Aesthetics and Characterisation of Guitar Pickups

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Abstract

Electric guitars pickups are what generates the electric signal that becomes the acoustic output of an electric guitar. I have investigated the relationship between alteration of certain characteristics of the guitar pickup and the tonal performance and the effects of manufacture defects and the identification of such defects. This can aid troubleshooting faults and quality control of manufacture, whilst providing the potential to understand tonal distortion in the audio output. There is a lack of visualisation of frequency response effects, so modelling with simulations may not reflect realistic conditions resulting from non-ideal component properties. The characteristics in question are the quantity and pattern of coiled turns within the pickup, the gauge of the wire used and the thickness of insulation. With the collaborative aid of Nottingham Trent University Music Engineering Lab, guitar pickups were manufactured to specified parameters and analysed using a VersaSTAT 4 Potentiostat Galvanostat Results showed a clear relationship between the frequency response and parameters variation. The measurements also allowed accurate manufacturing fault analysis. Further study will provide a more detailed analyses of model simulation comparisons and other varied characteristics of the pickup.

Keywords: *Electric Guitar, Pickups, Frequency Response.*

Introduction

This project is a collaboration between the Music Engineering Laboratory at Nottingham Trent University and the School of Engineering at the University of Lincoln, and it is expected that this work will result in peer-reviewed research papers. This collaboration will lead to more outputs going forwards. I have a personal interest in music, especially that made by electronic signals and processing. Guitars produce their acoustic outputs via electro-magnetic pickups. By varying elements of the guitar pickup construction different tones can be achieved. The Music Engineering Lab created pickups with controlled parameters so that the effects of such variations can be studied and analysed. Additionally, pickups were manufactured using different techniques and some with quantified manufacturing defects which allowed us to investigate and identify the effect of manufacture defects within the pickup.

Project Background

Guitar pickups produce an electrical signal by picking up varying magnetic fields from the vibrating guitar strings to induce varying frequency current within the pickup coil. Pick-ups consist of a number (related to the number of guitar strings) of magnetic cores with an enamelled wire coiled around the cores. The frequency response can be investigated by applying an AC voltage across the pickup to measure its absolute impedance[1]. Guitar pickups can be modelled as a series of inductor resistors, a capacitor, and an inductor. (Zollner, Zwicker, 2019). This can be shorted to an 'RLC circuit'. I am fascinated with the electronic signal processing and the effects frequency can have on a system when relating to sound. The project provided the opportunity to further develop my understanding of AC systems and suits my future studies in electrical engineering.
By changing the parameters of a) the quantity of turns b) the wire gauge, the electrical characteristics change. By performing practical experiments, the relationship between these can be investigated. Frequency response outputs can be modelled using equations and simulated circuitry. This modelling relies on components having absolute values and does not account for material impurities and manufacturing tolerances; these having impacts on resistances, inductances, and capacitances. Therefore, simulation modelling and empirical data can have deviations between them.

Literature Review

Compared to an isolated circuit, when connected to varying output loads, the guitar pickup's frequency and tonal response can be dramatically affected, especially relating to that of capacitive loads which would mimic a guitar jack cable or the resistive load on a guitar amplifier (Lemme, 2013). This introduces further areas to explore, considering the jack cables and amplifiers rather than the pickup as an isolated component. This would be more reflective as pickups are not used alone. Guitar Pickups can be modelled using simple circuit elements consisting of Inductors, Resistors, and capacitors (Zollner, Zwicker, 2019) This showing in relation to the Q factor (A parameter to describe how dampened the peak resonance is) impacting the performance. The inductor, resistor, capacitor circuitry within the Q factor article is useful to model virtual circuits to repeat virtual simulations to compare practical results (Scribner LLC (2019)). A similar study showed guitar pickups being manufactured with specific parameters and electrical characteristics such as inductance, resistance, and capacitance (Tian, C. Su, C. Yang, C. (2018)). However, the study does not explore the system responses, thereby leaving the performance curve unknown. It is evident that induvial components and values have effects on the frequency response however only small sample sizes have been investigated (Paiva, Pakarinen, Valimaki, 2012, 775). With these modelled results, manufacturing variation and non-ideal conditions are not considered.

[1] Impedance being an opposition to the alternating current due to both resistance and reactance.

Component identification can be done by deriving a Nyquist plot[2] of the system response (Jonscher, 1983, 67-81) - these plots can verify stability within a system and can hence be used to identify defects in manufacturing. More specifically the source of the defect can be identified, indicating if the performance is skewed due to capacitance, resistance, or inductance of an abnormal amount. This can thus give an indication of the physical fault, such as increased resistance due to faulty cable connection.

Methodology

Test pickups were all created by the Music Engineering Lab at Nottingham Trent University. The pickups were made to specific parameters of coil turns quantity and wire gauge to attain different characterisation results. The data used for analysis was collected using a VersaSTAT 4 Potentiostat machine by applying AC voltages, with changing polarity of current across the guitar pickups. The frequencies used were between 100 to 21000 Hertz as this is within the audible sound frequency range. Any higher and the data would not be useful given the context of sound and music, and any lower would not provide meaningful data relating to the pickup's performances. Frequencies tested were stratified logarithmically across the scale as for ease of processing and so there is not an unnecessarily large amount of raw data. Higher Specific Root Mean Squared (RMS) voltages were chosen, when possible, to minimise percentage error. The guitar pickups were connected through a customised junction box to facilitate cable and amplifier loads.
Only useful categories of data were extracted for additional analysis, namely the Frequencies, Impedances (Imaginary/Complex, Real and Absolute) and the phase angle between real and imaginary/complex impedances. Absolute impedances and frequencies were used to generate Bode plots[3], the most common logarithmic scale display of frequency response. Imaginary and complex impedances were used to generate Nyquist plots to analyse electrical characteristics and stability of the system. The phase angles between the two were used to generate Bode plots for an additional level of analysis, aiding most when there were apparent discrepancies in the data.
All analyses and graph generation were done in MATLAB to process the data, create lines of best fits, automating peak detection within the output profiles, isolating specific results and for customisation of graphs, as visualisation is a necessary aid to obtaining a higher level of understanding. Processing large quantities of data files and numbers was streamlined and made efficient using MATLAB.

Results

[2] A Nyquist stability plot of the frequency response is to measure a systems stability based on the shape that is produced by graphing complex against real components.
[3] Bode plots are graphical representation of frequency responses. Able to visualise responses at different frequencies.

For the variation in quantity of turns there was a clear relationship between the profiles of frequency response and turns. The greater the turns, the greater the impedance peak at resonant frequencies and the shifting of the resonance to a lower frequency. An increase in wire gauge raised the impedance of the resonant frequencies and shifted the resonance to a higher frequency. Manufacture errors affected output profiles. Using the data collected specific errors could be deduced. For example, an induced low pass filter was a result of a cable break. The findings from this research will be published in full later, intended for the Audio Engineering Society.

Further research will be done in collaboration with the Nottingham Trent University Music Engineering Lab examining additional results and comparing them to virtual models, analyses of manufacture anomalies, further varied characteristics (Magnetic cores and manufacture pitches) and practical performance when played as intended in a guitar.

Discussion

The UROS project has provided me with a great opportunity to develop and gain valuable skills and experience in the process of conducting research. Being a researcher within a wider project has improved my ability to have a professional capacity within a team setting, whilst working independently. My communication has grown as a result, and I've experienced networking between other researchers and academics.

Time is a valuable resource within the project. One issue was timing discrepancies between speed of manufacture of pickups and the testing of pickups. There were a lot of potential tests and data sets to record, therefore my time was managed wisely. Speaking with my supervisors some of the more in-depth data collection could be stratified throughout the whole sample group to reduce the time taken; I had to admit to myself it would take too much time. My time in the laboratory would have quadrupled having already spent day long sessions of around five hours in the lab per batch. My time management and realistic expectations were tested. At points the laboratory work became mundane, but I needed to persevere throughout to attain results.

Another area that was developed was my organisation. With so many different categories of data with so many samples involved, my laboratory work had to be rigidly organised with a suitable system and indexing. To avoid confusion, I had to develop an indexing scheme to efficiently manage data. The data was to be shared with other peers, so I had a responsibility to make my data accessible. I have taken away a higher degree of organisation within my work which I will be carrying onto my main studies.

My supervisors provided me with excellent guidance and support, having given me resources to begin my project with. Requiring self-motivation and drive to become familiar with tools given to me, from which I now have confidence. Being granted unique laboratory access over the summer provided me opportunity to work independently. Now being familiar with different analytical software (MATLAB,

VersaStudio and ZView) and hardware I can use this knowledge in the rest of my studies and potentially use it as a part of my final year project.
Poster creating was new to me, especially for an engineering related topic. I could not attend the UROS poster and Impact workshops due to geographical distance and timing, however the online guides proved useful, and the recorded sessions greatly aided my presentation. Resulting in a piece I am happy to demonstrate to an audience.

Conclusion

The UROS project has been invaluable to me, as a student. It has greatly improved my transferable skills, my communication within a team, personal growth, and self-reflection. I've been encouraged to work closer in a team whilst being expected to maintain personal responsibilities. On an academic level, my laboratory skills and organisation have been challenged. I have gained useful knowledge of subjects that are relevant to my degree. Without this opportunity I would not have been able to work closely with my supervisors; they have given me invaluable resources and access to programmes and hardware that I would not have otherwise. I will certainly apply the knowledge they have given to me and experience within my degree studies in the future. I would highly recommend the UROS project to any other students for the reasons mentioned and I have enjoyed my experience.

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