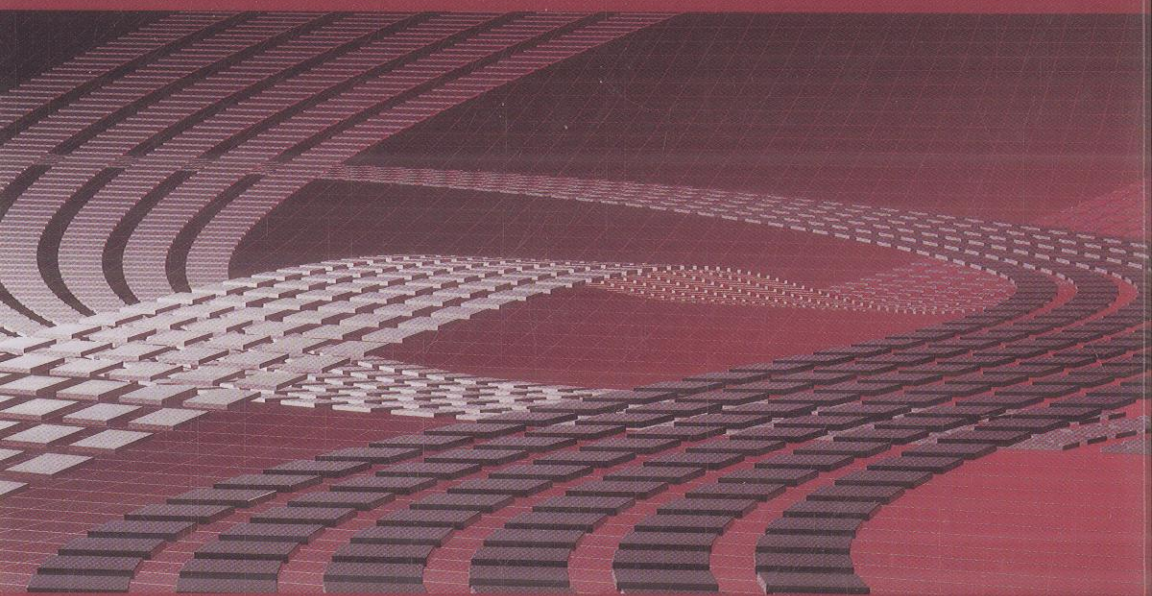


Mechanical Vibration and Shock Analysis



Mechanical Shock

Volume 2

Christian Lalanne

ISTE

 **WILEY**

Table of Contents

Foreword to Series	xi
Introduction	xv
List of Symbols	xvii
Chapter 1. Shock Analysis	1
1.1. Definitions	1
1.1.1. Shock	1
1.1.2. Transient signal	2
1.1.3. Jerk	3
1.1.4. Simple (or perfect) shock	3
1.1.5. Half-sine shock	3
1.1.6. Versed sine (or haversine) shock	4
1.1.7. Terminal peak sawtooth (TPS) shock (or final peak sawtooth (FPS))	5
1.1.8. Initial peak sawtooth (IPS) shock	6
1.1.9. Square shock	7
1.1.10. Trapezoidal shock	8
1.1.11. Decaying sinusoidal pulse	8
1.1.12. Bump test	9
1.1.13. Pyroshock	9
1.2. Analysis in the time domain	12
1.3. Fourier transform	12
1.3.1. Definition	12
1.3.2. Reduced Fourier transform	14
1.3.3. Fourier transforms of simple shocks	14
1.3.4. What represents the Fourier transform of a shock?	25
1.3.5. Importance of the Fourier transform	27

1.4. Energy spectrum	28
1.4.1. Energy according to frequency	28
1.4.2. Average energy spectrum	29
1.5. Practical calculations of the Fourier transform	29
1.5.1. General	29
1.5.2. Case: signal not yet digitized	29
1.5.3. Case: signal already digitized	32
1.5.4. Adding zeros to the shock signal before the calculation of its Fourier transform.	32
1.6. The interest of time-frequency analysis	36
1.6.1. Limit of the Fourier transform	36
1.6.2. Short term Fourier transform (STFT)	39
1.6.3. Wavelet transform	44
Chapter 2. Shock Response Spectrum	51
2.1. Main principles	51
2.2. Response of a linear one-degree-of-freedom system.	55
2.2.1. Shock defined by a force	55
2.2.2. Shock defined by an acceleration	56
2.2.3. Generalization	56
2.2.4. Response of a one-degree-of-freedom system to simple shocks	61
2.3. Definitions	65
2.3.1. Response spectrum	65
2.3.2. Absolute acceleration SRS	65
2.3.3. Relative displacement shock spectrum	65
2.3.4. Primary (or initial) positive SRS	66
2.3.5. Primary (or initial) negative SRS	66
2.3.6. Secondary (or residual) SRS	66
2.3.7. Positive (or maximum positive) SRS	67
2.3.8. Negative (or maximum negative) SRS	67
2.3.9. Maximax SRS	68
2.4. Standardized response spectra	69
2.4.1. Definition	69
2.4.2. Half-sine pulse	71
2.4.3. Versed sine pulse	72
2.4.4. Terminal peak sawtooth pulse	74
2.4.5. Initial peak sawtooth pulse	75
2.4.6. Square pulse	77
2.4.7. Trapezoidal pulse	77
2.5. Choice of the type of SRS	78
2.6. Comparison of the SRS of the usual simple shapes	79
2.7. SRS of a shock defined by an absolute displacement of the support.	80

2.8. Influence of the amplitude and the duration of the shock on its SRS	81
2.9. Difference between SRS and extreme response spectrum (ERS)	82
2.10. Algorithms for calculation of the SRS	82
2.11. Subroutine for the calculation of the SRS	83
2.12. Choice of the sampling frequency of the signal	86
2.13. Example of use of the SRS	90
2.14. Use of SRS for the study of systems with several degrees of freedom	92
Chapter 3. Properties of Shock Response Spectra	95
3.1. Shock response spectra domains	95
3.2. Properties of SRS at low frequencies.	96
3.2.1. General properties	96
3.2.2. Shocks with zero velocity change	96
3.2.3. Shocks with $\Delta V = 0$ and $\Delta D \neq 0$ at the end of a pulse	105
3.2.4. Shocks with $\Delta V = 0$ and $\Delta D = 0$ at the end of a pulse	108
3.2.5. Notes on residual spectrum	110
3.3. Properties of SRS at high frequencies	111
3.4. Damping influence	114
3.5. Choice of damping	114
3.6. Choice of frequency range	118
3.7. Choice of the number of points and their distribution	118
3.8. Charts	118
3.9. Relation of SRS with Fourier spectrum	120
3.9.1. Primary SRS and Fourier transform	120
3.9.2. Residual SRS and Fourier transform	122
3.9.3. Comparison of the relative severity of several shocks using their Fourier spectra and their shock response spectra.	125
3.10. Care to be taken in the calculation of the spectra	129
3.10.1. Main sources of errors	129
3.10.2. Influence of background noise of the measuring equipment	130
3.10.3. Influence of zero shift	132
3.11. Use of the SRS for pyroshocks	135
Chapter 4. Development of Shock Test Specifications	139
4.1. Introduction.	139
4.2. Simplification of the measured signal	140
4.3. Use of shock response spectra.	142
4.3.1. Synthesis of spectra	142
4.3.2. Nature of the specification	144
4.3.3. Choice of shape	144
4.3.4. Amplitude	146

4.3.5. Duration	146
4.3.6. Difficulties	150
4.4. Other methods	151
4.4.1. Use of a swept sine	152
4.4.2. Simulation of SRS using a fast swept sine	153
4.4.3. Simulation by modulated random noise.	157
4.4.4. Simulation of a shock using random vibration.	158
4.4.5. Least favorable response technique	159
4.4.6. Restitution of an SRS by a series of modulated sine pulses	160
4.5. Interest behind simulation of shocks on shaker using a shock spectrum	162
Chapter 5. Kinematics of Simple Shocks	167
5.1. Introduction.	167
5.2. Half-sine pulse	167
5.2.1. General expressions of the shock motion	167
5.2.2. Impulse mode	170
5.2.3. Impact mode.	171
5.3. Versed sine pulse	181
5.4. Square pulse	183
5.5. Terminal peak sawtooth pulse	186
5.6. Initial peak sawtooth pulse.	188
Chapter 6. Standard Shock Machines	191
6.1. Main types	191
6.2. Impact shock machines	193
6.3. High impact shock machines	203
6.3.1. Lightweight high impact shock machine	203
6.3.2. Medium weight high impact shock machine	204
6.4. Pneumatic machines.	205
6.5. Specific testing facilities	207
6.6. Programmers	208
6.6.1. Half-sine pulse	208
6.6.2. TPS shock pulse.	216
6.6.3. Square pulse – trapezoidal pulse	223
6.6.4. Universal shock programmer	224
Chapter 7. Generation of Shocks Using Shakers	233
7.1. Principle behind the generation of a signal with a simple shape versus time	233
7.2. Main advantages of the generation of shock using shakers.	234
7.3. Limitations of electrodynamic shakers.	235

7.3.1. Mechanical limitations	235
7.3.2. Electronic limitations	236
7.4. Remarks on the use of electrohydraulic shakers	237
7.5. Pre- and post-shocks	237
7.5.1. Requirements	237
7.5.2. Pre-shock or post-shock	238
7.5.3. Kinematics of the movement for symmetric pre- and post-shock	242
7.5.4. Kinematics of the movement for a pre-shock or post-shock alone	253
7.5.5. Abacuses	255
7.5.6. Influence of the shape of pre- and post-pulses	256
7.5.7. Optimized pre- and post-shocks	259
7.6. Incidence of pre- and post-shocks on the quality of simulation	264
7.6.1. General	264
7.6.2. Influence of the pre- and post-shocks on the time history response of a one- degree-of-freedom system	264
7.6.3. Incidence on the shock response spectrum	266
Chapter 8. Control of a Shaker Using a Shock Response Spectrum	271
8.1. Principle of control using a shock response spectrum	271
8.1.1. Problems	271
8.1.2. Parallel filter method.	272
8.1.3. Current numerical methods	273
8.2. Decaying sinusoid	278
8.2.1. Definition	278
8.2.2. Response spectrum	279
8.2.3. Velocity and displacement	282
8.2.4. Constitution of the total signal	283
8.2.5. Methods of signal compensation	284
8.2.6. Iterations	290
8.3. D.L. Kern and C.D. Hayes' function	292
8.3.1. Definition	292
8.3.2. Velocity and displacement	292
8.4. ZERD function.	294
8.4.1. Definition	294
8.4.2. Velocity and displacement	295
8.4.3. Comparison of ZERD waveform with standard decaying sinusoid.	297
8.4.4. Reduced response spectra	298
8.5. WAVSIN waveform	299
8.5.1. Definition	299
8.5.2. Velocity and displacement	300
8.5.3. Response of a one-degree-of-freedom system	302

8.5.4. Response spectrum	305
8.5.5. Time history synthesis from shock spectrum.	306
8.6. SHOC waveform	307
8.6.1. Definition	307
8.6.2. Velocity and displacement	310
8.6.3. Response spectrum	311
8.6.4. Time history synthesis from shock spectrum.	312
8.7. Comparison of WAVSIN, SHOC waveforms and decaying sinusoid.	313
8.8. Use of a fast swept sine.	314
8.9. Problems encountered during the synthesis of the waveforms	317
8.10. Criticism of control by SRS	319
8.11. Possible improvements	323
8.11.1. IES proposal	323
8.11.2. Specification of a complementary parameter.	324
8.11.3. Remarks on the properties of the response spectrum	329
8.12. Estimate of the feasibility of a shock specified by its SRS	329
8.12.1. C.D. Robbins and E.P. Vaughan's method	329
8.12.2. Evaluation of the necessary force, power and stroke	331
Chapter 9. Simulation of Pyroshocks	337
9.1. Simulations using pyrotechnic facilities	337
9.2. Simulation using metal to metal impact	341
9.3. Simulation using electrodynamic shakers	342
9.4. Simulation using conventional shock machines	342
Appendix: Similitude in Mechanics	345
Mechanical Shock Tests: A Brief Historical Background	349
Bibliography	351
Index	365
Summary of other Volumes in the Series.	369