



Modal parameter variability in industrial electric guitar making: Manufacturing process, wood variability, and lutherie decisions



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ABSTRACT

Recent studies showed that mechanical coupling between structure and strings can alter the sound of the solid body electric guitar. Modal frequencies and damping ratios of the structure can explain some sound differences between instruments. These vibratory parameters can vary because of lutherie decisions (e.g. intentionally fitting guitars with different woods for sound quality purposes), wood intrinsic variability, or making process variability. Yet the vast majority of solid body electric guitars comes from an industrial mass-production: the manufacturing process is designed for producing guitars that are the most similar possible. However, musicians and makers know that guitars of the same model both share features, and still have some individual properties. The experimental quantification of the modal parameter variability of nominally identical electric guitars in an industrial context is the aim of this article. This variability is assessed on one guitar set, and compared to other industrial objects. A second guitar set is investigated: it consists of guitars with maple or rosewood fingerboard, all other specifications being identical. This second set allows the comparison between making process and wood variability, with the variability due to an intentional lutherie decision: the change of the fingerboard wood.

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1. Introduction

The sound of the solid body electric guitar comes from the string velocity signal which is captured by the electromagnetic pickup, and sent through an electro-acoustical chain basically made of signal processing devices (effect pedals), an amplifier, and a loudspeaker for the sound radiation [1]. Without reconsidering the importance of the electro-acoustic chain, it is reasonable to think that the mechanical behaviour of the string has an influence upon the sound of the solid body electric guitar. Even if the structure of the instrument has been designed to avoid vibrations (the “solid” body overcomes feedback problems occurring with high-volume amplification), it is still found to vibrate. Strings and structure constitute a mechanically coupled system.

The string/structure coupling has been studied for various string instruments [2–5]. For the special case of the solid body electric guitar, Fleischer [6,7] showed that the string/structure coupling is well described by the driving-point conductance value at the fretting point on the neck. A model allowing a prediction of

decay time and timbre change effects from the knowledge of the conductance has been recently proposed [8]. The coincidence between a string playing frequency and a structure resonance may provoke a great energy transfer from the string to the structure. The resonance of the corresponding string partial is altered, causing decay time or timbre changes. The study of the modal basis of the solid body electric guitar therefore makes sense: modal frequencies control the conductance peak positions, and modal damping ratios control the spread of the conductance peak, so the chance of coupling.

The solid body electric guitar is the first musical instrument in history to have been originally designed for a mass-production: even if numerous craftsmen have gained a solid reputation among the guitar player community, the solid body electric guitar market has been dominated by the industry for over sixty years. In this context, the question of unit-to-unit vibratory behaviour variability deserves to be explored, since some guitar players claim they can notice differences between nominally identical solid body electric guitars.

Even if their making process is highly standardised, mass-produced musical instruments can present notable differences that can be measured physically or psychologically [9–12]. However, to the knowledge of the authors, no study covering a large scale of nominally identical musical instruments has been undertaken

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so far. Such investigations are a particular lack in the context of the solid body electric guitar. Industrial research has been interested in quantifying the uncertainties in the vibro-acoustical behaviour of industrial products. Indeed, it is a well-known fact that nominally identical products present variations, in particular in their vibratory behaviour [13]. It is also known that small variations in geometry or in assembly can lead to large variations in the final product's vibratory behaviour [14]. The aim of variability studies in an industrial context is often to numerically predict the vibro-acoustic behaviour of some mass-produced products [15–17]. Experimental studies are reported, for example for acoustic noise in cars originating from vibratory phenomena [18,19]. Some studies focused on the unit-to-unit variability of industrially-made nominally identical products: wind turbine blades [20] or automotive brake calipers [21] for example.

In the case of the solid body electric guitar, the variability in modal parameters can have different sources, such as the wood intrinsic variability, the industrial making process (machine tolerance, geometrical uncertainties, etc.), the lutherie decisions (different lutherie parameters, e.g. the wood of the fingerboard). The lutherie decisions and their influence on the modal behaviour have been previously investigated. In [22] it was shown that different wood species for the body control differently the torsional behaviour of the neck. Another study observed different vibratory behaviours that may be related to different neck-to-body junctions [23]. The difference between ebony and rosewood fingerboard has been mechanically quantified [24] in terms of mean conductance value over the low- and mid-frequency range.

This article aims at experimentally quantifying the modal parameter (frequency and damping) variability of nominally identical electric guitars in an industrial context. This variability is assessed on one set of 17 guitars, and takes into account the intrinsic variability of nominally identical wood species, and the variability due to the industrial making process. A second set of 24 guitars is investigated: it consists in 10 guitars with a maple fingerboard and 14 guitars with a rosewood fingerboard, all other specifications being nominally identical. This second set is used to compare the variability due to the industrial making process and intrinsic variability of nominally identical woods, with the variability due to an intentional lutherie decision: the change of the fingerboard wood.

Section 2 deals with the description of the experimental material and method, as well as the vibratory measurement analysis method. The identified modal frequencies and damping ratios are presented in Section 3. These results are then discussed in Section 4: the unit-to-unit variability observed for electric guitars is compared to that observed for other industrial products. Then a comparison of modal parameter variability due to the making process (including wood selection) with that due to an intentional lutherie decision is proposed, using two particular guitar sets.

2. Experimental method

This section explains the experimental protocol and analysis method carried out on the guitars described in paragraph Section 2.1: the driving-point mobility is measured on each guitar (paragraph Section 2.2), and the modal parameters are identified from these measurements (paragraph Section 2.3).

2.1. The guitars of the study

The unique opportunity of measuring industrially-made electric guitars in large number has been given by one of the world's leaders in the solid body electric guitar market: This North-American manufacturer produces more than 50,000 electric guitars a year,

which are sold all around the world. The guitars measured in this study come from the warehouse of this manufacturer and are either in transit from the factory to the music stores, or sent back by customers for small aesthetic defects (wrong colour or varnish). In any case, the measured instruments are ready-to-play guitars meeting the specifications and expected quality standards of the brand. Two distinct sets of guitars are investigated, each of them corresponding to one of the two reference models that are classically thought to organise the electric guitar as an instrument, in an organological sense [1]: *Type-1* is a *Gibson Les Paul*-like instrument, and *Type-2* is a *Stratocaster*-like instrument. Here is a more precise description of the two investigated models:

the Type-1 set: three versions of the model are available: the only intentional difference are the magnetic pickups mounted on the guitars. The size of the pickups, hence of the corresponding hollows in the body, is very similar. From the mechanical point of view, these guitars are therefore nominally identical. A mahogany neck with a 62.9 cm-scale length is glued to a mahogany body with maple top and single cut-away. Headstock and body are virtually symmetrical. The fingerboard is made of rosewood. Measurement are performed on 17 specimens of this model.

the Type-2 set: two versions of the model are available. The baseline guitar is common to the two models: a maple neck with a scale-length of 64.75 cm is screwed to a maple body with double cut-away. Headstock and body are strongly asymmetrical. *Type-2* guitars are further split into two groups, depending on the fingerboard wood: 10 guitars have a rosewood fingerboard, and 14 have a maple fingerboard. The former are denoted *RN*, and the latter are denoted *MN*, the designations *rosewood neck* or *maple neck* being inaccurate but usual in electric guitar making language. For clarity reasons, the terms *Type-2 RN* and *Type-2 MN* will be replaced by the terms *RN* and *MN* in the following of this article.

2.2. Measurement protocol

Two kinds of measurements are carried out on each guitar. First the guitar is weighed with the industrial weighing scale available at the warehouse. This scale has a 10×10^{-3} kg precision.

Vibratory measurements are then performed. They consist in classic transfer function measurements on the structure. In order to avoid the unwanted string vibration, the strings are damped with felt during the measurements. The guitar is laid on a frame onto which elastic straps are attached. This provides boundary conditions close to free conditions above 20 Hz, which is the upper limit for rigid body modes due to the supporting structure. It was checked that no additional damping was provided by the supporting structure. An impact hammer (*PCB Piezotronics 086C01*) provides an excitation force $f(t)$ to the structure, and the acceleration response $a(t)$ of the instrument is measured with an accelerometer (*PCB Piezotronics 352C65*) attached with wax to the structure. In order to not unstring the guitars for the measurements on the neck, the strings are slightly moved aside by a thin and light piece of wood, in order to provide enough space for the hammer to hit the neck without touching the strings [24]. The acceleration signal is integrated, providing the velocity signal $v(t)$ of the structure. A Fourier

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