Impedance Analysis on a Real Instrument and its Impact on the Manufacturing Process

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In recent years, the field of knowledge in musical acoustics has grown considerably but collaborative works between scientists and instrument makers remain rare. Such collaboration exists on clarinet and saxophone making, around tools that have been developed in the field of experimental acoustics. This collaborative approach has been driven in the Research and Development department of Henri SELMER Paris, an historical factory for the production of wind instruments, through impedance measurement. The use of this particular tool now classic in all acoustic laboratories in the study of the linear part of the wind instruments, has been systematized during the development and the improvement of our prototypes leading to an impressive number of impedance curves. Based on the idea of a musical ideal of a saxophone in terms of tuning and emission, a methodology for the use of this huge amount of impedance results has been defined, in order to highlight the deviations from this ideal and to analyze and consider the changes in terms of bore profile. We will present the analysis of existing instruments, explore and analyze the difficulties experienced on the archetypal alto saxophone. Essential correlations with the feelings of musicians will also be presented with selected examples from the prototyping work within the plant.

1 Introduction

The company Henri Selmer Paris has now about four hundred employees on its production site in Mantes-la-Ville. The plant has been industrialized significantly during the second half of the twentieth century. The cliché that is still now widely held of the Luthier manufacturing just a few custom instruments in his small Parisian workshop is no longer relevant. The plant now subtly blend the most modern techniques of industrial production and a know-how that is over a hundred years old to produce about ten thousand units per year (saxophones and clarinets). It is in this context that the company faces a more and more aggressive competition, especially from Asia, requiring innovations in areas where it excels, namely the acoustic qualities of its instruments. To this end, a Research and Development service of twelve collaborators carries out studies to improve the acoustical and mechanical properties of our saxophones and clarinets. The measurement of input impedance is used for about ten years now in our R&D service. Its use has been systematized in the last two years through the development of a new set of measurement head and analysis scripts more efficient and easy to use. There are now over ten thousand impedance measurements in the database of the plant. The remainder of this article describes the measurement system and how it is used to highlight areas for improvement in future developments.

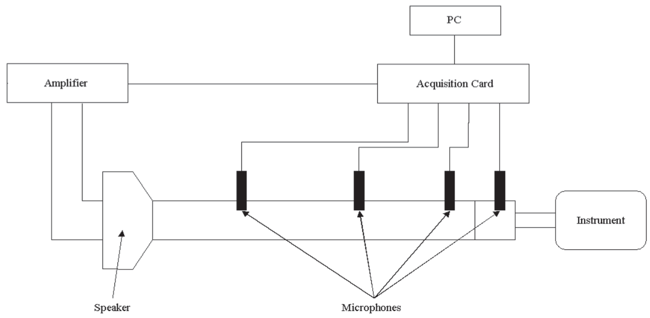

Figure 1: Schematic diagram of the measuring system of the input impedance.

Figure 2: Complete measurement installation with the analysis unit.

2 The measurement system

We use for impedance measurements, an acoustic system derived from the TMTC method [1]. It consists of a brass tube inserted into a PVC tube. At one end is the load that will be characterized through its input impedance, at the other end a speaker is used to produce a logarithmic chirp signal. Four microphones are positioned along the tube. The first one is located as close as possible to the load in order to have a measurement range as large as possible. The microphones are connected to an acquisition card, itself connected to a computer (Fig. 1). After calibration of the system, and knowing the propagation models of the acoustic waves in a tube it is then possible to know the acoustic speed and the pressure in the measuring plane. This type of installation allows the measurement with flow and temperature gradient.

This system allows to obtain impedance measurements between 50 Hz and 8000 Hz, as presented on figure 3:

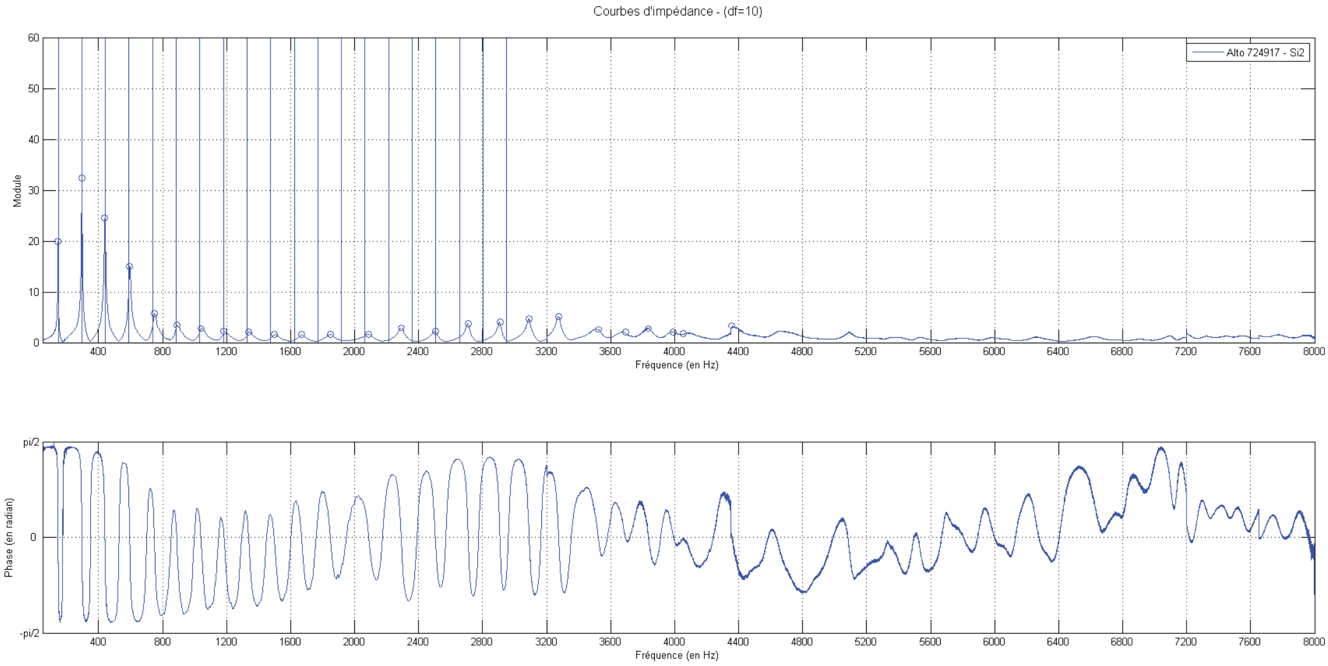

Figure 3: Example of impedance measurement of a low B on an alto saxophone.

3 Measurements analysis

From these measurements it is possible to extract a number of interesting information. Analysis scripts allow to retrieve the position of the resonances, the value of their modulus and to superimpose different instruments for comparison. In what follows (Fig. 4) we present some examples of graphical representations that we consider to be relevant to analyze each of the instruments measured.

3.1 Frequency map

The goal is to have a synthetic view of all the positions of the resonance peaks with respect to the even-tempered scale. We then observe the alignment of these peaks, the shifts induced by the successive opening of the two register holes and the irregularities that penalise the tuning of the instrument.

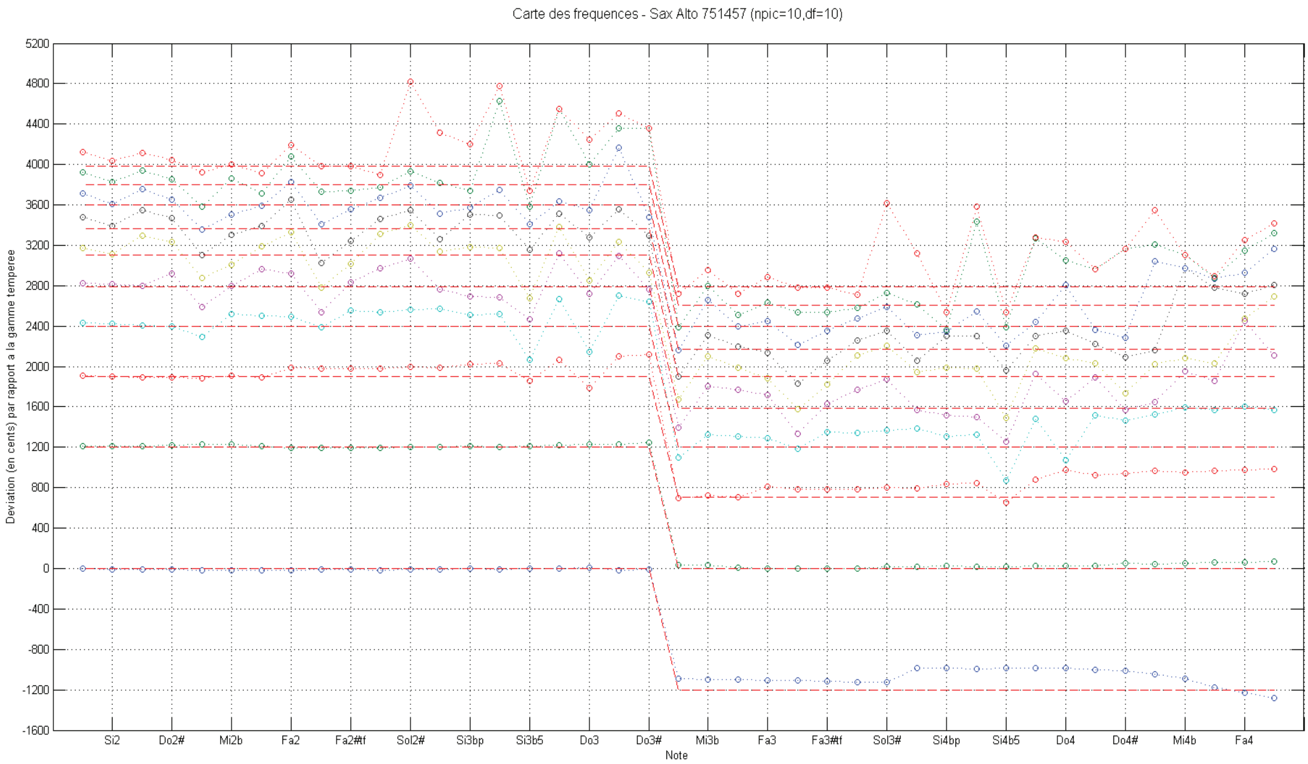

Figure 4: Frequency map of the ten first resonances of an alto saxophone.

3.2 Modulus map

This curve (Fig. 5) is complementary of the previous one to analyze emission problems, especially in the extreme low register of the saxophone. It is also interesting to quantify the effectiveness of register holes.

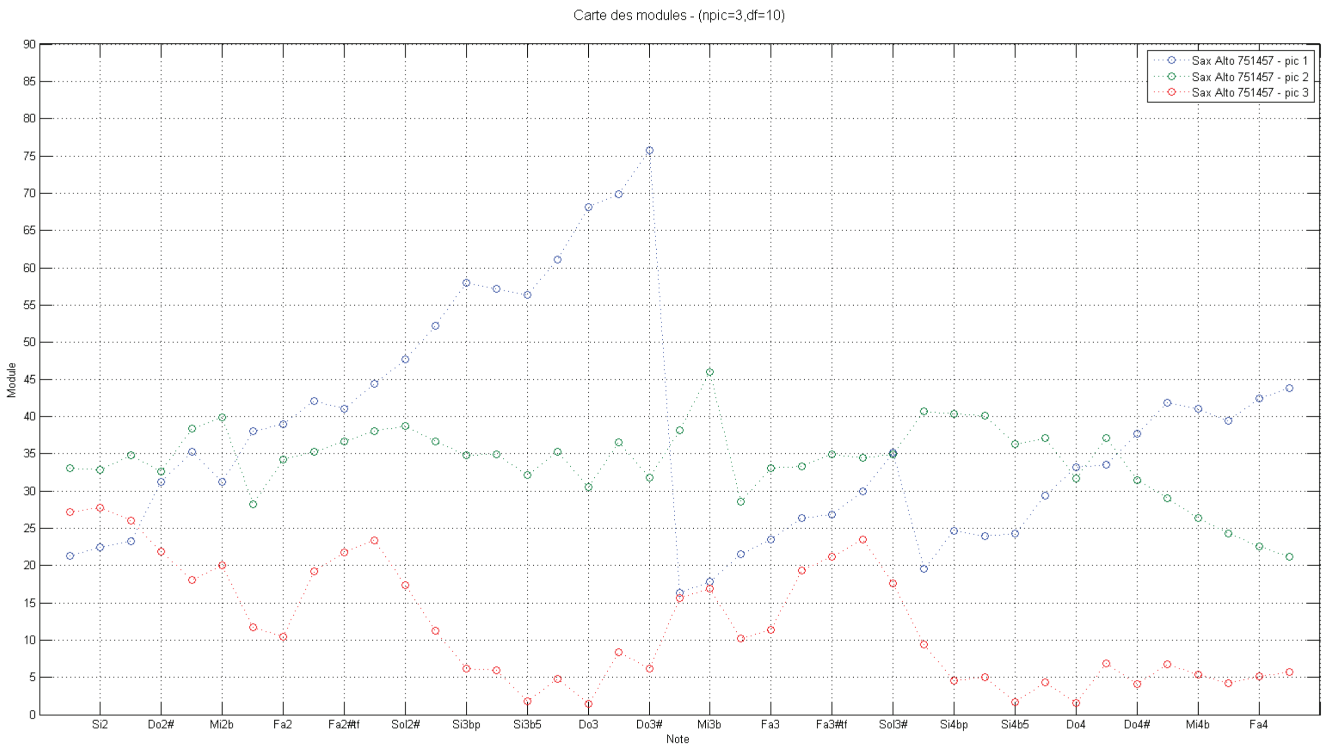

Figure 5: Modulus map of the three first resonances of an alto saxophone.

3.3 Shifts due to register holes

We can observe on this graph (Fig. 6) the frequency shifts introduced by the opening of the register holes. This shift is not negligible for the tuning of the registers of the instrument; it then must be measured and compensated.

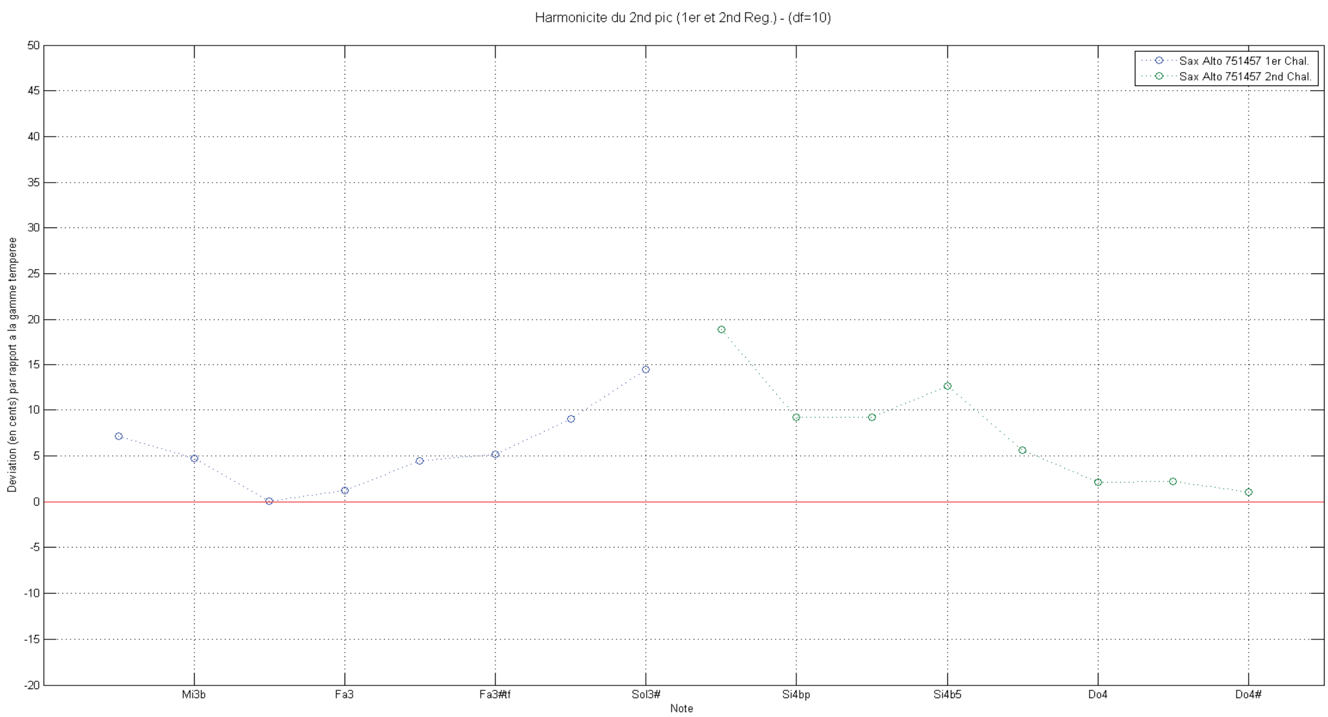

Figure 6: Frequency shifts of the register holes on an alto saxophone.

3.4 Harmonic profile of the bore

Shifts of the resonance peaks introduced by the register holes being known, we are interested in representing the variations in harmonicity (Fig. 7) between the peaks of the first register. For this purpose, the differences in cents between the various resonances are calculated. It gives a general idea of the final intonation of the instrument. Attention should also be given to the way the peaks are distributed in the low register of the instrument.

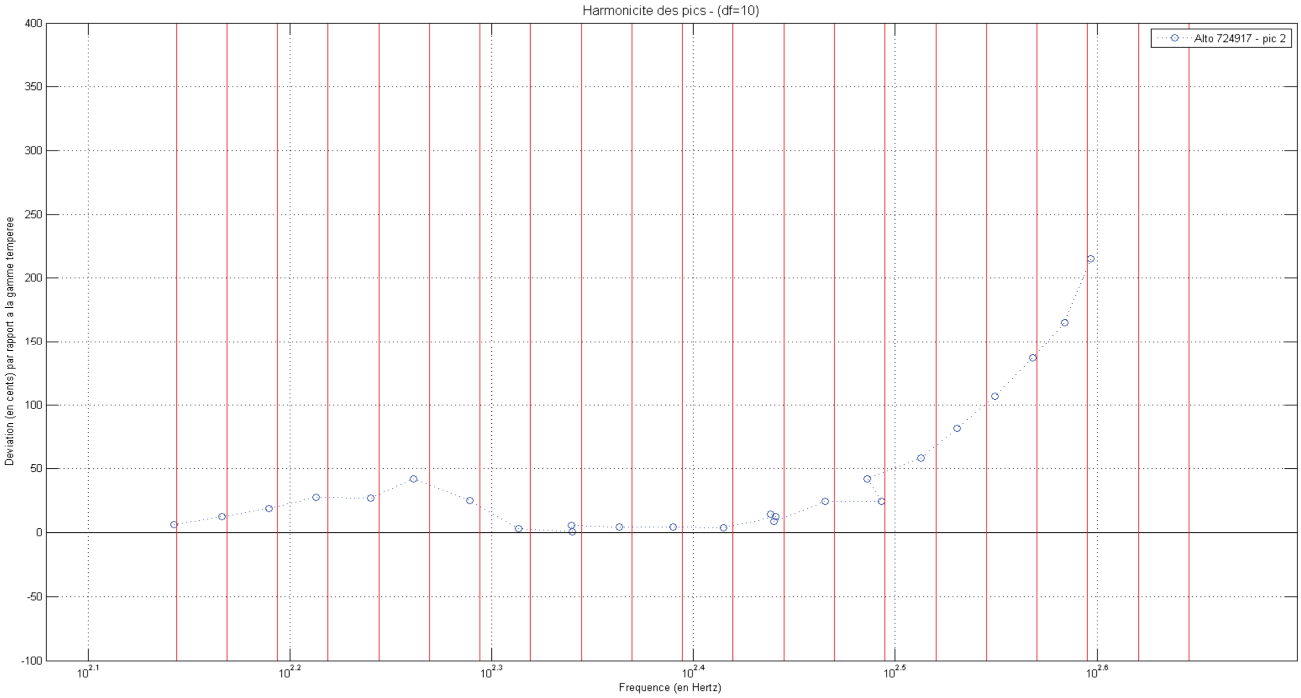

Figure 7: Harmonic profile of an alto saxophone – second resonance.

3.5 Tests campaigns

Using all these tools of analysis, we conducted test campaigns on selected changes. For example, on an alto neck we modified the tenon diameter, the bore profile, the entrance diameter, the shape and the position of the register hole. We were able to obtain ranges of curves to anticipate responses of the instrument. All these data are archived to serve as a basis for future developments. The remainder of this paper illustrates this approach using a given example.

4 Application on a real case of manufacture

We are now considering the specific case of a problematic that may be encountered during the development of an instrument. A musician complains about a lack of tuning penalizing the octave of the left hand of an alto saxophone (G3 to C#4). The work begins by asking the player to make an intonation diagram (Fig. 8).

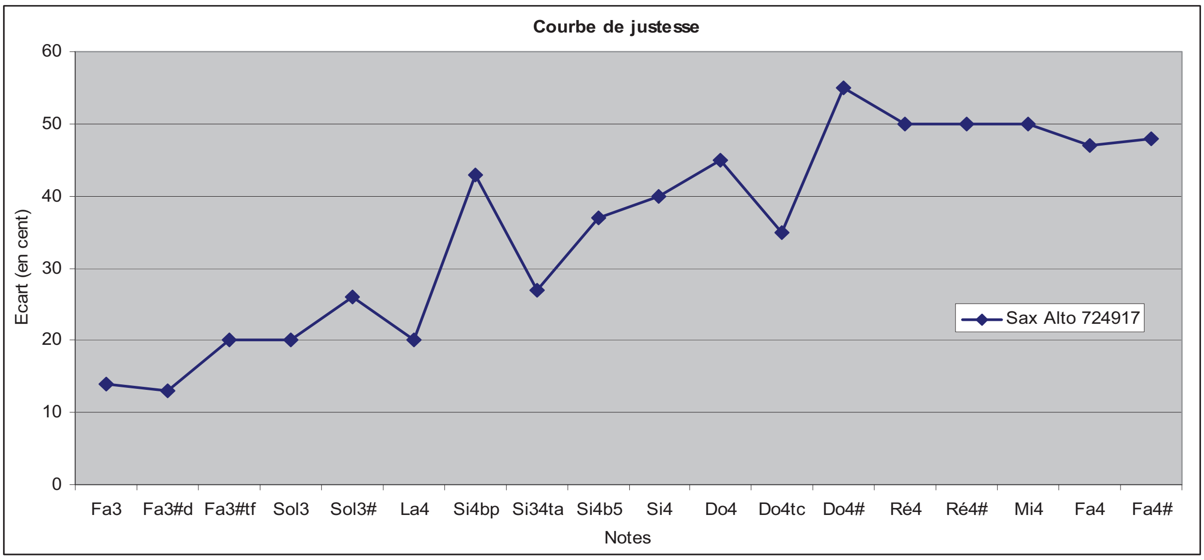

Figure 8: Intonation diagram of an alto saxophone - top of the second register.

The top of the second register is clearly too sharp. Octaves are expanding as we play up the scale to reach unacceptable values for the musician who must compensate to play in tune. As can be seen in Figure 7 which shows the same instrument, a default in harmonicity is superimposed on the shift introduced by the register hole. It was decided not to change the register hole but to change the bore profile of the instrument. We made a new impedance measurement and superimposed it on the previous one (Fig. 9).

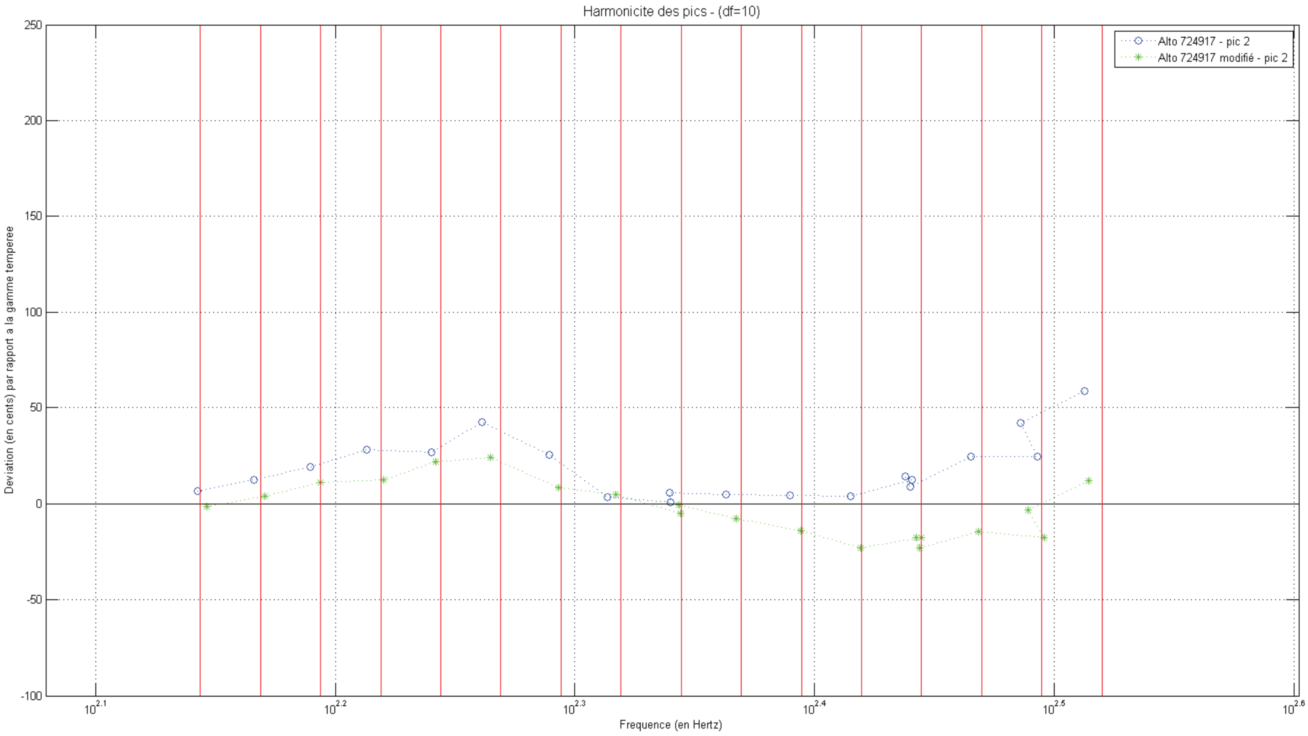

Figure 9: Harmonicity profile of an alto saxophone before (in blue) and after the modification (in green).

We can notice that the positions of the peaks at the top of the second register have been changed. We did again an intonation measurement with the musician to check the gain in terms of intonation (Fig. 10).

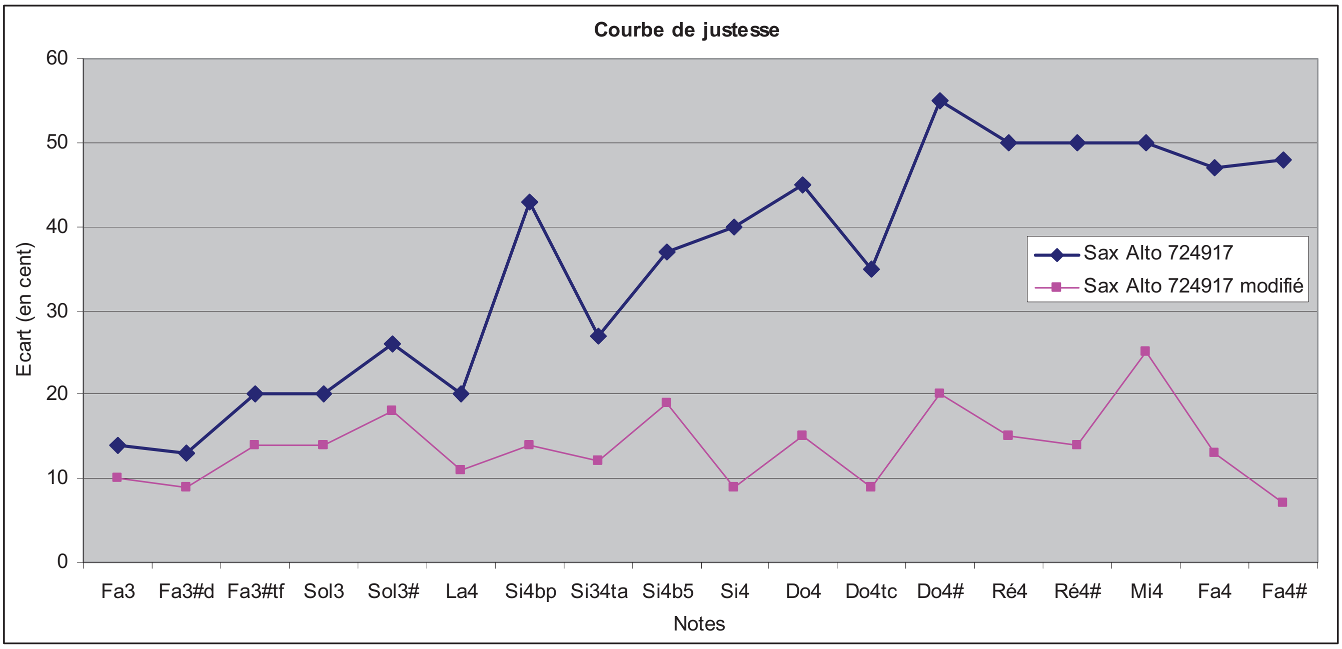

Figure 10: Intonation diagram of an alto saxophone before (in blue) and after modification of the bore profile (in pink).

The top of the second register is returned to acceptable values (between 10 and 20 cents). The instrument has been adjusted to meet the needs of the musician.

5 Conclusion

Measuring the input impedance is a tool commonly used in research laboratories for decades. It seems unthinkable that the industry of wind instruments does not benefit from these advances. It must take ownership of these tools to innovate. This work does not pretend to enlighten the well-informed reader on new scientific discoveries, it has a testimonial value to reinforce the idea that the impedance measurement has very concrete and immediate applications for the development of new instruments. Acousticians and manufacturers have a mutual interest in working together to ensure the sustainability of our industrial heritage.

Acknowledgements

We thank Patrice Dufay, Laurent Taverne and Marie-Laure Micale for their precious help throughout this work as well as all the factory employees of Henri Selmer Paris who participated directly or not to these studies.

References

[1] V. Gibiat and F. Laloë, Acoustical impedance measurements by the two microphone three calibration (TMTC) method, J. Acoust. Soc. Am., 88 p. 2533-2541, 1990.