

CBS MEMORANDUM

FROM: H. Suzuki
TO: E. TORICK
DATE: Sept. 21, 1983

cc: R. Finger, J. Pramburger (Steinway)

Subject: Soundboard Study

The effect of the crown of a piano soundboard on its vibration characteristics were studied using a spruce plank. It was found that the loss factor of the beam becomes smaller when a stress is applied to the beam (i.e., when the beam is slightly curved). The decrease of the loss factor made the peak level of the resonance higher indicating an empirically well known fact that a soundboard can be more responsive when it is curved. Of course, a soundboard may become too stiff when it is over stressed. It seems very important to study the stress distribution of a real soundboard with and without string tension. See the attached report for the details.

Effect Of Strain On The Vibration Characteristics Of A Rectangular Spruce Beam

I. Introduction

The crown of a piano soundboard seems to have two purposes. The first is to make the soundboard strong against the down bearing due to the string tension. Giving an arch to a structure (such as a bridge) is a common practice to make the structure stronger. This kind of effect may be easily understood. The second is to make the soundboard responsive to an alternative force applied by strings. It is often mentioned that a soundboard with a little crown produces a weak sound. The purpose of this study is to prove this fact experimentally. Instead of the crown (or the arch) a more physical term "strain" will be used, which indicates the degree of elongation or contraction. The most interesting parameter of the vibration characteristics is the loss factor. This determines how quickly the vibration dies away. It also affects the peak levels of resonances of the structure. If the damping is small, the resonance curve shows a very sharp and high peak. The peak level, however, may also be affected by the geometrical change of the structure from a flat plane to a curvature. Therefore, the peak level will also be measured as a function of strain. Another important parameter is the stiffness of the structure. Due to the geometrical change, the structure becomes stiffer when it is crowned making the resonance frequencies of the structure higher.

A simple structure, a beam, will be used instead of a real soundboard. This makes the experiment much simpler, and the effect of the strain on the above mentioned three parameters can be measured more accurately in more ideal conditions.

II. Measurement Technique

The test sample used for the measurement is shown in Fig. 1. A spruce plank has the thickness of 0.25", which is close to the thickness of a real soundboard near the edge. Three aluminum pieces are glued by epoxy adhesive at both ends and the center. The thickness of the glue layers was made as thin as possible to avoid the effect of the glue itself. The beam was clamped at both ends to a 440lb. granite table via trapezoidal shaped aluminum bases by two heavy duty C-clamps. The effective length of the beam was made 12" with clamped conditions at both ends. The two ends must be clamped to the granite table very carefully for this experiment. If the C-clamps don't hold the beam securely, the vibration energy of the beam leaks to the support, causing an error in the loss factor measurement.

By changing the slopes of the trapezoidal bases, the degree of the arch is changed. The strain of the beam on the surface was measured by glueing thin strain gages at three places (see Fig. 1) and taking the average of the three numbers. (While the beam is resting free, the resistances of the three strain gages were measured. Then after the beam was clamped with some arch, the resistances were again measured. From the change of the resistance, the strain was calculated.)

The aluminum center piece has a weight of 11.14gr. The top of this piece (shown by x in Fig. 1) was struck by a impact hammer. A force gage installed in the impact hammer picked up the force signal applied on the beam. The acceleration of the beam was measured by an accelerometer attached to the bottom of the center piece. The Dynamic Structural Analyzer HP-5423A calculated the transfer function (acceleration/force) each time the beam was struck. The transfer function was obtained as the average of 10 measurements. From the transfer function, the loss factor, peak level and the resonance frequency were calculated. This process was repeated several times for one condition and the results were averaged.

III. The Results and Discussion

The results are shown in Fig. 2. The strain is shown by the abscissa (null dimension). For the positive stress, the beam is curved upward. When the stress is equal to 0.0002, the center of the beam is raised by 1% of the length of the beam. Three ordinates are used to show three different curves

in one chart. The left ordinate is for the loss factor (null dimension). The middle ordinate shows the relative peak level in dB. The right ordinate is for the stiffness.

The dependance of the loss factor on the strain seems clear. As the strain increases, the loss factor decreases. The maximum of the loss factor is about 0.015 when the stress shows a small negative value. The reason for this bias may be caused by the initial strain which existed from the time when the aluminum pieces were glued. An important thing shown by this result is that the loss factor becomes smaller for a larger stress. A soundboard with less damping dissipates less energy making the sustain longer (assuming that the resonance frequencies are not changed). This is a very important property of the soundboard.

The peak level increases as the beam is curved upward. The rate of increase is roughly equal to the value obtained by $-20 \log (LF/0.015)$, where LF is an abbreviation for the loss factor. This means that the increase of the peak level is mainly caused by the decrease of the loss factor. The peak value did not increase for large negative values in the range of the measurement. The reason for this (assymetry) is not clear. The effect of the stress on the loss factor and the peak level clearly shows that a crown of a soundboard makes it more responsive to the force applied on it.

The fundamental resonance frequency of a beam with an additional mass at the center is given by

$$f_0 = \frac{4}{\pi} \left[\frac{3EI}{L^3 (M_a + 0.37 M_b)} \right]^{\frac{1}{2}},$$

where E is the Young's modulus, I is the area moment of inertia, M is the additional mass, M_b is the beam mass and L is the length of the beam. This equation shows that the effective mass of the system at the fundamental resonance frequency is $(M_a + 0.37 M_b)$. Then, the stiffness of the beam is calculated by

$$S = (M_a + 0.37 M_b) \cdot (2\pi f_0)^2.$$

The results are shown by the chain line in Fig. 2. The curve shows that the stiffness increases as the positive or negative stress is increased. This indicates that a soundboard with excessive crown may become too stiff for the effective radiation of the bass sound. Another negative aspect of the excessive stress is that it may cause a crack problem.

IV. Conclusion

The importance of the stress (or the arch) for the responsiveness of the soundboard was successfully proved by the experiment. The question is what an optimum stress distribution is for a soundboard of good quality. The currently used curvature of the soundboard was experimentally determined a long time ago, and it might be very close to the optimum shape. However, this problem may be illuminated from a different angle if the change in the stress distribution on the soundboard is measured when a free soundboard is installed into a frame and when the string tension is applied to it. This seems to be a very important next step for the improvement of the piano soundboard.

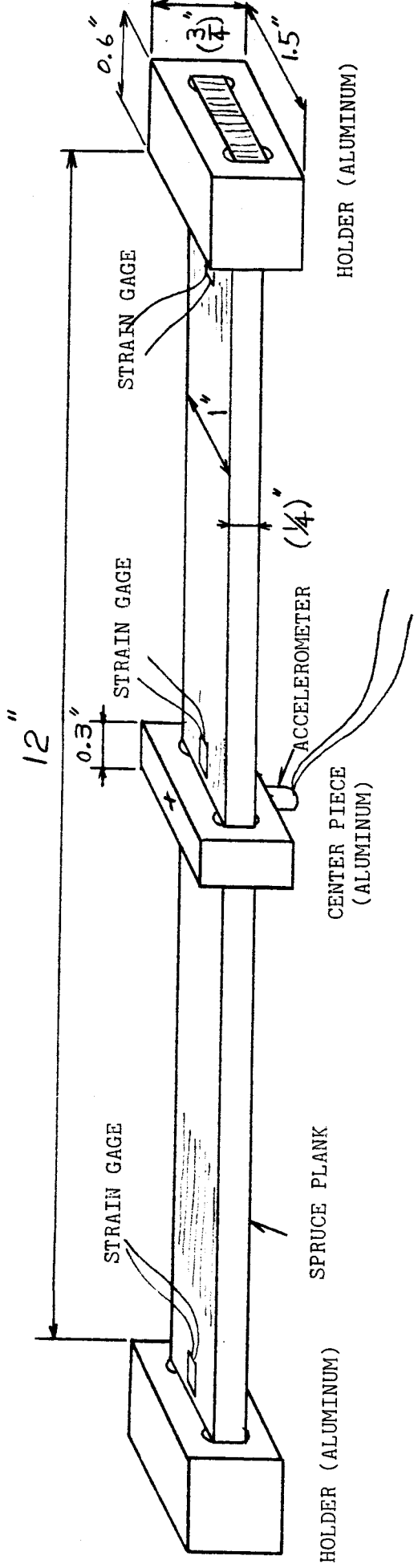


FIG. 1 Configuration of the test sample.

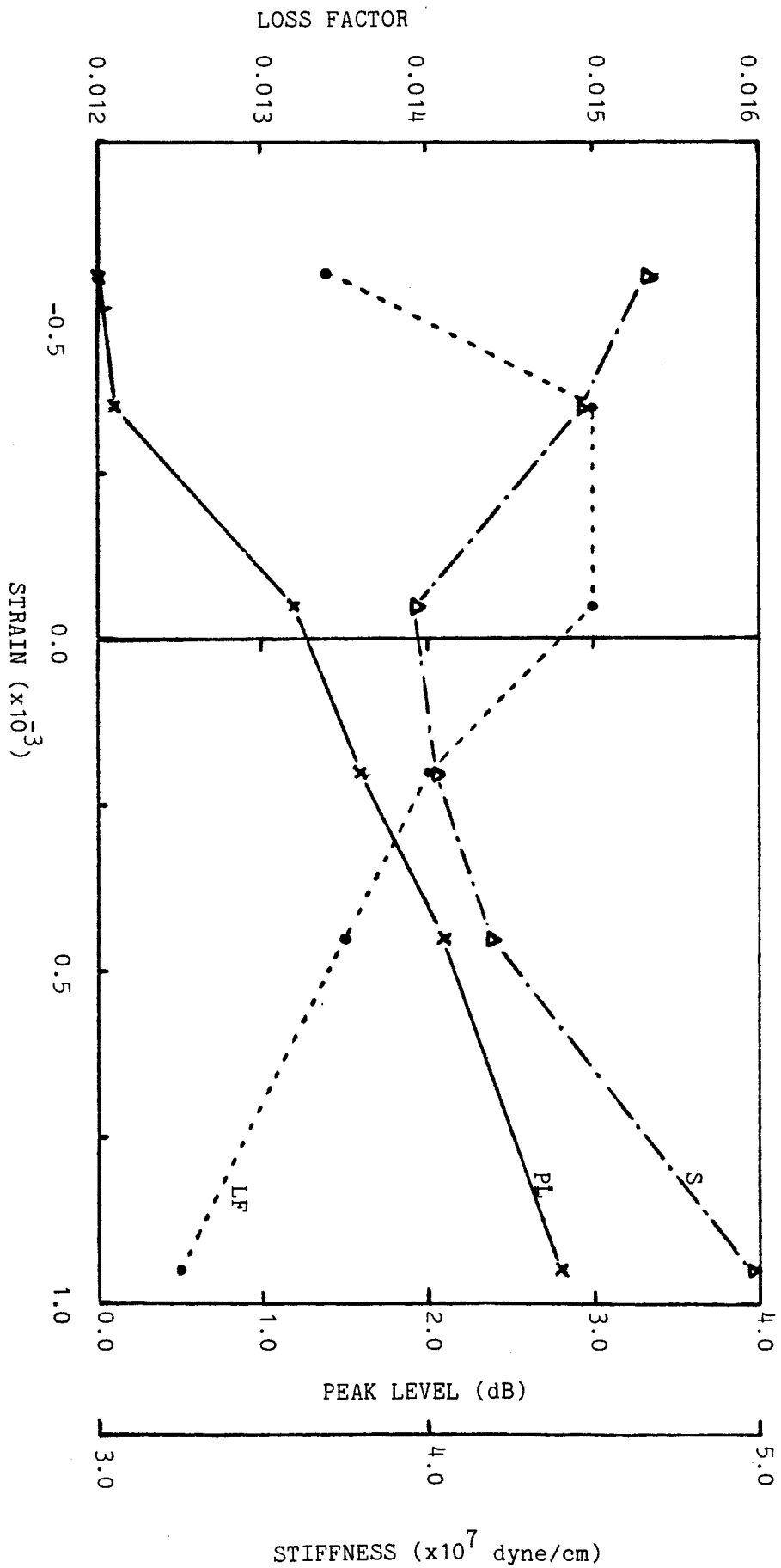


FIG. 2 Effect of the strain on the loss factor peak level, and stiffness of a spruce plank at its first resonance.