Inappropriate SRS Specifications

By

George Henderson
GHI Systems, Inc.

INTRODUCTION

The Shock Response Spectrum is a fairly simple concept, having been in use for years[1][2][3]. But it occasionally falls victim to an inappropriate test specification meant to exploit SRS features. The SRS may be used for two diverse purposes: 1) To predict the response of a structure under transient load, and 2) To measure the response of a structure under transient load. Purpose #1 is the primary reason for SRS use. Purpose #2 is a more complex, and less understood issue. Both are processed in an identical manner, but there are subtle differences in interpretation.

One example of Purpose #2 is an attempt to make the SRS a Fourier-like narrow-band signal detector. The intent is to detect very low-amplitude, short-duration and single-frequency resonances while at the same time characterizing the primary shock pulse. In other words employing the SRS for both purposes at the same time. In fact, there is only one case where the SRS behaves like the Fourier: when undamped.

It was thought that the SRS would operate in a pseudo-Fourier manner if two processing specifications are changed: 1) Reducing damping to near 0, thereby producing maximum sensitivity of the filter as shown in Figure 1, and 2) Setting the SDOF filter frequency progression to a small linear spacing over the frequency range, to provide FFT- like resolution. However, analysis of transmissibility versus damping ratio, ζ, curves shows that the above assumption is counterproductive.

THE SPECIFICATION

Let's suppose a company issues a test specification requiring suppliers to perform shock tests on products as part of an ongoing quality monitoring program. The specification includes two conflicting requirements: 1) The shock pulse is to be processed by an SRS analyzer having 1000 SDOF lines spaced linearly at 10 Hz increments, over the interval of 10 Hz to 10 KHz, and 2) using a damping ratio, ζ, of 0.010. This damping ratio results in an approximate transmissibility gain of $1/(2\zeta)$ = 50.

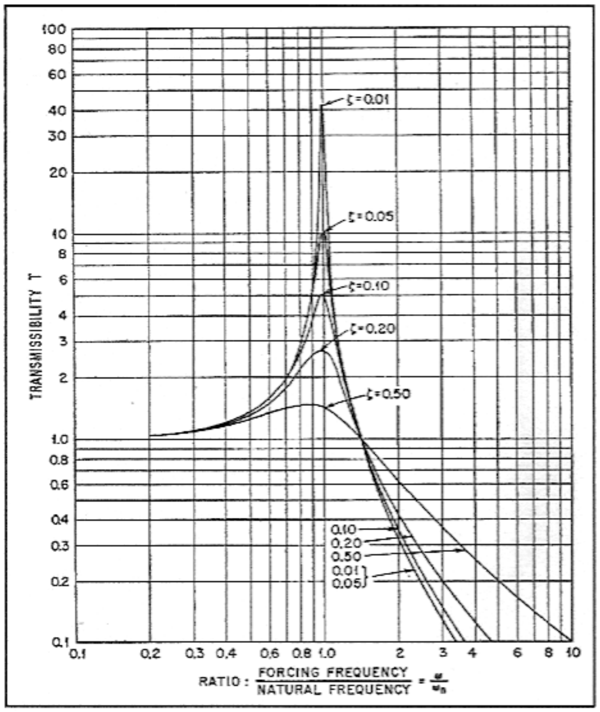

Figure 1. Transmissibility curve for viscous damped mechanical SDOFs. From Shock and Vibration Handbook, Fifth Edition, Harris and Piersol.

The intent of the two conflicting requirements appears to make potentially damaging shock machine resonances more evident on the SRS plot. Although the SRS is an excellent peak amplitude detector, a problem affecting its application in this case arises from the linear 10 Hz filter line spacing when using ζ of 0.01. This problem is filter response overlap, which occurs when the filter center frequencies f_r are too close together in relationship to their half-power bandwidths. The half-power bandwidth of an SDOF filter is approximately defined as $B = 2\zeta f_r$.

Overlap is also known as crossover, and may be visualized as a plot of two or more identical ζ response curves from Figure 1 overlaying others where their center f_r progression is defined as filters/octave for log, or filters/decade for linear presentations. An example of crossover overlap is shown in Figure 2.

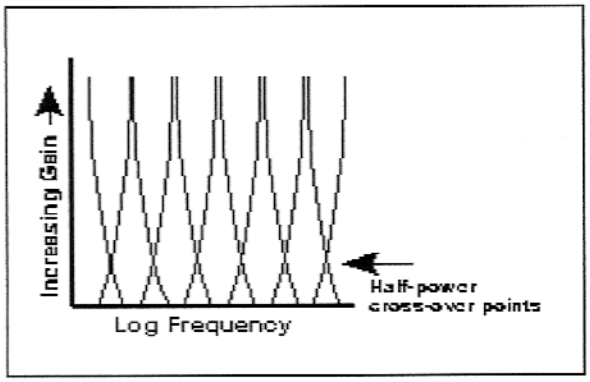

Figure 2 SDOF filter progression and crossover points, shown as 6 lines/oct progression in normal log - log format. Since half-power crossover points are proportional, there is uniform amplitude response across the analysis bandwidth.

THE PROBLEM

It has long been established that the proper relationship between f_r spacing and ζ is when the crossover occurs at the half-power amplitude points as shown in Figure 2 [4]. This can only be achieved using log frequency with relatively few filters such as six or 12 filters per octave. This becomes obvious when analyzing the various values of B that exist under the specification.

For the first SDOF at 10 Hz, B is 0.2 Hz. At the other extreme, 10 KHz, B is 200 Hz. The mid-range frequency of 5KHz has a B of 100 Hz. The low frequency condition is illustrated in Figure 3.

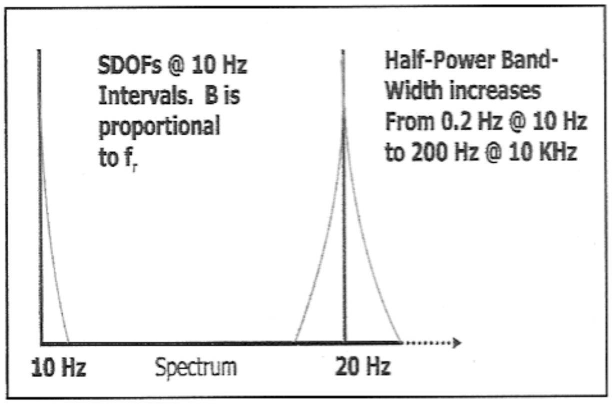

Figure 3 Example of SDOF filter spacing problem at the 10 Hz end of the 10 KHz linear spectrum.

For the first line at 10 Hz, the B would extend from 9.9 Hz to 10.1 Hz. There is no overlap here since the filter situated at the next interval, 20 Hz, will have a B extending from 19.8 Hz to 20.2 Hz. In fact, the filters are too far apart, and this creates another problem - lack of any response contribution between the filter skirts resulting in the SRS plot having amplitude errors within these gaps.

It is not until we reach an SDOF frequency of 500 Hz that the skirts crossover at their half-power amplitudes, shown in Figure 2.

Since B is proportional to f_r, as frequency increases above 500 Hz, the degree of overlap increases. The overlap will reach a maximum at the highest frequency of the plot, in this case, 10 KHz. At this frequency, the half-power bandwidth will be 200 Hz. This will envelop 20 adjacent SDOF filters spaced at linear 10 Hz intervals.

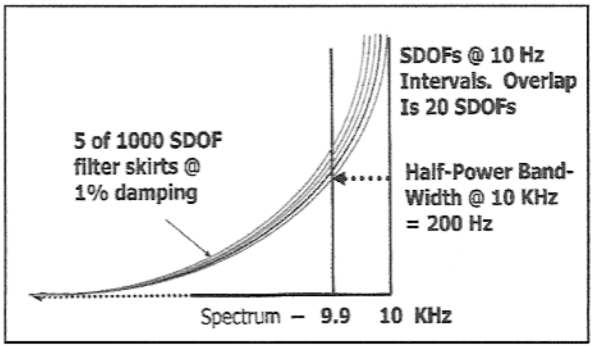

Figure 4 Example of SDOF filter spacing problem at the 10 KHz end of the 10 KHz linear spectrum. Only the lower frequency portion of the filter curves is shown for clarity.

This condition is shown in Figure 4. This high degree of overlap will cause contributions of response across these adjacent SDOF filters even if the signal is centered at an exact filter center frequency.

Considering perhaps the most critical response frequency of a product such as a hard disk drive - stack/actuator resonances near 500 Hz - the specification with $\zeta = 0.01$ would result in a B of 10 Hz at this f_r. Only at this f_r would the overlap provide normal SRS frequency resolution. However, any narrowband response signal contribution would still be smeared over at least two SDOF filters due to their broad shape, resulting in a loss of frequency resolution. This would be more pronounced at higher f_r frequencies. The sharp Fourier-like spike expected would be a low amplitude "hump."

If one compares the elegant narrowband filter shape of the FFT to the "lousy" filter shape of the SRS [5], a decision to use the FFT process would be made for this detection requirement. It would appear that a specification intended to provide high resolution detection from the SRS is inappropriate due to adjacent SDOF filter contributions.

COMMON PRACTICE

SRS plots are commonly specified as log-log amplitude versus frequency. There are various reasons for this other than achieving broad dynamic range, including the ability to judge the validity of the specified shock test by evaluating the up-ramps of the Residual Spectrum. A most important reason is that when SDOF f_r spacing is set in terms of lines per octave, there is proportionate spacing of the filters over the entire plot resulting in more uniform response with frequency. This is the most accurate condition.

Using the industry standard 1/6th octave log resolution, overlap crossovers are at the half-power points of adjacent oscillators at 5% damping. Lower damping ratios may warrant a finer resolution, but crossover at other than half-power points is not recommended [6].

Damping is usually specified at 0.05 (5%) of critical. This value is recommended in all test specifications that require SRS, and in addition, has been found to be a realistic value for representative real-world systems, when performing Purpose #1, predicting response.

Finally, the use of very narrow f_r filter spacing, less than the presently accepted 1/6th or 1/12th lines/octave for log plot standards, does not contribute to the analysis and can lead to misleading results as described herein.

RECOMMENDATIONS

It would be the recommendation of this writer to abandon the use of the SRS for the purpose of detecting narrowband resonances. This is more successively accomplished using Fourier spectrum (FFT) methods. If it is decided to continue to use the SRS for its primary strength - determining if the shock pulse is correct [7] - then solve the half-power bandwidth problems by using a normal log frequency plot at 1/6th or 1.12th octave SDOF filter progression, and 5% of critical damping.

The SRS is not a frequency domain tool although it confuses some because it appears in a amplitude versus frequency format.

CONCLUSIONS

Because of SDOF filter bandwidth overlap, the ability of the SRS to perform pseudo- Fourier analysis is lost when f_r progression is linear. At higher analysis frequencies, above 500 Hz, narrow-band energy detected in the time domain will be smeared across several f_r frequencies, and the resolving power will be sacrificed. It would be better to use the Fourier (FFT). The effects of lack of proper overlap at frequencies below 500Hz will be loss of amplitude accuracy which increases with decreasing frequency. Additionally, narrow-band resonance signals whose f_r is located midway between the 10 Hz spaced filter frequencies will not be detected at all, even if they are high amplitude.

Proper attention must be paid to the specifications for SRS processing to prevent inaccurate results. The user industry has developed commonly accepted specifications for SRS over the years [8]. These specifications are the result of academic analysis as well as practical experience.

It is not intended to dissuade the reader from using SRS. SRS is the primary tool for accessing transient loads, an application that is not the province of the FFT. Properly done, the SRS is a powerful tool.

References

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