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OBJECTIVE MEASUREMENTS OF THE PIANO

Klaus Wogram
Physikalisch-Technische Bundesanstalt

Summary

To get a good correlation between the musical and acoustical quality of pianos and their properties several measuring methods have been developed which yield objective and reproducible results. They include measurements of the input impedance and the radiation of sound boards, an artificial stimulation of the action and the determination of the elastical properties of the hammers. These methods are explained, followed by a discussion of the results.

Introduction

Judging the quality of musical instruments basically depends on the person who makes the judgment and on his position in the room. Whereas a listener not involved in producing the music only reacts to the sound of the instrument, for the musician, the quality is also linked with the possibility of realizing his own musical concepts by means of the instrument. Added to this, he is directly within the short range field of the instrument and also evaluates its mechanical characteristics /1/.

Subjective statements on quality can only be obtained and interpreted when the physical properties of the instruments are known as fully as possible. Particularly instruments with non-steady sounds, such as xylophones, guitars and pianos require additional investigation of the time structures of the spectra and their influence in the room for differing judgments in the short range and distant field to be understood. The methods used in the PTB for covering the objective acoustical properties attach great importance to the influence of the individual components on the overall sound /2/. Improvements of the quality can then be elaborated from the results by means of constructive changes of detail.

Methods

The oscillation energy of the piano string is transferred via the bridge to the sound board, which determines the timbre of the resulting sound, according to its filter effect and its matching with the atmosphere. The feedback to the string influences the type and velocity of the energy transfer, i.e. the decay characteristic of the piano. To analyze the interactions, a measuring set-up is used whose block diagram is represented in fig. 1. Its purpose is to measure the input impedance of the sound board for amount and phase as well as the sound radiation in the frequency range from 20 Hz to 10 kHz.
The sound board is set vibrating sinusoidally at 14 approximately equidistant measurement points on the bridges using an electrodynamic shaker of constant particle velocity. An impedance head placed between shaker and bridge supplies the force necessary to obtain the particle velocity which is kept constant via the control amplifier. As the proportionality is $Z \; F$ (v-const), on the attached level recorder the frequency dependence of the input impedance of the board is directly obtained. The sound radiated by this type of stimulation is measured at a distance of two metres vertical to the centre of the board and recorded without taking the directional pattern into account. Thus for each measurement point a set of three curves ($|Z|$, , L) is obtained which allows the sound transmission from the string to the board to be judged and its conversion into airborne sound to be realized. Fig. 2 shows the results for the sound board of a medium-sized piano with stimulation close to the centre of the treble bridge. The radiation range of preference above 100 Hz as well as the reduced energy conversion above 1000 Hz can be clearly recognized.

A comparison of the measurement results obtained for a back model, various mechanical components of which were changed shows that braces scarcely influence the acoustical parameters. Their only purpose is to maintain the intonation constant over a long period of time with its usual climatic variations. The significance of the iron frame can be rated in the same way. It takes over the tensile forces of the strings and is braced against the back. If the construction of the back is stable, the sound board is firmly fixed in its sound board braces; when the back is less stable, an additional strutting of the sound board braces by means of the iron frame is necessary. For this reason the type of construction and the fixing of the iron frame on the back can crucially influence the effect of sound transmission.

The differences in the sound velocity on the sound board parallel or vertical to the grain are adjusted by gluing on ribs. However, extensive measurements have proved that these differences are usually overcompensated by using many soft ribs. As the effect of sound radiation can be increased be decreasing the resonating mass, an attempt was made to replace the many flat ribs by fewer but stiffer ones. As fig. 3 shows, the new rib construction GI A1 increased the hardness and thus the reflecting capacity of the board, so that the piano sounds decay more slowly; t_{20} is the time which passed until the level dropped by 20 dB.

The transition to the real, non-steady piano sound is reached by means of an artificial touching device. It consists of two movable carts with fifteen lifting magnets each, arranged above the keyboard of the piano. They are stimulated by an electronic control device in such a way that a preselected, reproducible touch up to the volume "forte" is reached. The lifting magnets can be activated individually or in combination by an external keyboard. The touching device serves the stimulation of individual tones, the normal play by piano players for comparison and for the analysis of the repetition capability of the action (max. 25 touches per second). We refrained from recording total level curves as presented in previous papers /3/, because it has turned out that the total levels are not suited to serve as parameters for subjective sound quality. The time dependence of the decay rates and its spectral development seem more important. The use of high resolution real time narrow band analyzers makes it possible to detect the spectra at different moments as well as the non-harmony of the higher partials.

The typical decay curve of piano sounds is charcterized by the fact that the level drops again rapidly after a very quick rise before it decays considerably more slowly after a period of time which depends on the register /4, 5/. The early level range, between the maximum value and a drop of approx. 20 dB, is particularly important for the subjective evaluation of the sound /6/. the steeper the decay curve in this range, the more penetrating and "hollow" is the sound perceived. If, however, the salient point of the curve as the transition from the initial to the later decay time is moved further towards the maximum value, the initial steepness of the drop plays an even less important role. Chiefly responsible for these correlations is the input impedance of the board, whose frequency dependence is known from the sound board investigations. Specific modifications of the sound board braces, ribs and bridge can lead to an improvement of the quality, as a result of an increase in the initial decay time (cf. fig. 3).

As the sound board of a piano is an acoustically passive element, the development of the timbre is mainly determined by the type of stimulation of the strings by the hammer heads. In order to be in a position to evaluate the tuning process, i.e. the matching of the properties of the hammer heads with the string sound board system, a method has been developed by which the elastical release forces of the hammer heads can be objectively measured. Thus an approximated optimum curve can be obtained for each type of instrument, based on the work of the tuners. By means of an accelerometer, slung upon the top side of the hammer heads with a defined mass, the peak values can be obtained and recorded above the number of the corresponding piano key/hammer. Fig. 4 illustrates the measurement values of a set of hammer heads upon delivery and after tuning. It can be clearly seen that the medium and lower bass ranges (No. 1-30) were softened by pin pricks, whereas the surface of the descant felts (starting at No. 58) had to be hardened.

Literature

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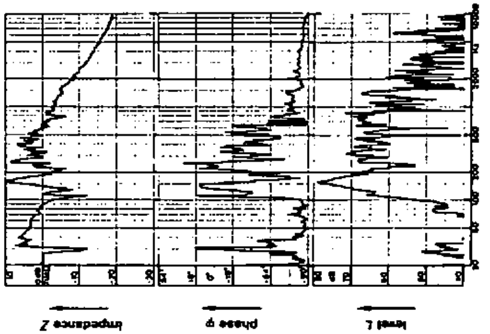
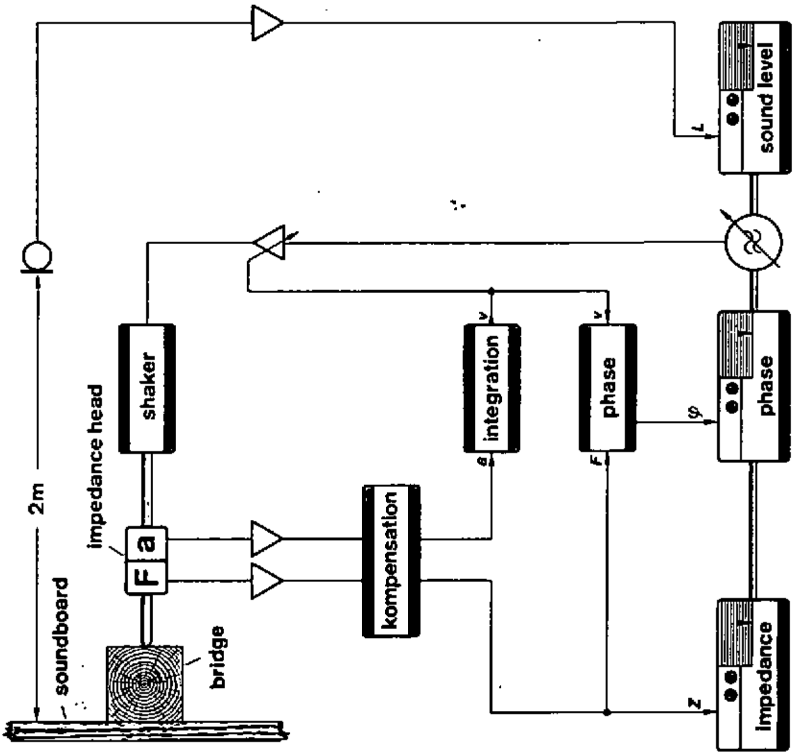

impedance Z
phase φ
level L
frequency

Fig. 2


soundboard
bridge
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F
a
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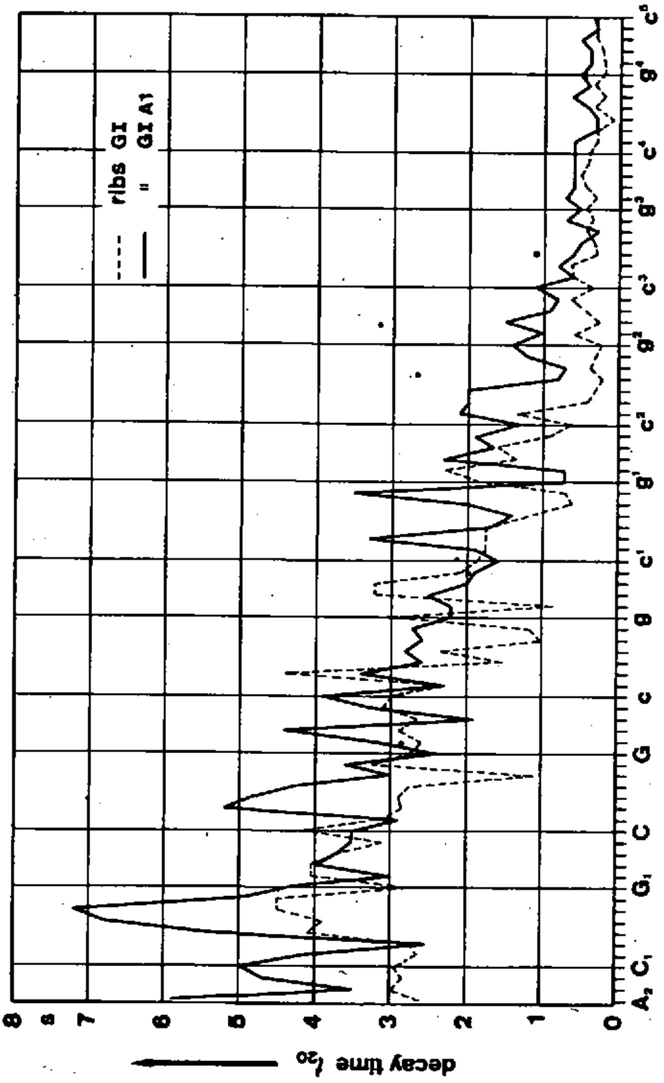
Impedance

Fig. 1


--- ribs GI
— " GI A1
decay time t_{20}
0
1
2
3
4
5
6
7
8
A₂
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c¹
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c⁴
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c⁵

Fig. 3

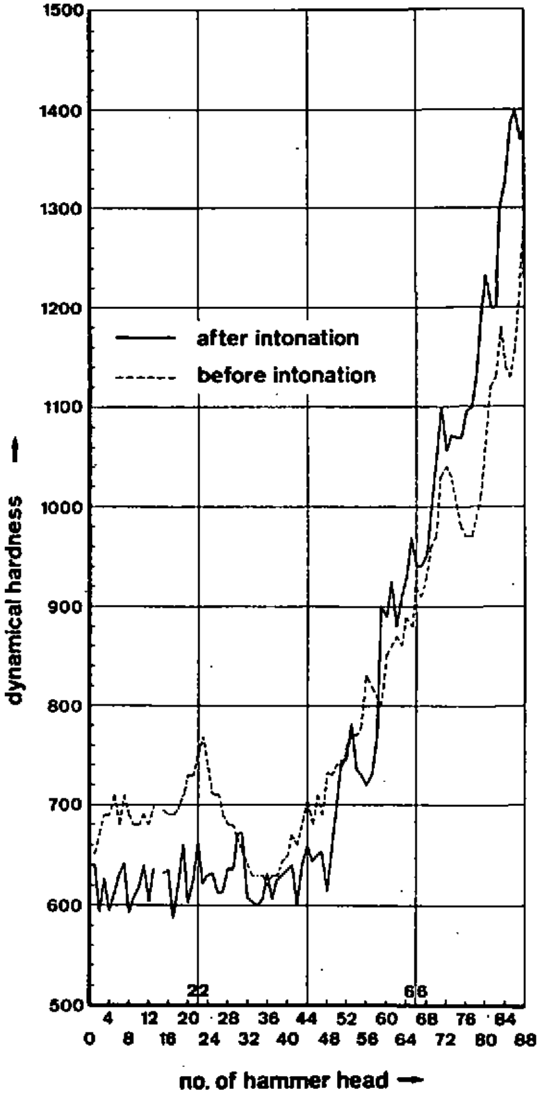
1500
1400
1300
1200
1100
1000
900
800
700
600
500
dynamical hardness ↑
after intonation
before intonation
22
66
4 12 20 28 36 44 52 60 68 76 84
0 8 16 24 32 40 48 56 64 72 80 88
no. of hammer head →

Fig. 4