# Method of Piano Hammer Parameters Determination

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**Summary:** The piano hammer parameters measuring device described here gives a possibility to investigate the dynamical force-compression characteristics of piano hammer, and, using the hereditary (hysteretic) hammer model, to find the hammer parameters by numerical simulation of the dynamical experiments.

## INTRODUCTION

According to the hammer models considered before the loading and unloading of the hammer are the same. The usual model of the hammer connects the force exerted by hammer and the hammer deformation in the form of the power law dependence (1, 2). In this case the features of the hammer are strongly determined by two parameters: the hammer stiffness $F_0$ and the compliance nonlinearity exponent $p$, which may be easily measured in static experiments.

However, the dynamical features of the piano hammers are significantly more complicated. The results of the experiment provided by Yanagisawa, Nakamura and Aiko (3, 4) show the significant influence of hysteresys, i.e. loading and unloading of the hammer are not alike. Furthermore, the force-compression relationships of the hammer are essentially nonlinear, and the slope of the dynamic force-compression curve is strongly dependent on the hammer velocity. The model of the hammer that takes into account all the dynamical features of the hammer was derived in the paper (5). According to this model the piano hammer possesses history-dependent properties or just, in other words, is made of the material with memory. In this case two additional hereditary parameters: hereditary amplitude $\varepsilon$ and relaxation time $\tau_0$ are involved to describe the hysteretic behaviour of the hammer. To measure the nonlinear elastic and hereditary parameters of the hammer a device described below was developed.

## PIANO HAMMER PARAMETERS MEASURING DEVICE

The experimental arrangement shown in Fig. 1 gives a possibility to investigate the dynamical force-compression characteristics of piano hammer, and, using the hereditary (hysteretic) hammer model, to find the hammer parameters by numerical simulation of the dynamical experiments.

The device consists of the three main parts. The first mechanical part gives the needed velocity of interaction of the hammer with the string. The second and the third parts are a piezoelectric wide-band force sensor, and an infra-red optical sensor for registration of hammer deformation. The analogue signals from these two sensors are converted into two sets of data by a digital signal processor ADSP-2181. This 8 channels, 12 bit signal processor allows:

- to set up data communication speed from device sensors to computer,
- to present data in a scope mode or in an analyser ( FFT ) mode,
- to save data in a file,
- to print oscillograms and spectrograms.

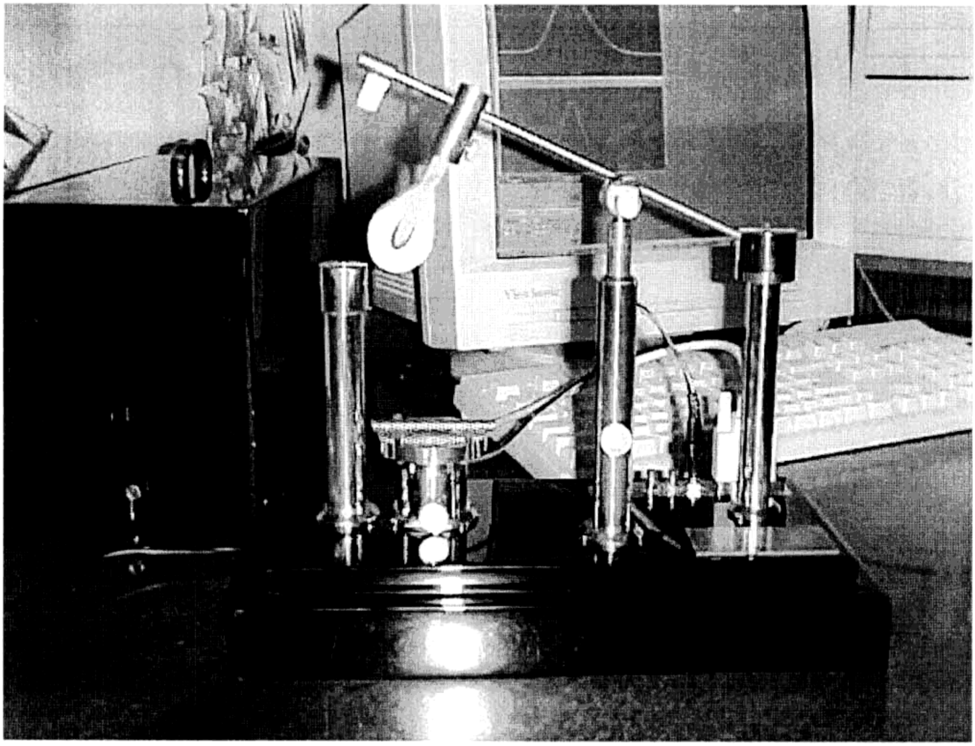

**FIGURE 1.** A Piano Hammer Parameters Measuring Device.

The examples of the dynamical force-compression characteristics measured by Yanagisawa and Nakamura by using the similar experimental arrangement are presented in Fig. 2 by various signs. The solid lines are the calculated curves obtained by using the hysteretic model of the hammer. The agreement of the results from the hysteretic model with the experimental results is rather good. Thus, the values of the hammer parameters were obtained. The analysis of the hammer-string interaction shows that the nonlinear hysteretic model of the hammer provides predictions about the vibration spectra of struck strings for real pianos that come closer to measured data than predicts the nonhysteretic model. In addition to the correct spectra, the hysteretic model gives more suitable values of the hammer compression (6).

The hysteretic model may predict the excited spectra for the various hammer velocities using only one value of the hammer stiffness, that is the hammer parameter indeed.

If the hammer stiffness $F_0$ and the compliance nonlinearity exponent $p$ are defined from the static measurements, or for some certain hammer velocity, these values can not give the true description of the hammer-string interaction for the other velocities of hammer in case of using the nonhysteretic hammer model.

## WAY OF HAMMER PARAMETERS MATCHING

The piano hammer parameters measuring device in conjunction with the hysteretic model of the piano hammer is a powerful instrument as for matching the piano hammers, as well as for their manufacturing. The numerical simulation using the hysteretic hammer model may significantly simplify the process of the manufacturing of piano hammers.

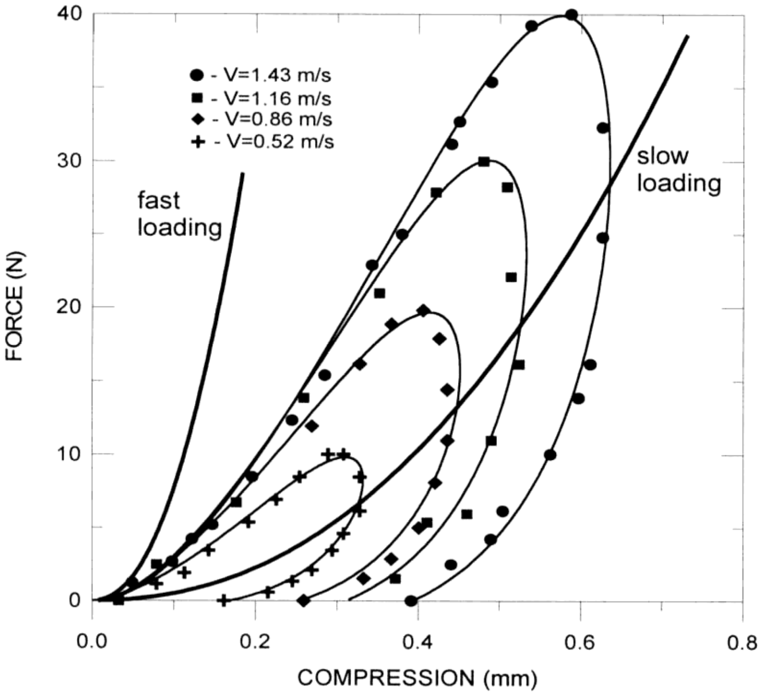

**FIGURE 2**. Force-compression characteristics for A1 hammer for the various initial hammer velocities. Circles, squares, triangles, and asterisks denote the experimental data points.

Actually, there are many parameters (e.g. the instantaneous hammer stiffness, the stiffness nonlinearity exponent, mass, radius of curvature, the hereditary parameters, and so on) describing the properties of a hammer. The conditions of piano hammers manufacturing vary also on a large scale. By using of this measuring device it is possible to find the dependencies of the hammer parameters on the technological conditions during manufacturing. Therefore the knowledge of these dependencies gives a good practical hint to choose a better technological process for the hammers manufacturing. In this sense, the hysteretic hammer model is an irreplaceable model.

## CONCLUSION

The results of dynamical measurements of piano hammers are very important. It is very interesting to prove the hysteretic hammer model in practice, also.

The combination of the experimental piano hammer testing and the hysteretic hammer model together is the good practical way to improve the hammer quality and thus, the piano voicing.

By numerical simulation of the hysteretic model it is possible to calculate the hammer parameters that provide the needed spectrum of the piano string vibrations.

The analysis of the hammer-string interaction shows (6), that the nonlinear hysteretic model of piano hammer provides predictions about the vibration spectra of struck strings for real pianos that come closer to measured data, than predicts the nonhysteretic model. In addition to the correct spectra, the hysteretic model gives more suitable values of the hammer compression.

A piano hammer parameters measuring device gives the possibility to find the dependencies of the hammer parameters on the key number.

It seems, for the one set of the good hammers such explicit dependence exists. The numerical simulation of the known data shows, that: hereditary amplitude $\varepsilon$ increases and relaxation time $\tau_0$ decreases with a key number definitely. Probably, the value of $p$ increases with a key number also.

The hammer stiffness is a constant value in hysteretic model. This parameter depends on the hammer size, wear, manufacturers. For the one certain set of piano hammers it is possible to find the value of the instantaneous hammer stiffness $F_0$ experimentally.

The knowledge of the hammer parameter dependencies on the key number permits to produce the hammers with the features needed.

## ACKNOWLEDGMENTS

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## REFERENCES

1. Ghosh, M., *Indian J. Phys.* **7**, pp. 365-382 (1932).
2. Hall, D. E., Askenfelt, A., *J. Acoust. Soc. Am.* **83**, pp. 1627-1683 (1988).
3. Yanagisawa, T., Nakamura, K., Aiko, H., *J. Acoust. Soc. Jpn.* **37**, pp. 627-633 (1981).
4. Yanagisawa, T., Nakamura, K., *J. Acoust. Soc. Jpn.* **40**, pp. 725-729 (1984).
5. Stulov, A., *J. Acoust. Soc. Am.* **97**, pp. 2577- 2585 (1995).
6. Stulov, A., "Comparison of string vibration spectra excited by different piano hammers," in *Proceedings of the Institute of Acoustics*, St Albans, UK, ISMA'97 Conference, Vol. 19: Part 5, book 1, pp. 231-238, 1997.