Chapter 19
Method to Predict the Shock Response Spectrum Shape from Frequency Response Functions

Jason R. Blough, James DeClerck, Charles VanKarsen, and David E. Soine

Abstract In an effort to understand the details of why a Shock Response Spectrum (SRS) has a particular shape, a method was designed to predict the shape of the SRS based on Frequency Response Functions (FRFs). Gaining a full understand of the relationship between the FRF of a structure and the SRS shape should prove to be very useful in reducing SRS test time and allow the general shape of an SRS response to be predicted more efficiently using finite element methods or experimentally obtained data. To allow comparisons of different shock response plates and fixtures through the use of FRFs a normalized Shock Response Spectrum (nSRS) was developed. The nSRS is derived directly from the FRF of a structure and when coupled with a library of characterized impactor input spectrums allows an SRS to be predicted without performing any testing. This approach allows modifications to the shock response plate/fixture to be evaluated efficiently and the effect of different impactors to be studied without performing a large number of experimental tests. It is hoped that this approach to understanding and predicting SRSs improves the understanding of how the structural dynamics effects an SRS and efficiency of testing.

Keywords Shock • SRS • Experimental

19.1 Introduction

The purpose of this work is to streamline Shock Response Spectrum (SRS) testing. One of the difficulties in performing SRS tests is predicting or understanding what the necessary fixtures and impactors are to achiever an SRS which falls within the required limits. This paper outlines an approach based on initial Frequency Response Function (FRF) measurements, a library of estimated input power spectrums from various impactors, and the standard SRS calculations.

Experimental data along with FEA modeling was done to understand what aspects of a shock response plate and fixture can be important in the shape of the SRS curve.

19.1.1 Normalized SRS Calculation

To allow more consistent comparisons of experimentally acquired SRS measurements the concept of the normalized SRS (nSRS) was developed. The nSRS was developed because each time that the resonant shock plate was excited the excitation level was of a different amplitude, this led to SRSs that were of different amplitudes. Having different level SRSs made them difficult to compare, when what was of interest was the knee frequencies and the shape of the SRS above the knee frequency. The concept of the nSRS allowed SRS functions to be overlaid such that these comparisons could easily be made.

The nSRS is calculated following the flow chart shown in Fig. 19.1.

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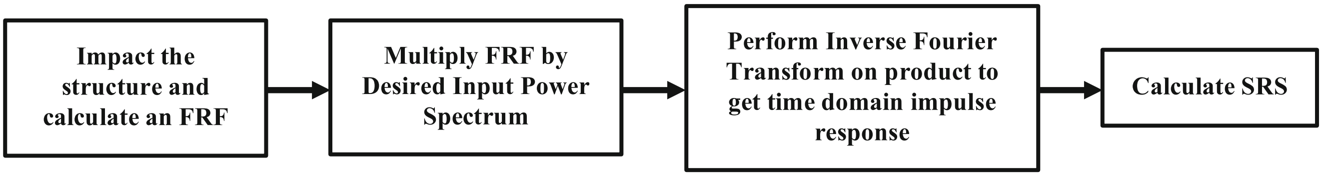

Fig. 19.1 Process to compute normalized SRS

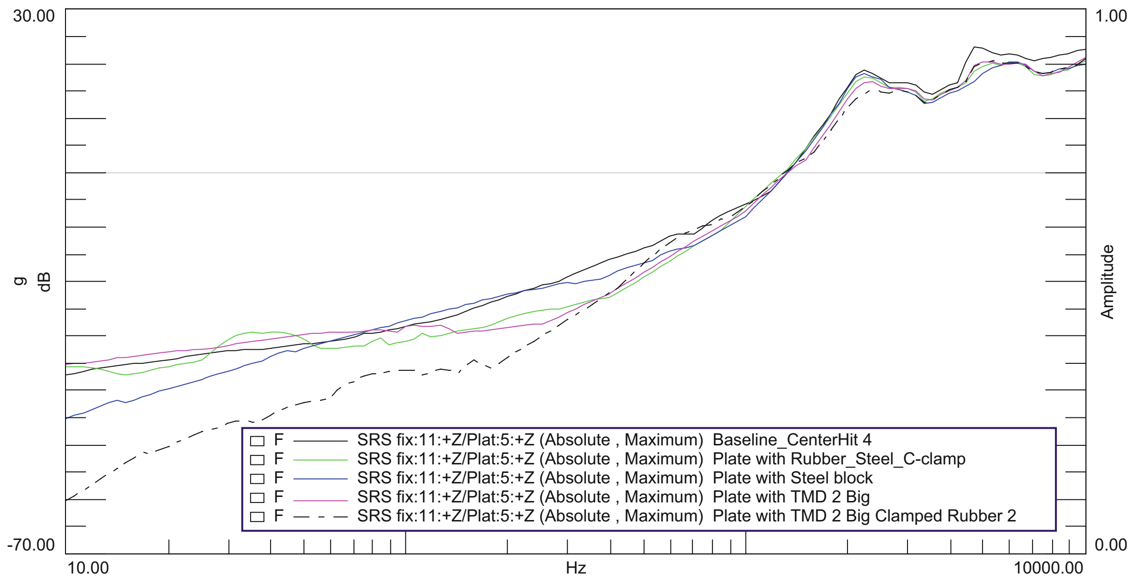

Fig. 19.2 nSRS functions for different structural modifications

The FRF is typically measured using an instrumented modal impact hammer which measures the force input into the structure. The level of excitation provided by the impact hammer can cause system non-linearity's to be excited if the impact force is high enough. These non-linearity's will be apparent in the FRF but unless severe do not appear to have a large impact on the shape of the SRS. The FRF could be measured using other impact devices or a modal shaker as well.

The input power spectrum is the autopower spectrum that would be generated by the impactor of interest. The shape of the input power spectrum controls which modes of the resonant plate are excited, modes which are above the frequency where the excitation energy of the impactor has rolled off will not be excited with an equal amount of energy as the lower frequency modes. The roll-off of the impactor's power spectrum has a significant impact on the shape of the SRS at the higher frequencies and is the reason that most SRS functions end with a flat or negative slope instead of an increasing amplitude. To assess the effect that a different impactor might have on a measured SRS, various input power spectrums can be used with the measured FRF.

Once the product of the FRF and the desired impactor input spectrum is calculated, it is inverse Fourier transformed to a resulting time domain impulse response. This time domain impulse response is then used as the input to the SRS calculation.

The advantage of the nSRS over a standard SRS is observed when comparing multiple test cases to more accurately understand the effect of structure and impactor changes. An example of overlaid nSRS functions can be seen in Fig. 19.2.

If a standard SRS is used, the SRS functions cannot be easily overlaid as shown in Fig. 19.3 which shows multiple SRS functions from the same structure but with slightly different force inputs. Note how difficult it would be to assess small changes in the SRS even without changes to the structure in this case.

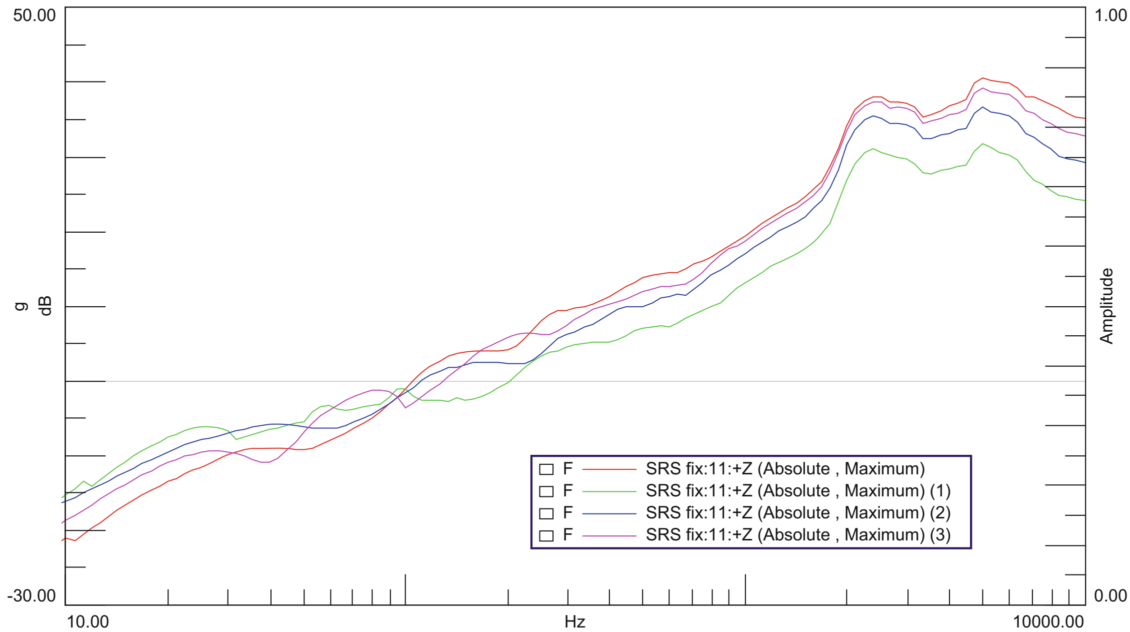

Fig. 19.3 Overlayed SRS functions for different structural modifications

19.1.2 Correlation Between FRF Shape and SRS Shape

Having developed a procedure which allows experimental SRS measurements to be compared by normalizing relative to the input spectrum several test cases were evaluated to understand how well the FRF of a system correlated to the estimated SRS.

The resonant plate systems tested, include the following variations which are all based off of the same resonant plate and fixture. Structural modifications were made to the resonant plate to assess the changes in the SRS. The modifications are listed below:

1. Baseline resonant plate and fixture.
2. Baseline resonant plate and fixture with two large tuned mass dampers attached on one side.
3. Baseline resonant plate and fixture clamped to ground on one side through rubber material.
4. Baseline resonant plate and fixture with steel mass bolted to one side of plate.
5. Baseline resonant plate and fixture with steel block clamped to plate through rubber material.

Pictures of the modified resonant plate are shown in Fig. 19.4.

FRFs were measured on the baseline plate/fixture along with each of the modified resonant plate setups and are shown in Fig. 19.5.

Figure 19.6 left shows a zoomed in view of the first natural frequency while Fig. 19.6 right shows a zoomed in view of the second natural frequency. In both cases, it can be seen that the differences in the FRFs are very significant.

The estimated SRS functions related to the systems with these FRFs are shown in Fig. 19.7. Note that the SRS does not roll-off or decrease in amplitude at the very high frequencies due to an impact input autopower spectrum which does not roll off. In most cases, it is expected that the impactor would produce an input autopower spectrum with roll-off at these very high frequencies and hence the SRS would roll off as well.

Figure 19.8 shows a zoomed in view of the SRS curves near the knee frequency and above. While there are very apparent differences in the SRS curves, they do not exactly track the differences which the FRF’s might suggest.

In understanding how the FRF’s and SRS’s correlate to one another several analyses were performed. While no perfect correlation was discovered, when comparing the energy summation in the FRF around a natural frequency and the amplitude of the corresponding peak in the SRS there was quite good correlation. It is believed that a perfect correlation was not achieved because of the nature of the SRS being a peak hold type estimate as well as the differences in the damping in the FRF, this can have a sizable effect on the SRS amplitude.

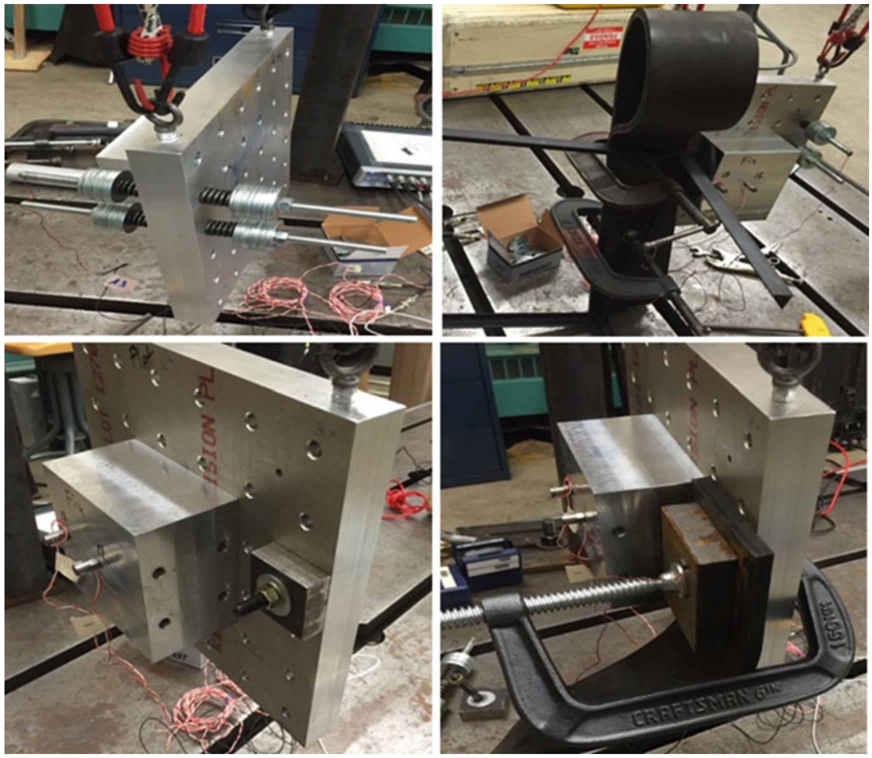

Fig. 19.4 Resonant plate test configurations

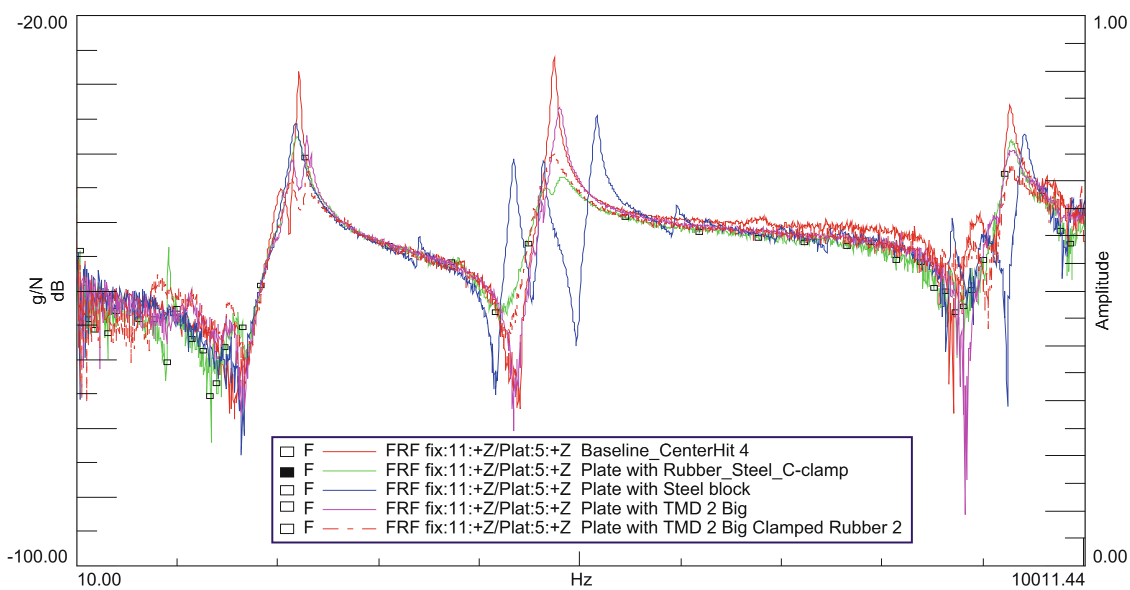

Fig. 19.5 FRFs of resonant plate configurations

19.1.3 Effects of Measurement Quality on the SRS Shape

In an attempt to understand more about how measurement quality affects the computation of an SRS, a study was done with experimental data. The study involved striking the resonant plate and fixture with different hammers with different intensities.

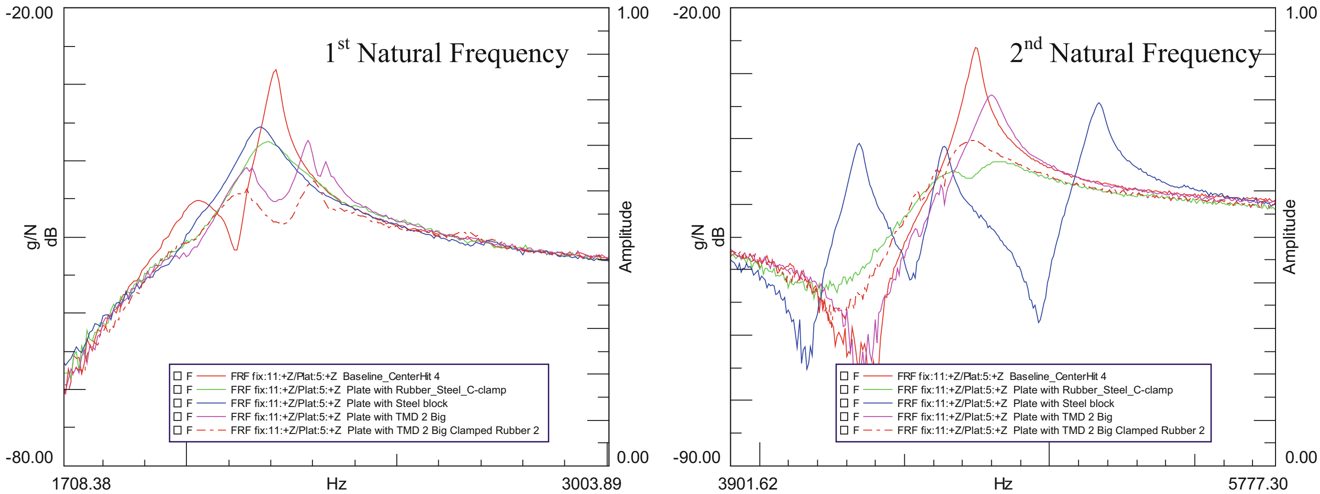

Fig. 19.6 Zoomed in view of the first natural frequency (*left*) and second natural frequency (*right*) of the resonant plate

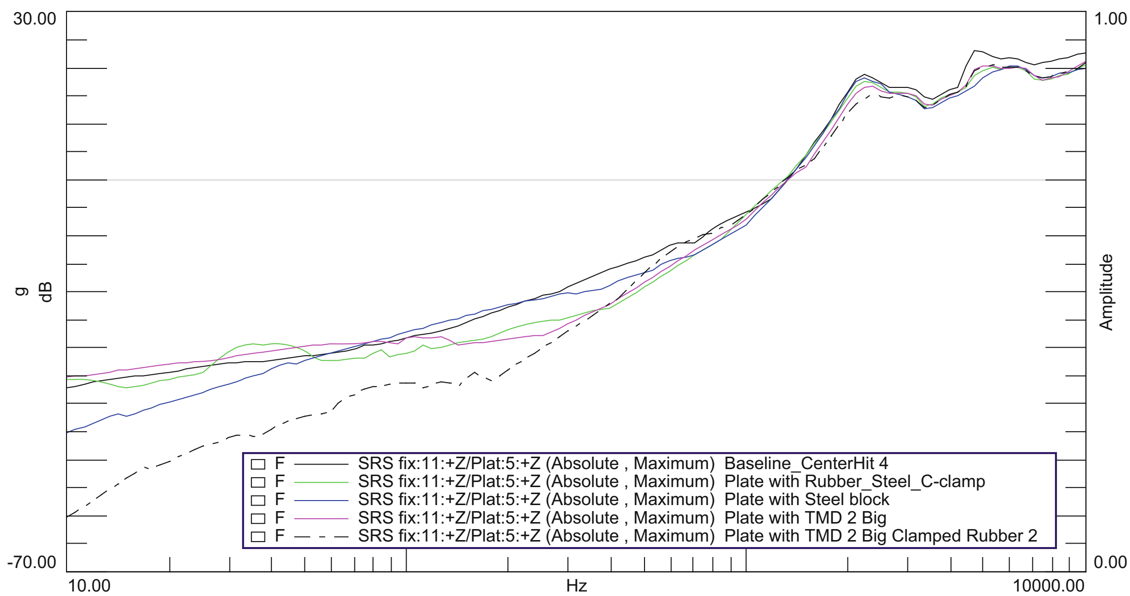

Fig. 19.7 SRS's of the resonant plate configurations

Figure 19.9 shows that as the intensity of the impact and the energy imparted into the plate increases the SRS amplitude also increases. Figure 19.9 also show a relationship between the input autopower spectrum and the SRS shape. When the input spectrum rolls off at lower frequencies the amplitude of the SRS also decreases at frequencies above the input spectrum roll off as would be expected.

In the extreme cases, the resonant plate was struck with enough force to cause a non-linear response as shown in the FRF's of Fig. 19.10. The non-linearity's are evident due to the non-symmetric shape of the peak in the FRF.

Figure 19.11 shows the SRS functions which result from the impacts used to measure the FRF's in Fig. 19.10. Note, all of these functions were measured using the same impactor with different intensities of impact. The shapes of the SRS functions change with the intensity of the impact considerably. An interesting observation is that it is not easy to tell from an SRS whether a structure has been impacted hard enough to drive it to a non-linear response.

A group of tests were also performed where several different impact hammer/hammer tip/impact intensities were collected. The FRF's from these tests are shown overlaid in Fig. 19.12. Note that many of the FRF's from this testing have a high amount of noise at the higher frequencies. These high noise measurements would typically be rejected due to the level of noise and efforts made to acquire measurements with less noise made.

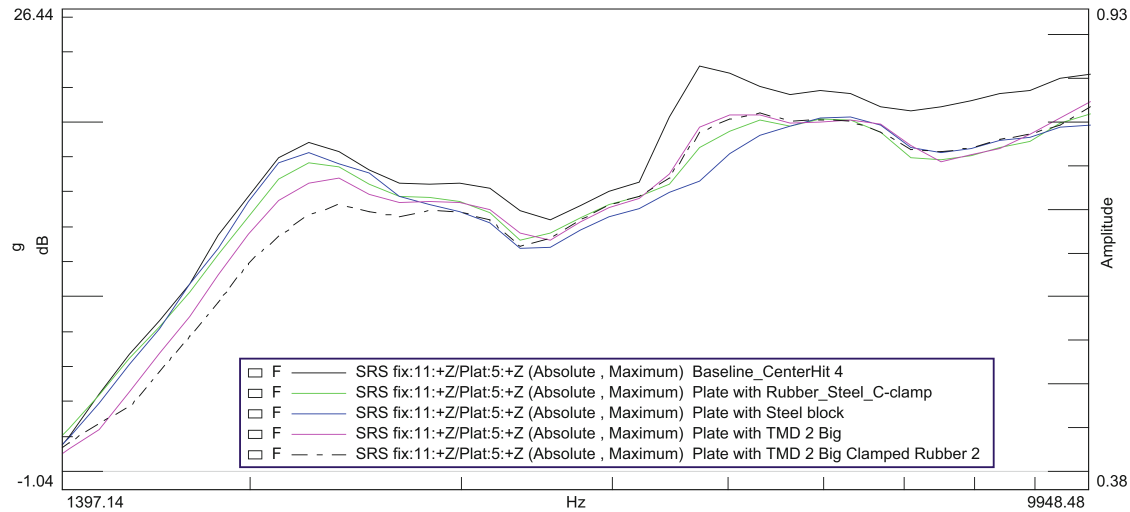

Fig. 19.8 Zoomed in view of SRS functions for resonant plate

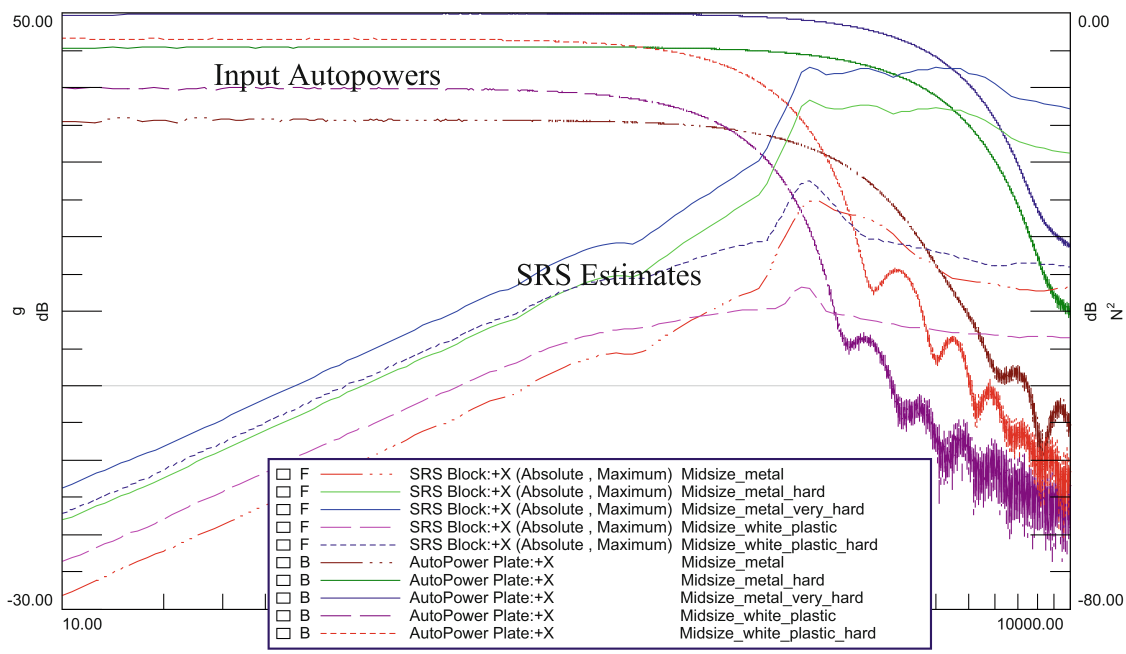

Fig. 19.9 Input autopower spectrum and SRS overlaid to show relationship

Even with the high levels of noise on some of the measurements it is very apparent that there are differences in the response of the structure, both linear and non-linear, around the peaks of the natural frequencies. Calculating SRS functions from these same tests results in the SRS's shown in Fig. 19.13.

An interesting aspect of the SRS's in Fig. 19.13 is that while some of the input measurements contained a very high level of noise as evidenced by the noisy looking FRFs, the SRS functions do not indicate the input to the SRS calculation was noisy. This is due to the fact that the SRS is a peak hold type of function and is not sensitive to noise. This would imply that no matter the quality of the original measurement made, the SRS will look acceptable. Additionally, the differences in the SRS's in Fig. 19.13 are completely from the differences in the inputs to the resonant plate and fixture, no other changes were made. This indicates that there is great potential to shape an SRS by changing only the input used to excite the resonant plate. Another conclusion that can be drawn from these SRS's is that an input which does not excite to as high a frequency will typically have a flatter SRS response at the higher frequencies.

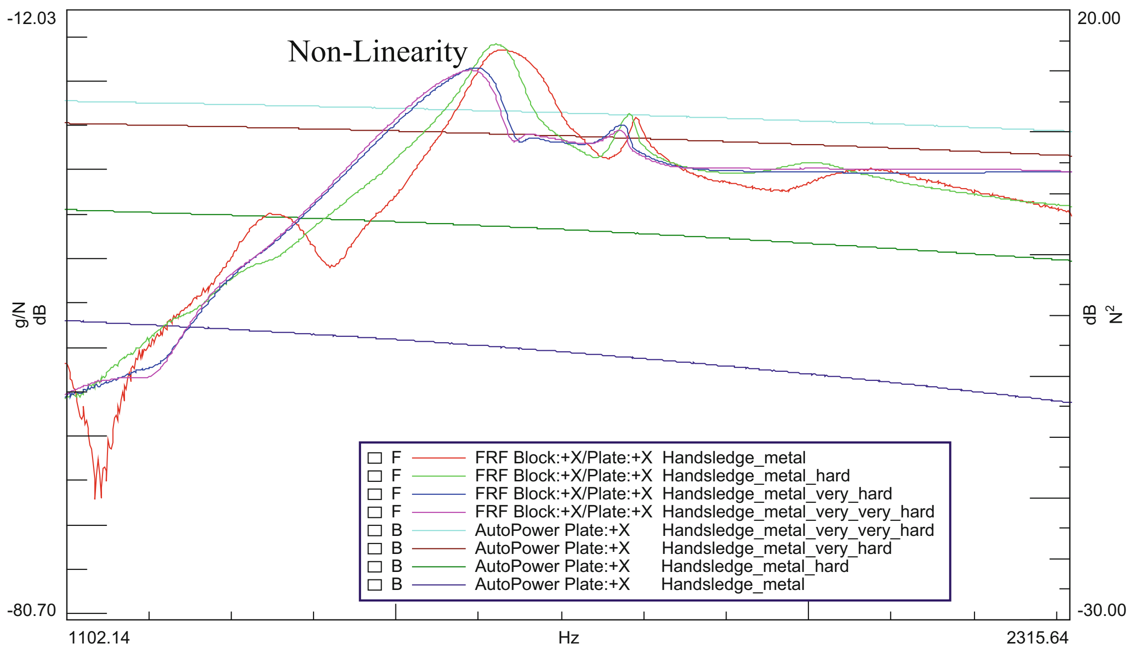

Fig. 19.10 FRF showing non-linearity due to very hard impact

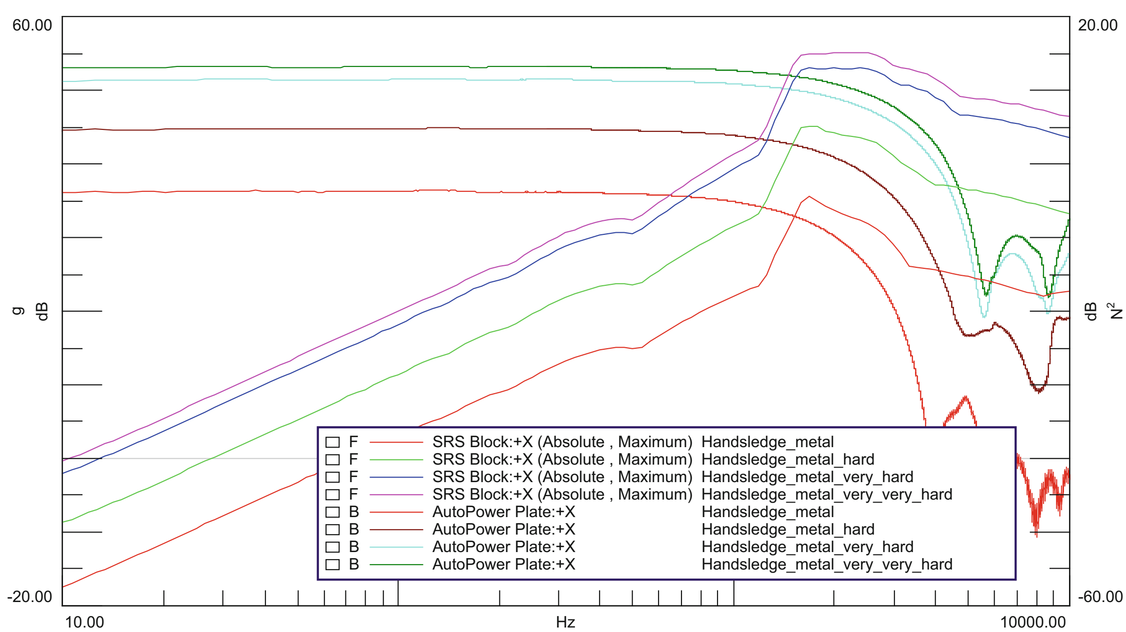

Fig. 19.11 SRS functions due to varying intensity impacts

19.2 Summary

The *normalized SRS* (nSRS) was developed which allowed several different experimental studies to very easily be evaluated to explore the structural response aspects of an SRS. The nSRS is calculated by estimating the Frequency Response Function (FRF) of a structure, multiplying this FRF by the input autopower spectrum of a particular impactor, and then taking the Inverse Fast Fourier Transform (IFFT) of this product and calculating an SRS from the resulting time domain impulse response.

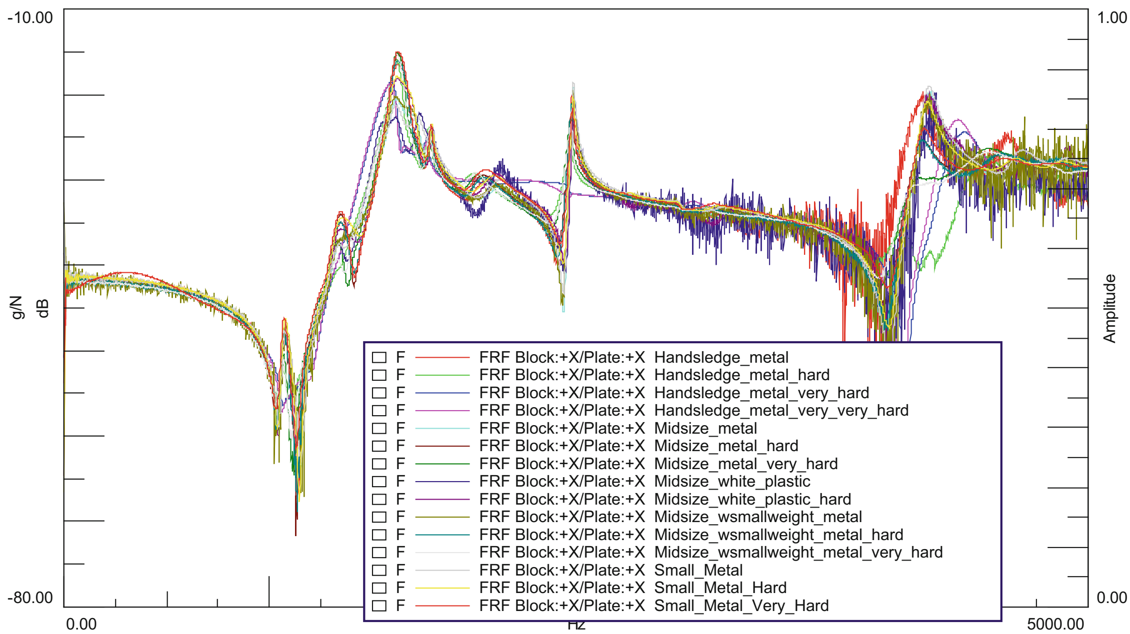

Fig. 19.12 FRFs overlaid from many different input functions

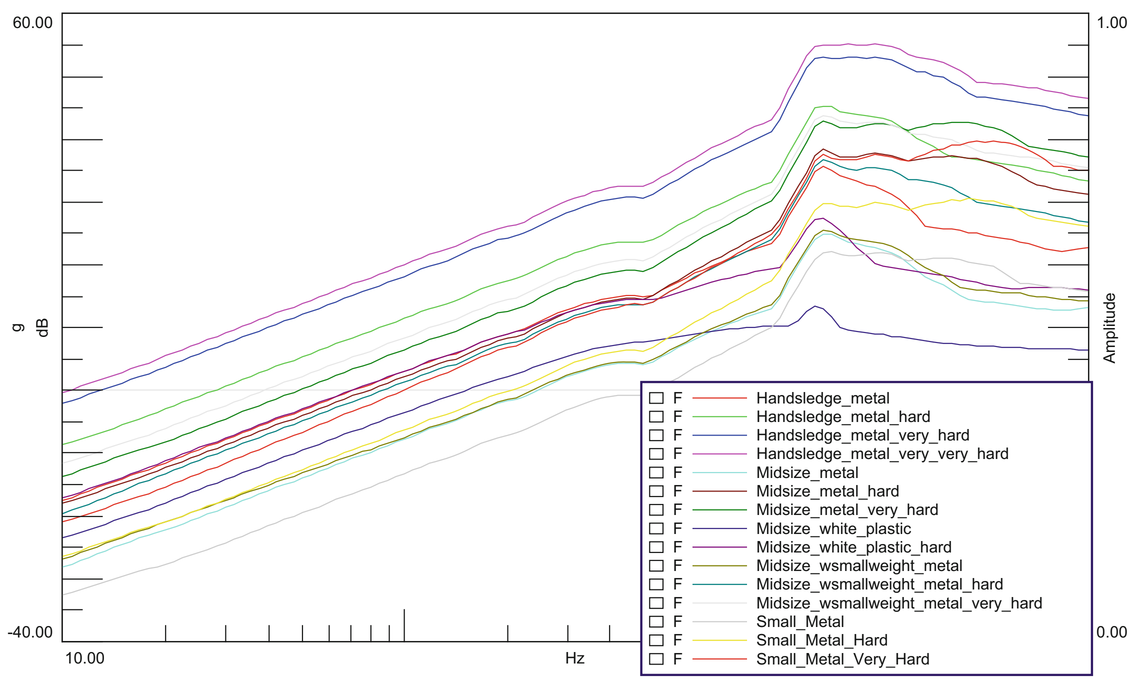

Fig. 19.13 SRS functions calculated from many different input functions

Modifications were made to the shock response plate and both FRFs and SRS functions estimated. The modifications included clamping to ground through heavy rubber, adding tuned mass dampers, bolting on mass, and clamping rubber with added mass. These structural modifications produced very large changes in the FRFs at all natural frequencies as well as changes in the SRS functions. While the changes in the SRS functions were significant they did not appear to track the changes in the FRFs directly. The best correlation between the FRFs and the SRS functions was achieved by comparing overall energy in bands around the natural frequencies but was not an ideal correlation.

To assess the effect that different impactors have on the shape of the SRS the same shock plate/fixture assembly was impacted with many different hammer/tip combinations and with different impact intensities. While the FRFs were unchanged, except when the impact was hard enough to excite non-linearities, the SRS functions showed large differences due to the roll-off in energy at the higher frequencies related to the measured input autopower spectrums from the different hammers. If the input autopower spectrum rolled off at a lower frequency the corresponding SRS also began to decrease in amplitude at a lower frequency.

The last study performed was to assess the appearance of the SRS due to different levels of quality of the measurement process. It was shown that using a very noisy FRF measurement in the nSRS calculation still resulted in a smooth SRS function. Additionally, FRFs clear non-linearity's in them did not significantly change the shape of the SRS function in a way that the non-linearity was apparent. One disconcerting fact that arose from the study of different FRF measurement qualities and the SRS relationship is that by only looking at the SRS it is not obvious whether it is a valid measurement or based on a very noisy input, which for any other reason would be considered of insufficient quality to make engineering decisions.