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Project Type: Vibration Design

Reverse Engineering the Electric Pick Gun

Adam Bartlett, ID: a1646071

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1 Reverse Engineering the Electric Pick Gun

This project takes a look at lockpicking and some of the tools and techniques used by the modern-day locksmith. In particular the design and operation of a tool known as the electric pick gun, which is essentially just a vibrating pinned-free beam, will be broken down and discussed in more detail.

2 Project Description

2.1 Background

In order to understand how an electric pick gun works, and why they are such a powerful tool when put in the right hands, one must first have a basic understanding of the concepts behind lockpicking and locks in general.

A lock typically consists of five components, as shown in figure 1 below, the most important of which are the driver/key pins. For a lock to open all of the driver/key pins must separate at the shear line so the plug is able to rotate.

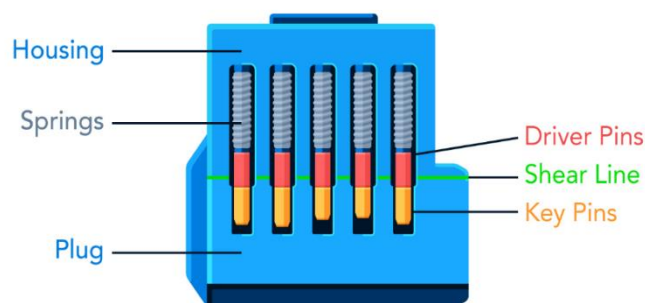


Figure 1: Internal components of the standard pin & tumbler lock (Goodman 2017)

Lockpicking is the art of finding and exploiting the manufacturing/design flaws that exist within a particular lock to the point which it can be opened without the original key. The largest flaw associated with most locks has to do with the alignment of the pin holes in the plug. Ideally these holes would be perfectly aligned but due to realistic manufacturing tolerances they are often slightly offset by a fraction of a millimetre.

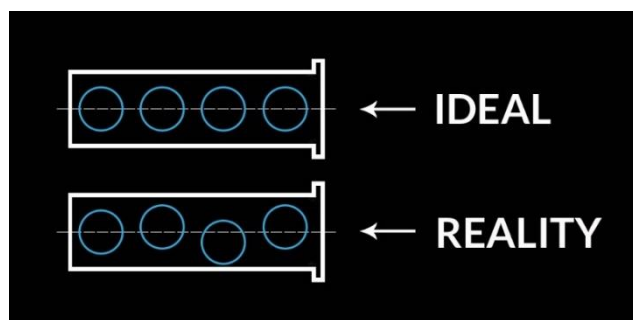


Figure 2: The primary manufacturing flaw associated with most pin & tumbler locks (Goodman 2017)

By inserting a tool known as a tension wrench into the lock a moment can be imposed on the plug, causing one of the driver pins to bind. Once located the bound driver pin can be raised to the shear line using a standard pick and the plug will be free to rotate until the next driver pin is bound. Repeating this process to open a lock is known as “Single Pin Picking (SPP)” and is generally considered the most time consuming and skill intensive technique used by locksmiths. There are several alternative lockpicking tools and techniques that exist within the modern-day locksmith’s arsenal, the most recent of which is the pick gun. Several different forms of pick guns exist, both mechanical and electrical, but they all work in a similar fashion.

Mechanical pick guns use a pinned-free beam to impact all of the pins at once, as seen in figure 3. Newtons third law dictates that the impact force applied to the key pins is translated to the driver pins causing them to rise independently. The resulting gap left between the two pins makes it easier for the driver pins to set at the shear line. The effectiveness of this method is highly dependant on the individual lock it is used on and could take anywhere from three to one hundred attempts to work.

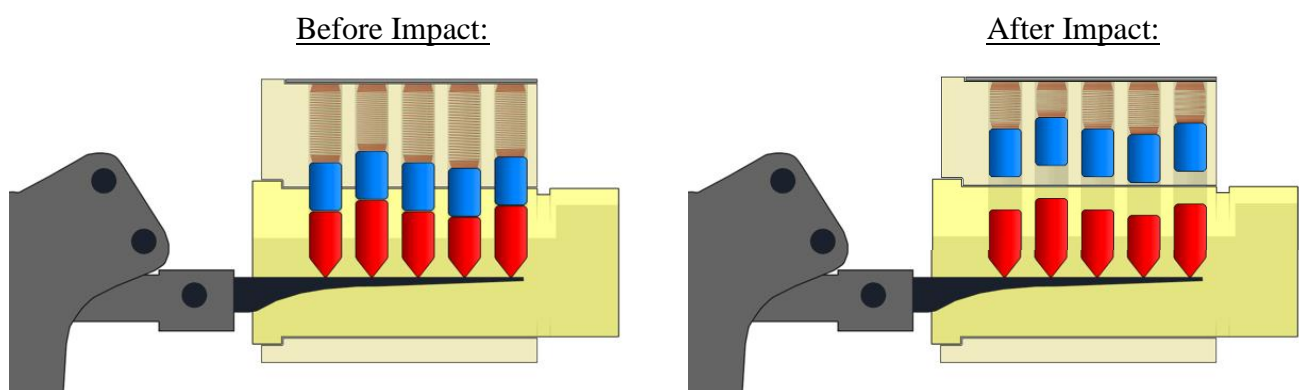


Figure 3: How a pick gun works

Electric pick guns work in a similar way to mechanical pick guns except they rely on the vibration from a pinned-free beam instead of a single impact force. The high frequency of vibration greatly increases the rate at which the driver pins are set as more combinations are tried in a shorter period of time. The vibration, along with the resulting collisions that accompany it, also cause the pick to deform in relation with higher frequency mode shapes. This is actually a good thing as the varying shape of the pick changes the order/force at which the key pins are hit, effectively making sure the pick gun keeps trying different combinations.

Electric pick guns, whilst more effective than mechanical pick guns, are not without their faults. They require power to work and generally make a lot of noise due to the collision between the lock and the pick. Additionally, these collisions leave scratch marks clearly indicating that the lock has been tampered with. Some skill, all be it less than single pin picking, is required when operating a manual or electric pick gun.

The user still has to know how to tension the lock using a tension wrench and how to select the correct amplitude of vibration (in the case of the electric pick gun). If the vibration amplitude is set to low the driver pins will simply not reach the shear line and if it is set to high they key pins can get stuck, oversetting the lock.

2.2 Literature Review

The content discussed in this literature review looks at the different actuation methods used to create vibration within an electric lock pick gun. Both methods that are currently in use and alternative methods that could provide better results will be investigated.

Actuation methods used to power electric pick guns can usually be sub-classified into two basic categories, electromagnetic actuation or motor actuation (Tyler 2007). Electromagnetic actuated pick guns use an electromagnet to excite some kind of beam holding a pick. This type of actuation method was never put into production as it lacked the ability to control the amplitude and frequency of the pick's vibration (Tyler 2007).

In terms of motor actuated vibrations there are two different methods that exist. The first of which, seen in figure 4, revolves around the impact force between an offset cam attached to the motor and a pinned-free beam (Tyler 2007). The cam strikes the rear end of the beam causing it to bounce between the frame and a knurled screw. The knurled screw can be moved in or out in order to adjust the amplitude of vibration. On the other hand, the frequency of vibration cannot be adjusted because these devices are powered by a DC motor that rotates at a constant speed. The vibration caused by this actuation method is of a violent nature and causes a lot of noise to be generated from the internal collisions within the device. Additionally, this violent vibration is known to knock the knurled screw loose therefore making it hard to maintain a constant vibration amplitude. This type of actuation method is used throughout most of the electric pick guns available on the market due to its simplistic design (Tyler 2007).

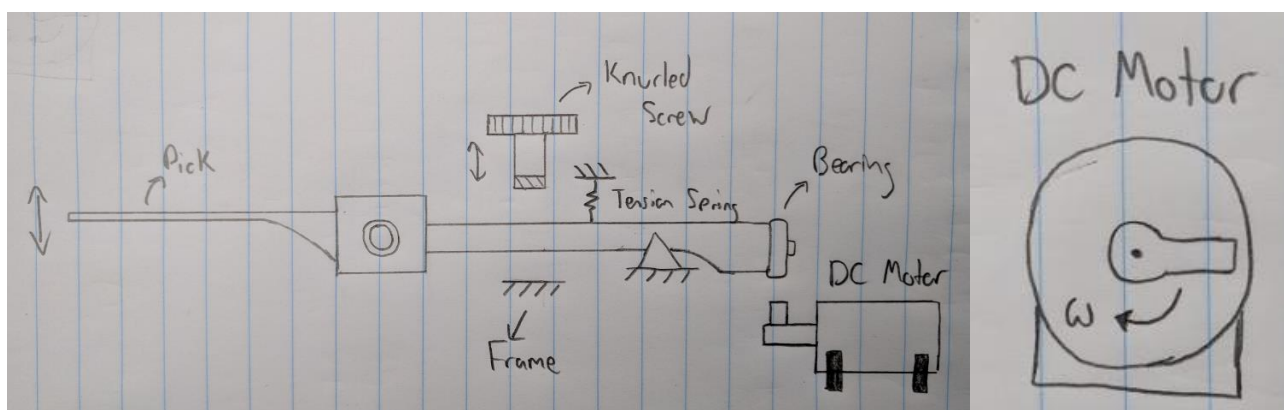


Figure 4: Impact – Motor actuation method

The second motor actuation method involves the inertial force created by a rotating mass and is best described by a patent written by K.C Frederickson (2011). The device, shown in figure 5, is known as a harmonic force generator and is intended to be used for an active vibration

control system. It was initially created to counteract some of the vibrations associated with helicopter blade rotations but can be used for many other purposes.

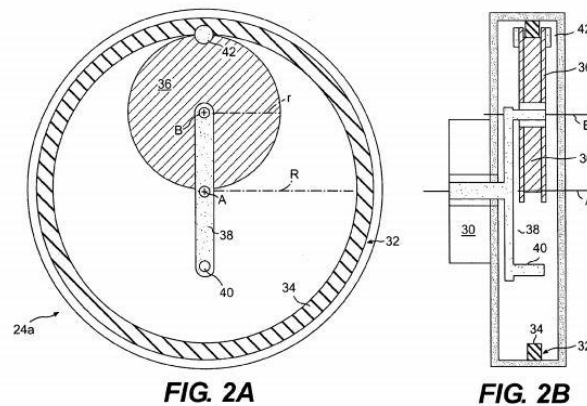


Figure 5: Harmonic force generator

In terms of functionality it works by rotating an internal mass, which has half the diameter of the device it is located in, at high velocities using a variable speed motor. As this mass rotates around the centre of the device it creates an inertial force that travels along a single axis, the value of which is equal to:

$$F = mR\omega^2 \sin(\omega t)$$

Figure 6 shows it in action and also points out another important point of the design in that as the mass completes one rotation about the device the resulting inertial force will complete one harmonic cycle.

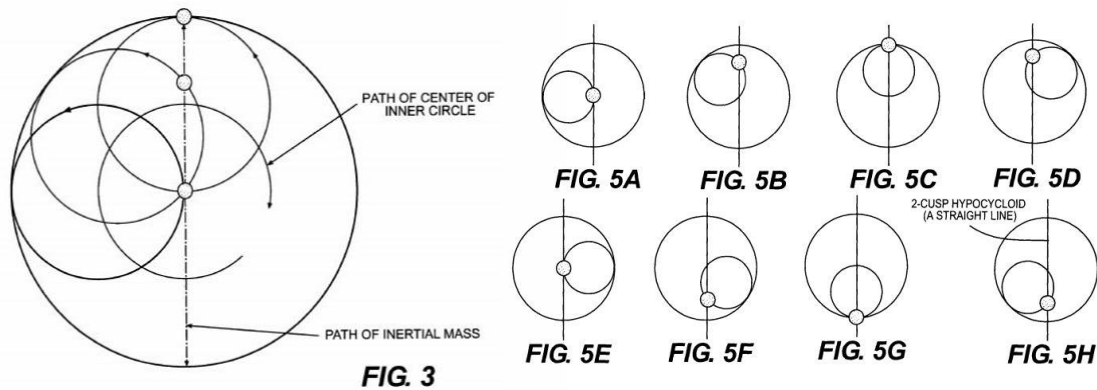


Figure 6: Location of inertial force due to mass rotation

Using this method of actuation in an electric pick gun gives the user the ability to control both the frequency and amplitude of the harmonic force to ultimately control the vibration amplitude of the pick. Also, because this motor actuation method doesn't rely on violent forces it is quieter and more efficient.

2.3 Project Aim & Goals

Aim:

This project aims to reverse engineer the electric pick gun to find out how it manipulates the vibration amplitude of a pinned-free beam in order to open locks without a key. Once determined a prototype of the vibration mechanism is to be created and analysed using Ansys.

Goals:

1. Perform market research and literature reviews to figure out the primary components that exist within an electric pick gun, in addition to the current vibration actuation methods that are being used to power them.
2. Design a custom prototype of an electric pick gun's vibration mechanism using the knowledge learnt from market research and literature reviews.
3. Model this prototype in Ansys and use finite element analysis (FEA) to find out:
 - What its natural frequencies are and how they relate to the target material
 - What parameters of the design govern the frequency and amplitude of the pick's vibration
 - How these parameters can be manipulated to give the user control over the amplitude of vibration

2.4 Methods

To satisfy the aims and goals set out in this project the following approach was undertaken. First some initial background research was performed to find out exactly how electric pick guns use the vibration of a pinned-free beam to open pin & tumbler locks. Following this a literature review was conducted to determine the different actuation methods that could be used to create this vibration. In addition to this market research was also conducted, in section 2.5, to see what primary components are contained within both low and high-end devices.

Using the information discovered thus far several prototypes were constructed focusing around required components, the sizing of these components, actuation methods and selected materials. The final design, located in section 2.6, was then modelled in Ansys so finite element analysis could be used to see how the different parameters/inputs to the design effect the amplitude vibration of the pick. The full results for the discoveries made during this finite element analysis can be found in section 2.7.

2.5 Market Research

Market research was conducted to figure out what electric pick guns are currently available for purchase in addition to the primary components they are made up of. In particular two different brands and models of electric pick guns were selected for investigation, as seen below in figures 7 & 8. These pick guns were selected due to their differences in cost, quality and appearance. Comparisons were made between the two devices by looking at their specifications, user manuals, user reviews and general performance.



Figure 7: Multipick's Kronos – High End [\$330]



Figure 8: KLOM's Electric Pick Gun – Low End [\$60]

Both of these pick guns, along with several others on the market, stimulate the vibration of the pinned-free beam using repetitive impacts from a rotating piece of metal attached to a DC motor. They are made up of relatively similar components, the most important of which are:

- A straight replaceable pick that interacts with the key pins in the lock.
- A pinned-free beam that acts as the catalyst for the vibration.
- A DC motor, usually spinning at 12,000 to 13,000 RPM, that acts as the source of vibration.
- A knurled screw that can be adjusted to change the amplitude of vibration, the desired range of which appears to be somewhere between 1 to 4mm depending on the lock (Multipick 2017).

In terms of overall performance and effectiveness the more expensive Kronos pick gun seemed to get better reviews and was able to open a more varied range of locks in a shorter time frame. This was most likely due to its more robust knurled screw, as the vibration causes this component to loosen overtime therefore increasing the vibration amplitude and reducing its effectiveness on the lock. Reviews from the KLOM pick gun confirm this as many users pointed out that it required constant adjustment to have a change at working. Another negative attribute for both of these pick guns is the amount of noise they produce as a result of their actuation method.

2.6 Prototype Design

The final prototype utilises the harmonic force generator, discussed during the literature review, as the vibration actuator of the pick gun. This actuation method was selected as it removed the need for a knurled screw, the main problem associated with current electric pick guns, as the vibration amplitude can be adjusted by simply varying the speed of the motor. Using this method also removes the impact between the motor and the back of the pinned-free beam hopefully reducing the noise it produces. Besides the harmonic force generator there are only three other components required to make this design functional: The variable speed motor, a pinned-free beam and replaceable picks.

The sizing of the pinned-free beam was estimated according to scale images of the electric pick guns investigated during market research. The dimensions of the pick were measured from a Multipick branded manual pick gun using digital Vernier Calipers. They were then slightly modified by making the pick longer and thinner to accommodate vibration. As for the harmonic force generator its radii were set to 20 & 10mm to make sure it remained in proportion with the size of the pinned-free beam and could realistically fit inside of some kind of housing. The weight for the mass used in the harmonic force generator was arbitrarily selected as 4g. After initial testing on Ansys this value turned out to be ok but suboptimal and therefore was changed to 6g.

In terms of materials both the pined-free beam and the pick were selected as 301 stainless steel. This is the type of steel generally used in the production of high end picks as it is durable and resistant to corrosion. Spring steel was also considered for the pick, as it would have facilitated more vibration, but was ultimately not selected in the final design.

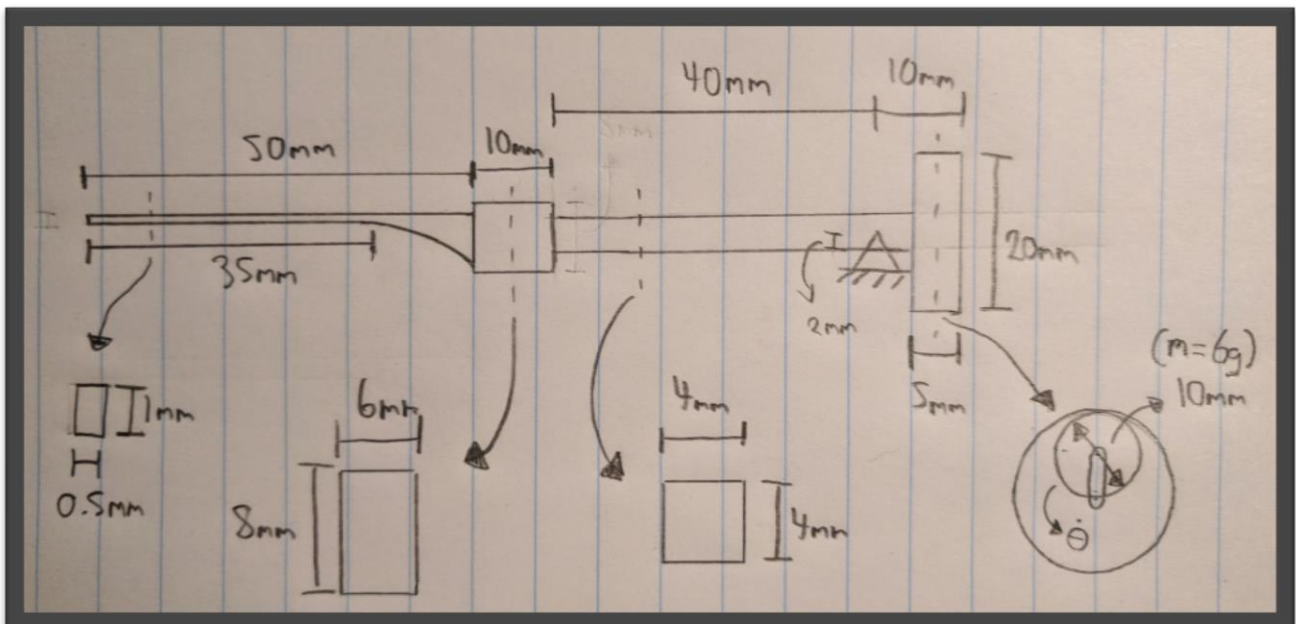


Figure 9: Final prototype design of the electric pick gun's vibration mechanism

2.7 Results and Discussion

This section of the report will delve deeper into the vibration response characteristics of the aforementioned prototype. The design itself was modelled using Ansys and finite element analysis was conducted in order to determine:

- Its natural frequencies and their resulting mode shapes
- The vibration amplitude of the pick in response to varying harmonic forces

2.7.1 Natural Frequencies

Modal analysis was conducted on the Ansys model of the prototype to discover its natural frequencies and their resulting mode shapes. The first six natural frequencies are presented in table 1 below, ranging from 0 to 3150 Hz. In terms of mode shapes three distinct patterns were observed: Vibration as a result of the pinned joint as well as both side to side and up and down vibration of the pick.

Mode	Frequency [Hz]
0	0.00
1	209.99
2	531.43
3	828.16
4	1246.10
5	2319.60
6	3152.90

Table 1: Natural frequencies of the prototype

Pin Vibration:

Because the pin is unable to resist rotational motion about its axis a 0 Hz mode shape exists. This is the dominant mode shape and is therefore the main contributing factor towards the vibration amplitude of the pick. The location where the motor connects to the harmonic generator, marked with a red circle, bends slightly. Because of this, special considerations might have to be made in terms of how these two components are connected.

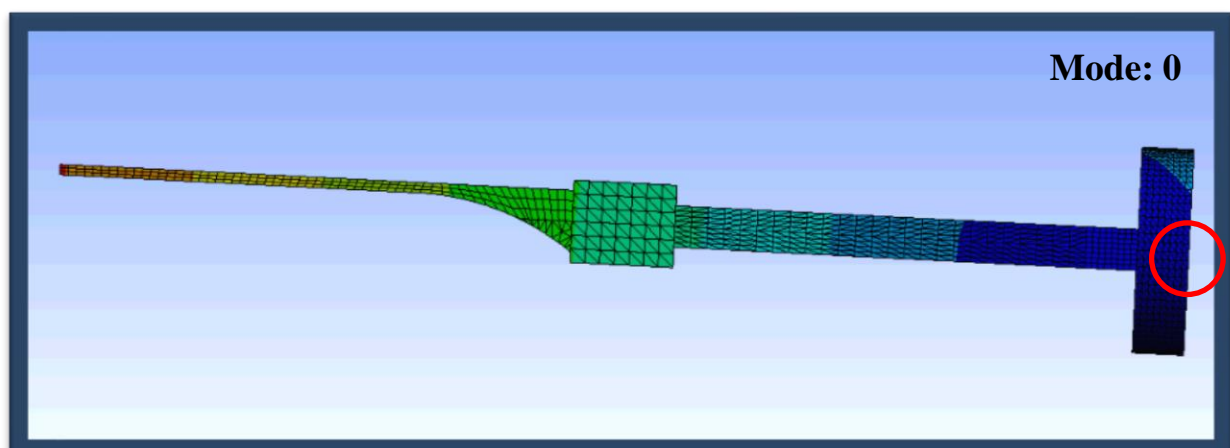


Figure 10: Vibration due to pin joint

Side to Side Vibration Mode Shapes:

Mode Shapes 1, 3 & 4 represent the first three side to side vibration modes of the pick. These vibrations occur before the up and down pick vibrations because the thickness of the beam is much thinner on this axis. The harmonic force applied to the beam will not excite these mode shapes but they are likely to occur from collisions within the lock. There is even evidence of this as electric pick guns leave scratch marks on the inside of locks indicating that they have been tampered with. Therefore, although these mode shapes are not desired they are likely to occur as a result of the lock picking process.

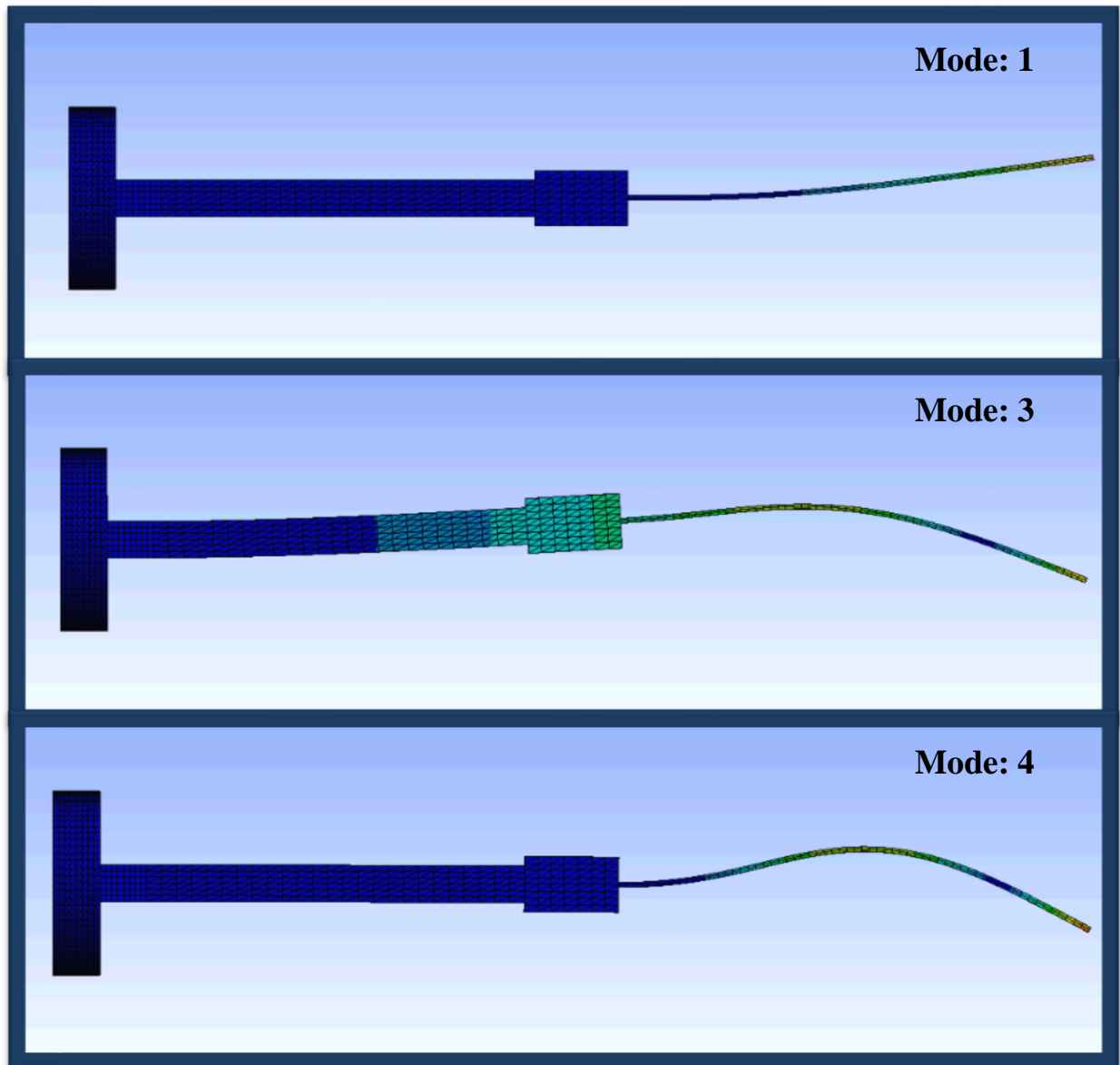


Figure 11: Side to side vibration mode shapes

Up and Down Vibration Mode Shapes:

Mode shapes 2,5 & 6 represent the first three up and down vibration modes of the pick. These mode shapes can occur as a result of the harmonic force although they are unlikely to be dominant as the motor speeds, determined in the next section, don't reach high enough vibration frequencies. However, it is still possible for these mode shapes to occur from the impact between the pick and the lock during operation. The vibration amplitude of the pick caused by these mode shapes helps offset the time, and vary the forces, applied to the key pins of the lock. This increases the number of combination attempts applied to the key pins in turn increasing the probability that the lock will eventually open.

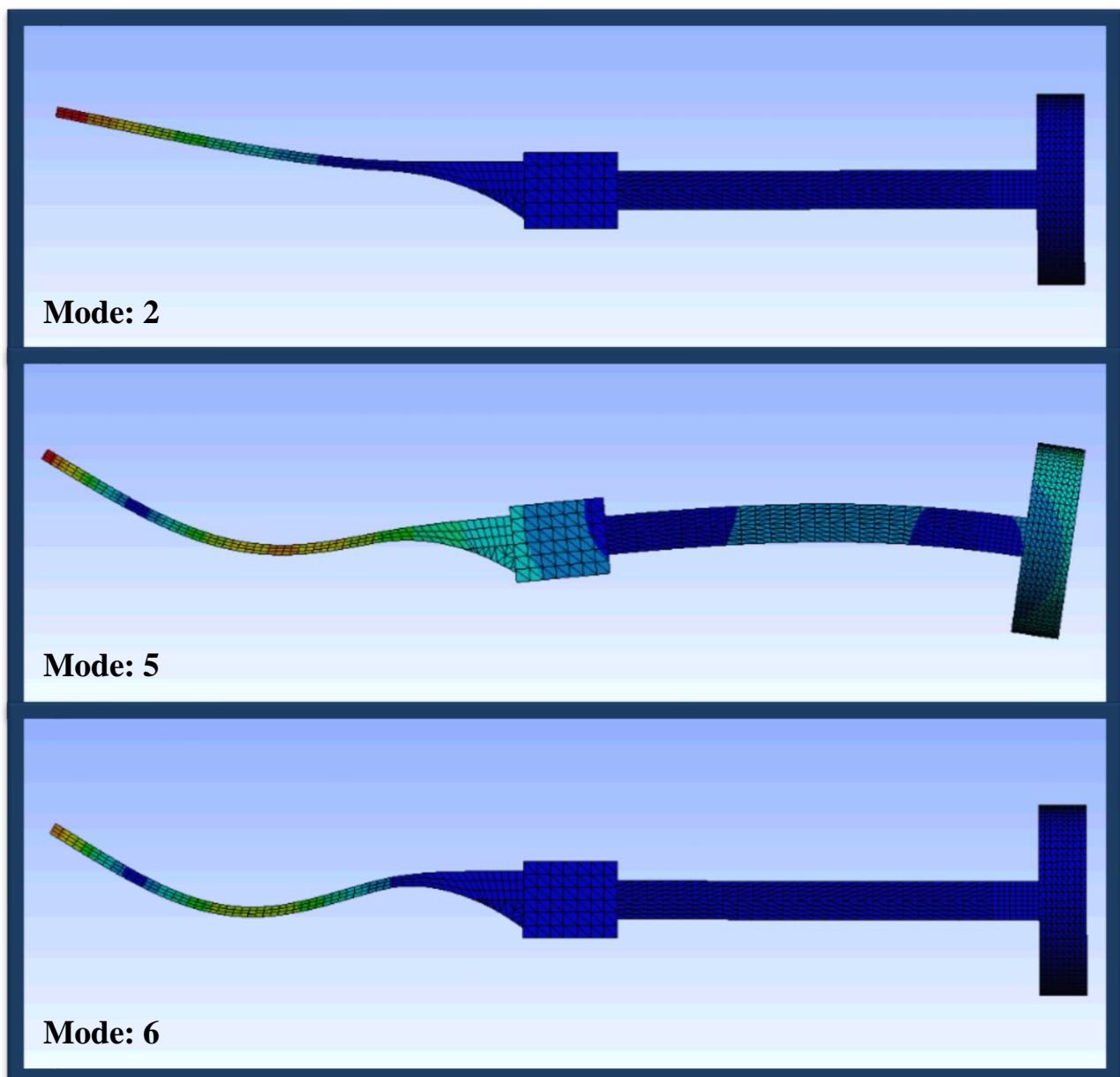


Figure 12: Up and down vibration mode shapes

2.7.2 Harmonic Force Response

Harmonic analysis was conducted on the Ansys model of the prototype to figure out how the amplitude of the pick responded to varying harmonic forces. As the amplitude and frequency of the harmonic force are both dependent on the rotational speed of the motor a simple frequency response graph would not suffice. Therefore, to obtain valid results the following steps were conducted:

1. Determine an appropriate testing range for motor speed, arbitrarily selected as:

$$2500 \text{ RPM} \leq \text{Motor Speed} \leq 8500 \text{ RPM}$$

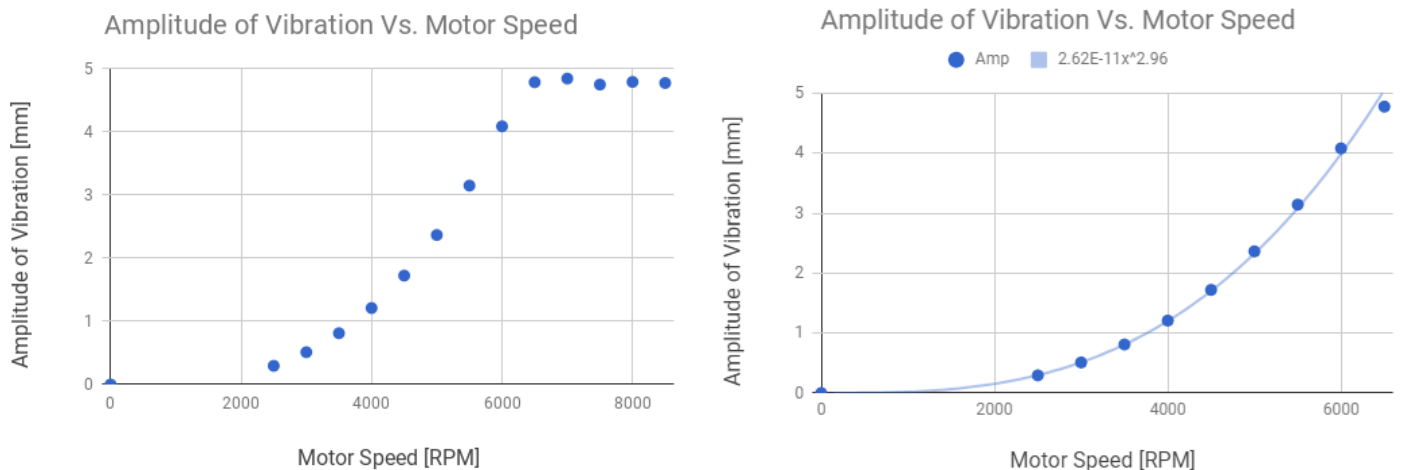
2. In increments of 500 RPM calculate the harmonic force in correspondence with the current motor speed, using the equation:

$$\text{Harmonic Force} = mR\omega^2$$

3. Convert the current motor speed from RPM to Hz. As a single rotation of the motor is equivalent to once cycle of the inertial/harmonic force therefore:

$$\text{Target Vibration frequency} = \frac{\text{Motor Speed}}{60}$$

4. Set the amplitude of the harmonic force in Ansys to the above value and solve the problem to find the total deformation of the pick at the target vibration frequency.
5. Repeat steps 2 – 4 until all the data is collected.



Graph 1: Amplitude of the pick's vibration in relation to a specific motor speed

The results of this test, shown above in graph 1, indicate that the vibration amplitude of the pick only increases between 0 and 6500 RPM. This is ok as the desired amplitude of 1 to 4mm exists within this range and there is likely to be some kind of vibration amplitude restriction from the pick gun's casing anyway. From the graph on the right the following

equation was derived to estimate the vibration amplitude of the pick given a specific motor speed:

$$\text{Vibration Amplitude} = (2.62 \times 10^{-11}) \times (\text{Motor Speed})^{2.96}$$

Where:

$$\{\text{Motor Speed} \in R \mid 0 < \text{Motor Speed} < 6500\}$$

This power series equation has a coefficient of determination of approximately 99.9%, making it highly accurate at predicting the mean value of the vibration amplitude. Using this equation, the final desired results were determined as shown below in table 2:

$$3750 \text{ RPM} \leq \text{Desired Motor Speed} \leq 6000 \text{ RPM}$$

Desired Amplitude	Required Motor Speed
1mm	3758 RPM
2mm	4749 RPM
3mm	5446 RPM
4mm	6002 RPM

Table 2: Required motor speeds for desired vibration amplitude range [1-4mm]

Please note that these results are only valid for the vibration of the pinned-free beam outside of a lock. As it is possible that the impacts applied to the pick as a result of vibrating inside of a lock could damp this vibration amplitude. Further research would have to be conducted to see if this is the case and whether or not it has any effect on the performance of the device.

2.7.3 Future Work & Marketability

Possible future work could involve seeing how the pick responds to external collision forces introduced by vibrating inside of a lock. Additionally, it could be worth looking into different sensors and control systems in order to increase the accuracy of the vibration amplitude if it ends up being a problem.

Although the prototype is still in the initial stages of design its marketability can be estimated at this point in time. In terms of performance it seems to have a more effective, yet complicated, method of vibration amplitude control and requires slower motor speeds in order to function. Because the internal collisions between the pinned-free beam and knurled screw have been eliminated it is likely that the prototype would be significantly quieter than the competition. The added complexity of the design would likely drive up manufacturing costs making the prototype pick gun more expensive. All in all, continued research into this prototype would not be worth it as the market is already saturated with devices that work effectively and the consumer base is small only consisting of locksmiths, special forces units and enthusiasts.

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4 Plagiarism Declaration

I declare that this report is the result of my own independent research; materials from the work of other researchers such as any data, figure, table, etc. have been acknowledged.

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Signed by Adam Bartlett