The Innovation of Oscillators in Rhodes pianos

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***Abstract*—For decades, the enchanting sounds of mechanical-electric keyboards have been a source of inspiration. However, there has been a lack of significant innovation in their mechanical components for many years. This paper deals with development of oscillators for mechanical-electric keyboard instruments, specifically focusing on innovations in a frequency spectrum due to modifications in the geometry of mechanical parts, variations in materials, sensing position and hammer strike position. Drawing from the original oscillators of Rhodes Mk7 instrument, new virtual models were created using software SolidWorks and subsequently analyzed using software Ansys. These models were then physically fabricated and subjected to examinating. The final assessment involved comparing the frequency spectra of the upgraded assemblies with the original assemblies and analyzing resulting data.**

***Index Terms*—Tines, oscillators, hammer, Rhodes, piano, spectral analysis**

I. Introduction

In mechanical-electric instruments, there are several essential components crucial for sound generation, including the excitation system which contains hammer, oscillation system – tines or tips supported by tone bar (in Rhodes pianos) – and sensor that detects changes in the electromagnetic field engendered by oscillation of the tine [1]. First pioneers of this kind of musical instruments came from war times early in 1940's, when Harold Rhodes made his first acoustic prototype of *Xylette*, also known as *Army Air Corps Piano* which evolved in electrified version of today mechanical-electric pianos known as Rhodes pianos with the first mass-produced model *Fender Rhodes Piano Bass*. Over the years, numerous new models have been produced and sold worldwide. Worth mentioning is iconic model Mk I which had been produced from 1976 to 1979 in two variantions (Suitcase and Stage, one with and one without 80W amplifier from the Peterson FR7054 series, which later in 1977 was replaced by a newer FR7710 series amplifier with 100W stereo output). This model introduced new twisted tone bars that created a much more compact system, stable and longer tone with a supporting second harmonic. However, there was no significant mechanical change in the tines. [2] [3] [4]

This paper studies inovations in frequency spectrum compared to three keys from Rhodes piano model Mk7 (F1, F3 and F6) and simulations simulated in software Ansys dependent on changes in mechanical parts, especially geometry of the tines base and their material, position from the sensor and hammer shapes with their strike position. For technical evaluation commonly use methods in data and signal proccesing were chosen, namely Short-time Fourier Transform (STFT) and Fast Fourier Transform (FFT). From more musical perspective were used two laws, Weber-Fechner psychoacoustic law and Ohm-Helmholz psychoacoustic law (assembled from two different laws, Theory of hearing from H. von Helmholz and Ohm's acoustic law) [5] [6].

Different base geometries were considered, simulated and finally ended on three new shapes for tines that were manufactured – rectangular, triangular and square. Simulations of these shapes reported significant differences in their frequency spectrum compared to the original assemblies. Every tine was tested and manufactured in two materials configuration – stainless steel and structural steel (basic properties of used materials are listed in Table I) [7]. Manufactured assemblies were tested on a simple wooden system with an adjustable position for smooth setup of the different hammer strike positions.

The results indicate distinctions in energy mostly in lower pitch notes, keys F1 and F3, which also have the greatest potential for generating higher number of partials than higher notes. On the other hand, higher notes have ability to generate much more inharmonic sound and clusters of partials and add more noise to overall sound. The most interesting and unique assembly, whether in terms of simulation or real measurements, seems to be F1 key assembly with square base, made from structural steel, that generates stable partials in first and second band according to Ohm-Helmholz psychoacoustic law. Other assemblies will be described in the following results section.

The remainder of the paper is structured in the following manner. Section II. briefly describes the assembly and wooden system modelling procedure, their individual parts and setup for virtual assembly simulations in Ansys. Section III. explains the actual tests of the assemblies and describes in detail the testing of the hammer strike positions including their designed shapes and the different tine sensing positions. At the end, Section IV. describes the best assemblies in terms of innovativeness of the frequency spectrum followed by discussion and conclusions in Section V.

II. Creation and simulation of assemblies

A. Parts creation

Firstly, it was necessary to measure sizes of the individual parts in assemblies. The individual proportions of the oscillator

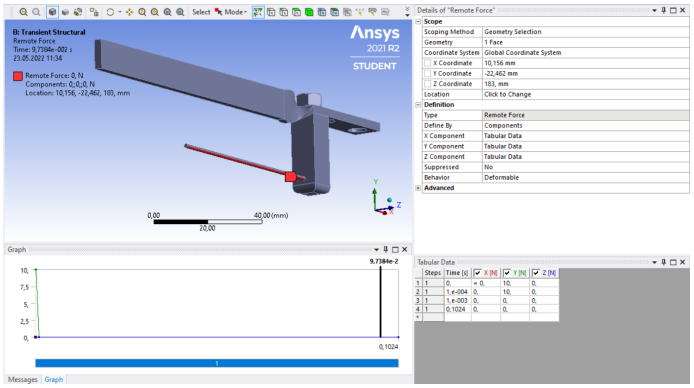

Fig. 1. F3 key oscillation system with 10 N *Remote Force* applied on Y axis.

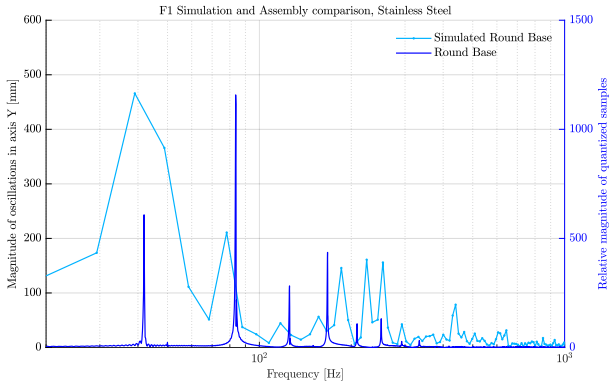

Fig. 2. Comparison of simulation and physical assembly.

systems were transformed into virtual assemblies using SolidWorks, which were then modified to create the experimental tine base shapes. Each oscillation system consists of a tine mounted (most often welded) on a block that connects tine with a support component – tone bar, through bolt. Specific shape of tone bar, usually used for lower notes, ensures that the oscillating tine will not interfere with a tone bar. This assembly creates look similar to a tuning fork and provides more stable tone. Example of virtual assembly tested with 10 N *Remote Force* in Ansys is shown in Figure 1.

All hammer parts (hammer tips, hammer, holder and key pedestal) were printed on 3D printer from PLA material. Three basic hammer tip cross-section shapes have been proposed with different curvature at the point of impact. To better accommodate the energy transfer of the tip strike, one of the designed tips was wrapped with a damping material.

Main wooden construction of the testing system consists of three basic parts, two gates and one sliding axis (shown in Figure 3). One of the gates is used for mounting the electromagnetic sensor and connecting this sensor to the TS connector. The other gate is used to mount the oscillator assembly itself. On the sliding axis there is a small wooden block for screwing the striker of the hammer tip and the key itself.

B. Ansys simulations

The created virtual assemblies were then exported from SolidWorks and imported into the Ansys environment. At first, a contacts of the individual contact parts were defined (these were bolt-to-tone bar, tone bar-to-block and bolt-to-block contacts) which ensure stability of simulation. Without defining these constraints, the simulation itself would collapse and the individual parts would interfere. Subsequently, the mesh with finite number of elements for the overall assembly was generated. To calculate the frequency spectrum from the simulation, the sequence of analyses was set in the order of *Modal Analysis* and *Transient Analysis*. Prior to the actual process of calculating the transient analysis, the modal analysis that will subsequently be an input for the transient analysis needs to be set up. Thus, the 100 modes of the assembly were set to be captured over the audible spectrum range, i.e. 20 Hz to 22 kHz. A very important point of the simulation was the choice of initial and boundary conditions, which are vital for the resulting values of the simulation. By definition, boundary conditions are those that a function must satisfy at certain points. These points often lie on the edge of the domain that the function solves [8].

Main condition for the *Modal Analysis* was a solid support (referred to as *Fixed Support*) defined on the tone bar, specifically on the walls of the bolt fixing holes. For *Transient Analysis*, an external force (referred to as *Remote Force*) of various magnitudes ranging from 5 N to 100 N was applied to points at $\frac{1}{4}$, $\frac{1}{6}$, $\frac{1}{8}$, and $\frac{1}{16}$ of the length of the tine (measured from the fixed end). The forces were oriented upwards, perpendicular to the bottom part of the tine. Overall time of simulation was set to 102.4 milliseconds with step 0.1 millisecond. This setup ensures that a number of output data or samples will corresponds to a power of two and will fit into FFT window correctly. Important result data were obtained from *Directional Deformation*. The results table contains data of the average, maximum and minimum deflection of the system in millimeters relative to a certain axis of the system. For the purpose of FFT analysis, the data for the maximum deflection was stored and further processed in Excel and Matlab. A comparison of final FFT analysis from F1 key simulation and associated physical assembly is shown in Figure 2.

III. Physical Testing

After all simulations have been performed, the real assemblies were manufactured and tested on previously introduced wooden system. The designed PLA tips were tested first on a testing assembly with rectangular base from structural steel and fixed strike position (approx. $\frac{1}{4}$ of the length of the tine, also measured from the fixed end). These tips were in three cross-section configurations – semicircular, triangular wrapped with damping material and beveled triangular.

Semicircular and beveled triangular tips generated more clusters in second band and less carrier harmonics from first band. On the other hand, tip with damping material amplified

TABLE I
BASIC PROPERTIES OF USED MATERIALS.

Material	Properties	Value
Structural steel	Modulus of Elasticity in Lift E	190 GPa
	Specific Electrical Conductivity σ	$0.6 \cdot 10^7$ S/m
Stainless steel	Modulus of Elasticity in Lift E	180 GPa
	Specific Electrical Conductivity σ	$0.2 \cdot 10^7$ S/m
PLA	Modulus of Elasticity in Lift E	0.098 GPa
	Density ρ	1.25 g/cm^3

TABLE II
BANDS OF PARTIALS IN THE SPECTRUM AND THEIR PROPERTIES ACCORDING TO OHM-HELMHOLZ LAW.

Band	Range and Properties
1st Band	1st to 8th Harmonic Partials
Properties	Fundamental color composed of intervals
2nd Band	9th to 16th Harmonic Partials
Properties	Cluster band composed diatonically
3rd Band	17th to 32nd Harmonic Partials
Properties	Continuous, quasi-harmonic spectrum
4th Band	33rd to 64th Harmonic Partials
Properties	Noisy, non-harmonic spectrum

more harmonics from 1st band and brings more stability to a overall sound with less inharmonic partials and noise.

A reference tip (with triangular cross-section wrapped with damping material) was selected for subsequent testing of strike positions, with regard to its performance in generating four harmonic overtones in the first band on the tested assembly (basic characteristics of individual bands are described in Table II). This adds clarity and stability to generated tone.

Thereafter, on testing assembly with rectangular base the strike positions were examined. These positions were taken depending on length of the current tested tine in later experiments, but for assessment general behaviours of the system were performed tests for F1 key only. The strike positions were divided into three areas on the tine – from attachment (or fixed end) to $\frac{1}{3}$ length of tine, from $\frac{1}{3}$ to $\frac{2}{3}$ and from $\frac{2}{3}$ to end of the tine. Area from attachment to $\frac{1}{3}$ generates weak fundamental frequency which is newly represents by stronger subharmonic partial. This area also amplifies rather high frequencies around 1000 Hz and higher, which makes unstable and inharmonic sound. Next area, from $\frac{1}{3}$ to $\frac{2}{3}$, generates more fuller spectrum in 1st band and solves problem with sustainability of the overall sound. The third section was determined at a distance of the remaining third of the total length of the tine. This section has the characteristic of simple bending, so the tine cannot be played too vigorously (forte or fortissimo), because they might not vibrate at all and the tone would not be produced. This would cause a serious problem for players, which is why this area was discarded after first few attempts.

After selecting preferred hammer shape and the location of the strike, an effect of distance between sensor and tine were tested and additional experiment with strumming technique similar to excitation system in cembalo. In distance experiments positions were tested on and off-axis of the sensor, specifically 5 mm, 20 mm and 40 mm distances on-axis and 0 mm, 10 mm and 20 mm off-axis. The on-axis tests ended with preffered position of tine remoted 20 mm from the sensor. The condition of these tests was to find a signal transmission without unwanted effects. In position 5 mm from the sensor, signal transmits sounds with significant attenuation. The signal was the loudest due to the greater influence of the magnetic field compared to the other tests, but the problem was also caused by the large area of the magnetic field, which caused a unidirectional vibrato effect in the steady state part of the tine oscillation, in other words, caused the tine to stop oscillating faster. On the other hand, the sensed signal at a distance of 40 mm away was significantly quieter and unusable due to coil noise from sensor. The signal at a distance of 20 mm was clearer than in previous tests, with no loss of volume and no unwanted effects, so 20 mm was chosen as the ideal distance for further tests. The off-axis tests were examined also in three states – 0 mm, 10 mm and 20 mm. The distance of the tine from the sensor axis largely affected only the loudness of the overall transmission but not its timbre, so a point at 0 mm, i.e. on the axis, was chosen as the reference point.

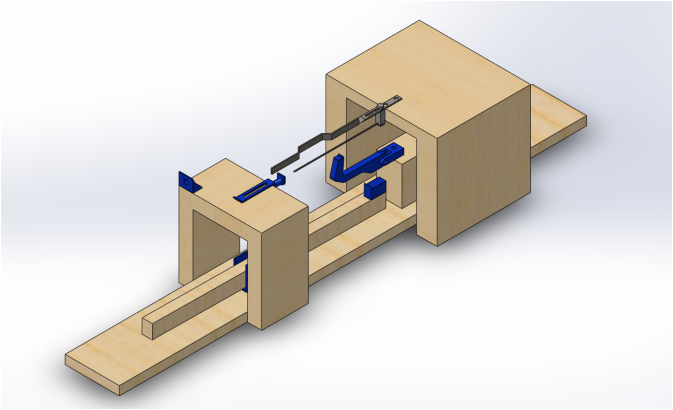

Fig. 3. Virtual model of full testing system with F1 key.

Experimental excitation tests were based on the method of playing an atypical keyboard instrument – cembalo. The exciter for this test was a classic acoustic guitar pick. The plucking was done for both tests in the center of the tine. In the first test, tip of the tine was in the same plane as the tip of the sensor magnet. In the second experimental measurement, the tip moved deeper from the sensor plane and thus affected the magnetic field from the side. The resulting signals from both measurements had a small amount of generated partials (mostly only fundamental frequency) and more audible clusters of inharmonic partials.

IV. RESULTS

Compared to the original instrument, the redesigned tines reach mainly into the first band of partials. The most different timbre of the F1 assemblies was the one with the square base made from structural steel. This was the most prominent in both the simulated and physical versions in generating partials

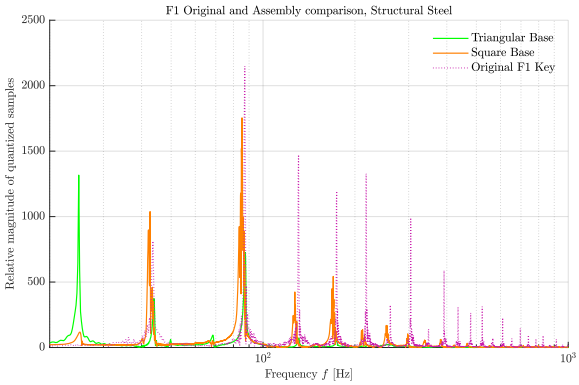

Fig. 4. Comparison of the F1 assemblies with original.

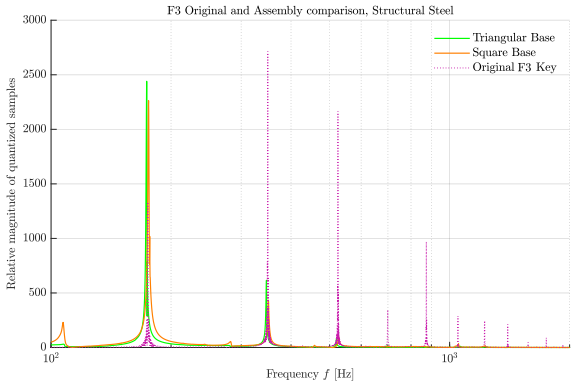

Fig. 5. Comparison of the F3 assemblies with original.

in both the 1st and 2nd harmonic bands (shown in Figure 4), and was also notable for the stable retention of these overtones over a relatively long reverberation time. The most significant F3 assembly, due to the stability and representation of the partials in the spectrum, was the structural steel assembly with the triangular base, which generated 7 of the total 8 partials from the first band. This assembly also had significant, more stable in time and energy, overtones than the previous variants (see Figure 5). The most new, in terms of timbre, setup of all the F6 assemblies tested was the one with the triangular base, which in both material variants produced interesting and unusual partials (especially inharmonic clusters that produce a metallic and tinkling sound) that are distinctly different from the original pure tone (shown in Figure 6). More detailed results and graphs are available in my bachelor thesis [9].

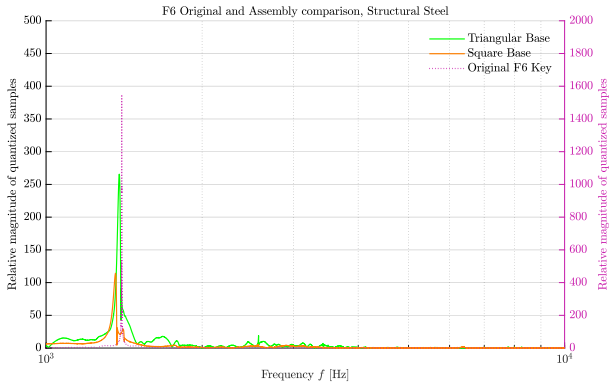

Fig. 6. Comparison of the F6 assemblies with original.

V. Discussion and Conclusions

In this paper several different mechanical parts of the Rhodes piano were redesigned with a focus on spectrum innovations, simulated and measured. New designs were highly focus on base of the tine (main oscillator of the assembly) and hammer tips. These designs were modelled in software SolidWorks and then simulated in software Ansys. Simulations were performed in several different configurations of the hammer positions and different impact forces to better understanding the effect of a given force and position on the generation of partials by the assembly. Then the physical assemblies were tested and compared with simulations and original instrument. Finally, newly designed assemblies that generated a unique sound and had the most stable partials in different ratios compared to the original were introduced.

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