds = 4 Hz
Several simulations are presented in this report:

- Draw “o” with no vibration
- Draw “o” with “worst case” vibration
- Overlap previous two simulations for comparison
- Draw “o” with the springs acting as rods and compare to “worst case” vibration simulation
- Draw “o” with proposed damping solution and compare to “worst case” vibration simulation
- Draw “o” with better proposed damping solution and compare to “worst case” vibration simulation

For simulations 4 and 5 the spring values need to be changed to attempt to damp the vibration. The spring numbering is defined on the next page.

Peak to Peak statistics are also measured. Measuring from peak to peak on Nastran is difficult because the display resolution is inadequate, so the calculated values are inserted as well. The measured and calculated values are very close so most likely the resolution of the software program accounts for the difference.
Simulation 1

- Input: none
- Spring 1 & 2 values: 10000n/m
- Spring 3 & 4 values: 30000n/m
- Peak to Peak measurement:
  - Calculated: 0"
  - Measured: 0"

Figure 4. "o" With No Tremor Input Vibration
Simulation 2

- Input: 4Hz input vibration
- Spring 1 & 2 values: 10000n/m
- Spring 3 & 4 values: 30000n/m
- Peak to Peak measurement:
  - Calculated: .475"
  - Measured: .465"

Figure 5. “o” With Maximum Vibration. The maximum has been defined as .475"
Overlap of no vibration simulation and worst case vibration simulation.

Figure 6. Overlap of Simulation 1 and 2.
Simulation 3

- Input: 4Hz input vibration
- Spring 1 & 2 values: 10000n/m
- Spring 3 & 4 values: 30000n/m
- Peak to Peak measurement:
  - Calculated: .475"
  - Measured: .465"

Red line represents a pen with no damping. Blue line represents pen with vibration damping with above parameters.

Figure 7. Simulation With Springs Acting as Rods. The blue and red line match.
Simulation 4

- Input: 4Hz input vibration
- Spring 1 & 2 values: 0.5n/m
- Spring 3 & 4 values: 1.5n/m
- Peak to Peak measurement:
  - Calculated: 0.207"
  - Measured: 0.213"

Red line represents a pen with no damping. Blue line represents pen with vibration damping with above parameters.

Figure 8. Simulation with Damping Working.
Simulation 5

- Input: 4Hz input vibration
- Spring 1 & 2 values: .05n/m
- Spring 3 & 4 values: .15n/m
- Peak to Peak measurement:
  - Calculated: .0394"
  - Measured: .0433"

Red line represents a pen with no damping. Blue line represents pen with vibration damping with above parameters.

Figure 9. Simulation with Excellent Vibration Damping.
Chapter 3

MODEL AND CALCULATIONS

Creating Model:

Vibration theory was important to completing this study because it influenced simulation settings and was used to verify that the end results made sense. First a very basic model of the pen shell and pen core had to be made.

Figure 10. Basic Pen Model.
This is a system of springs so it can be simplified to help with future calculations.

Figure 11. Pen Model Simplification.

Step 1: The K1 springs can be summed into one spring, $K1 + K1$, we will call it $K1_{tot}$. The upper portion of the pen shell is no longer needed in the simplified model. As well, the K2 springs can be summed into one spring, we will call it $K2_{tot}$. The springs are combined in a parallel manner, the following model proves why:
Consider a mass $m$ with a spring on either end, each attached to a wall. Let $k_1$ and $k_2$ be the spring constants of the springs. A displacement of the mass by a distance $x$ results in the first spring lengthening by a distance $x$ (and pulling in the $-\hat{x}$ direction), while the second spring is compressed by a distance $x$ (and pushes in the same $-\hat{x}$ direction).

The equation of motion then becomes

$$m\ddot{x} = -k_1x - k_2x = -(k_1 + k_2)x \quad (1)$$

$$\ddot{x} = -\frac{k_1 + k_2}{m}x, \quad (2)$$

Figure 12. Proof for Parallel Combination of Springs. Weisstein, Eric W., Springs—Two Springs and a Mass, 1996-2007

Step 2: The springs are in clearly in parallel and can be combined by series combination, this sum we will call $K_{tot}$.

- Equation 1: $K_{tot} = k_{1tot} + k_{2tot}$
Calculations:

The calculations were completed in Microsoft Excel as shown in Table 1.

Table 1. Excel Calculations

<table>
<thead>
<tr>
<th>pencore mass</th>
<th>Fdriving</th>
<th>b1</th>
<th>b2</th>
<th>k1 single</th>
<th>k1 tot</th>
<th>k2 single</th>
<th>k2 tot</th>
<th>Tdamping</th>
<th>Fnatural</th>
<th>Fdriving/Fnatural</th>
<th>damping ratio</th>
<th>TR (x/y)</th>
<th>x(m)</th>
<th>x(ln)</th>
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<tbody>
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<td>25.1312</td>
<td>0.0762</td>
<td>0.0254</td>
<td>0.05</td>
<td>0.1</td>
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<td>0.0254</td>
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Each category is described in detail below:

- **Pencore mass**: The pen core mass is .0212 Kg
- **Fdriving**: This is the driving frequency for our model.
  - Equation 2: \( F_{driving} = 4Hz \times 2\pi \)
- **b1**: Distance between k1tot and the center of mass of the pen core
  - Defined as three inches
- **b2**: Distance between k2tot and the center of mass of the pen core
  - Defined as one inch
- **K1single**: This is the value of one spring labeled K1. It varies with each simulation.
- **K1tot**: This is the summation of the K1 springs.
  - Equation 3: \( K_{1tot} = K_{1single} + K_{1single} \)
• $K_{2tot}$: This is the summation of the K2 springs. In order to prevent wobbling we must satisfy the equation
  
  * Equation 4: $k_{1tot} \cdot b_1 = k_{2tot} \cdot b_2$. B1, b2, and k1tot are all defined so k2tot can easily be solved for.

• $K_{2single}$: We must know the value of each K2 spring in order to enter it in the simulation software.
  
  * Equation 5: $k_{2single} = \frac{k_{2tot}}{2}$

• $K_{tot}$: Series combination of k1tot and k2tot.
  
  * Equation 6: $K_{tot} = k_{1tot} + k_{2tot}$

• $C(damping)$: Each spring was assumed to having a damping coefficient, this value can be changed but was set to .01 for each spring. For the calculations all four damping coefficients were added to equal .04.

• $F_{natural}$: Natural frequency of our system.

  * Equation 7: $F_{natural} = 2\pi \cdot \sqrt{\frac{K_{tot}}{pencoreMass}}$

• $R$: It is the frequency ratio:
  
  * Equation 8: $r = \frac{F_{driving}}{F_{natural}}$

• $Damping Ratio$: Measure of how oscillations die down

  * Equation 9: $\delta = \frac{c}{2 \cdot \sqrt{K_{tot} \cdot pencoreMass}}$
• **TR**: Defined as transmission ratio. It is the ratio of the vibration amplitude of the mass (pencore mass) X to that of the moving support (pen shell) Y.

\[
\frac{X}{Y} = \frac{\sqrt{1 + (2 \cdot \delta \cdot r)^2}}{\sqrt{(1 - r^2)^2 + (2 \cdot \delta \cdot r)^2}}
\]

○ Equation 10:

• **X(m)**: Defined as the distance between the red line drawn in figure 4 and the blue lines drawn in figure 8 and figure 9. This measurement has units of meters.

\[
X = Y \cdot \frac{\sqrt{1 + (2 \cdot \delta \cdot r)^2}}{\sqrt{(1 - r^2)^2 + (2 \cdot \delta \cdot r)^2}}
\]

○ Equation 11:

• **Xo(in)**: Defined as the distance between the red line drawn in figure 4 and the blue lines drawn in figure 8 and figure 9. This measurement has units of inches.

\[
Xo = X \cdot 39.37
\]

○ Equation 12:

Chapter 4

VIBRATION THEORY

Vibration Theory:

Several of the factors in the calculations were determined prior to making the model.

A pen has to be relatively light for people to use. In this case the pen shell plus the pen core weight about 45 grams, which is the same as about ten nickels. Using Newton's second law we can write \( m\ddot{x} = -kx - cx \); from this equation we can conclude that if \( k \) and \( x \) are constant then increasing the mass will cause the pen position to decrease. Increasing mass to reduce vibration is a good idea however we can't increase it so much that the user is unable to hold the pen, therefore a ten nickel weight seemed reasonable.
The transmission ratio (TR) is another important factor in vibration theory. The figure below gives us an insight into how to adjust the TR value.

The x-axis is the frequency ratio R. The "turnover point" can be seen at 1.414, so when R is greater than 1.414 vibrations begin to dampen. The y-axis is the transmission ratio.

The goal is to have a TR value of less than 1, but also we want the vibrations to damp quickly so we need the damping ratio, $\delta$, to be as small as possible. Looking at equation...
10 the denominator needs to be increased as much as possible for TR to be less than 1. R and \( \delta \) are the two variables that can change, it's crucial to note that these variables are related through Ktot. Equation 9 shows that if we increase Ktot we can decrease \( \delta \) and lower TR, however if we increase Ktot then equation 7 shows that Fnatural will increase. Increasing Fnatural will decrease r as seen in equation 8. R cannot be decreased too much because the requirement of \( r < 1.414 \) must be met so vibrations will damp. There is a balance and tradeoff between selecting the proper spring constant values and rate at which the vibrations will decrease. The blue line in Figure 9 shows successful vibration damping. For that simulation TR was very small, .08, and R was big, 5.78, however \( \delta \) is slightly increased to .22; a smaller \( \delta \) value is better but R would have been effected through the adjustment of Ktot.
Chapter 5

CONCLUSION

Calculation Analysis:

Table 1 shows the Xo results, which is the distance between the blue line damping solution, in our simulations with vibration input, away from the red line “o” seen in Figure 4. As expected the results of the calculations matched the logic of vibration theory. Generally when the individual spring constants K1 and K2 were low, the transmission force to the pen core was low causing Xo to be very low. This means that our blue line results in Figure 8 and Figure 9 should look more and more like Figure 4, which clearly seen in Figure 9. As a sanity check if a rod was substituted in for the individual springs, then K1 and K2 would be very high resulting in a high TR and displaying a large Xo, which is apparent in Figure 7. The calculation results differ slightly from the simulation results because the simulation results are not as precise. Overall the calculation results match the theory of damping vibrations and agree with the simulation results.

Simulation Analysis:

The first simulation, figure 4, demonstrates what a perfect “o” looks like, that has no vibration input possibly seen in normal handwriting. After that’s established a simulation was run to see what the worst case “o” would look like for a person who had a
tremor that only moved in one direction, had a frequency of 4Hz, and had amplitude of .475"; this is seen in Figure 5. Once those baseline simulations were established we moved onto simulations that attempted to damp the 4Hz, .475" vibration. Figure 7 shows what a very large K1 and K2 would result in, which acted as expected by not damping the vibration at all. The next two simulations decreased the K1 and K2 values significantly. The blue line in both Figure 8 and Figure 9 have less sinusoidal oscillations, and even better Figure 9 looks very close to Figure 4. The project’s goal of damping a specific input vibration using 4 internal springs has been accomplished and is clearly seen in Figure 9.

Feasibility:

The model parameters in this study were made to be realistic, like a pen shell and pen core made out of aluminum, and a reasonable overall pen mass. A factor that will be an issue is if the springs can be fabricated to exhibit very low spring constant values. Maybe a different type of spring can be considered; instead of a coil spring maybe a leaf spring is a better solution. The scope of this project has demonstrated proof on concept; to internally reduce vibrations in a writing instrument.
Appendix

Detailed drawing of Inner Ring.
Detailed drawing of Outer Ring.
Detailed drawing of Pen Shell.
Detailed drawing of Pen Core.
Detailed drawing of Wheel and Rod.
Bibliography


2. Noriega, Julio A. “1-7” Lab5A Vibration Theory, 22 March 2009


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