Table of Contents

Preface ix

Chapter 1. Vibration Theory 1

1.1. Problem 1
- 1.1.1. Justification of tests in a mechanical environment 1
- 1.1.2. Quality of environmental tests 2
- 1.1.3. Generating sets of vibrations 2
- 1.1.4. “Shock and vibration” terminology 3
- 1.1.5. Testing methods 3
- 1.1.6. Uncertainty in measurement 3
- 1.1.7. Interlaboratory comparison and proficiency testing 4
- 1.1.8. Metrology management 4

1.2. Different types of mechanical signals 4
- 1.2.1. Overview 4
- 1.2.2. Mathematical prerequisites 5
- 1.2.3. Types of mechanical signals 13
- 1.2.4. The different types of mechanical signals – a practical approach 17

1.3. Theory of vibration – reminders 19
- 1.3.1. Fundamental law of dynamics 19
- 1.3.2. Concept of DOF 19
- 1.3.3. Systems comprising 1 DOF 20
- 1.3.4. Free oscillations of an undamped system 22
- 1.3.5. Free oscillations from an undamped system 23
- 1.3.6. Forced oscillations of a damped system 27
- 1.3.7. Systems with several coupled DOF 36

1.4. Concept of mechanical impedance 46
- 1.4.1. Overview 46
- 1.4.2. Definitions 47
- 1.4.3. Resonance and antiresonance 60
- 1.4.4. Problems with environmental laboratory simulation 66
- 1.4.5. Conclusion 68

1.5. Electromechanical analogies 68
- 1.5.1. Overview 68
- 1.5.2. Maxwell's analogy of the "force tension" type 70
- 1.5.3. Darrieus' Analogy “force intensity’ 71
- 1.5.4. Units and electrical mechanical correspondence 74
- 1.5.5. Establishment of electric diagrams 75

1.6. Analog and logic computer simulation 78
- 1.6.1. Overview 78
- 1.6.2. Structure of an analog and logic calculator 78

1.6.3. Resolution of various systems . . . 78
1.6.4. Sequential programming of analog computers . . . 79
1.7. Conclusion . . . 80

Chapter 2. Signal Analysis . . . 81
2.1. Overview . . . 81
2.1.1. Temporal or spectral form . . . 81
2.1.2. Correlation functions . . . 81
2.1.3. Probabilities . . . 82
2.1.4. Spectral analysis . . . 82
2.1.5. Notion of shock spectrum . . . 84
2.2. Spectral density of power . . . 85
2.2.1. Overview . . . 85
2.2.2. PSD Study . . . 87
2.3. FS–Fourier Integral . . . 103
2.3.1. Overview . . . 103
2.3.2. Considerations of use . . . 105
2.3.3. Analysis of the results . . . 105
2.3.4. Calculation example . . . 106

Chapter 3. Test Preparation . . . 109
3.1. Test demand analysis and associated test specifications . . . 109
3.1.1. Review of testing demand . . . 109
3.1.2. Test specifications analysis . . . 110
3.1.3. Commercial proposal or contract . . . 111
3.1.4. Order review . . . 111
3.2. Test initiation . . . 111
3.3. Test fixtures . . . 112
3.3.1. Overview . . . 112
3.3.2. Principles of construction . . . 114
3.3.3. Concepts of strenght of materials . . . 118
3.3.4. Manufacturing influence . . . 123
3.3.5. Conclusion . . . 124
3.4. Test execution . . . 125
3.5. Test reporting . . . 126

Chapter 4. Testing . . . 129
4.1. Sine vibration tests . . . 129
4.1.1. Fixed frequency testing . . . 129
4.1.2. Swept sine tests . . . 130
4.1.3. Conclusion . . . 146
4.2. Vibration testing in noise or random . . . 146
4.2.1. Overview . . . 146
4.2.2. Concepts on random functions . . . 148
4.2.3. Random vibrations . . . 153
4.3. Specific tests . . . 158

Chapter 5. Equipment Applications . . . 163
5.1. Vibration sources and effects . . . 163
5.1.1. Overview . . . 163
5.1.2. Vibration sources . . . 163

5.1.3. Vibration effects . . . 164
5.1.4. Notions of fatigue and damage due to vibrations . . . 164
5.2. Electronic equipment . . . 167
5.2.1. In land vehicles . . . 167
5.2.2. In ships and submarines . . . 168
5.2.3. In aircrafts, helicopters, missiles . . . 169
5.2.4. Conclusion . . . 170
5.3. Design of electronic equipment subjected to vibrations . . . 170
5.3.1. Operating mode . . . 170
5.3.2. Design techniques . . . 172
5.3.3. Printed circuit boards . . . 177
5.3.4. Components assembly . . . 183
5.3.5. Cases . . . 185
5.3.6. Wiring . . . 190
5.3.7. Conclusion . . . 191
5.4. Study of a particular case – example of analysis of an electronic bay . . . 191

Chapter 6. Controlling Generators of Vibrations and Shocks . . . 197

6.1. General principles . . . 197
6.2. Typical configuration of the equipment used . . . 199
6.3. Traceability of tests . . . 199
6.4. Control in sinusoidal mode . . . 200
6.4.1. Generalities . . . 200
6.4.2. Generating a signal . . . 201
6.4.3. Signal acquisition . . . 201
6.4.4. Measurements . . . 201
6.4.5. Corrections . . . 204
6.4.6. Safety devices on controllers . . . 205
6.4.7. Safety devices on the measuring channels . . . 205
6.4.8. Back-ups . . . 206
6.4.9. Deferred time . . . 206
6.5. Random control . . . 207
6.5.1. Signal generation . . . 207
6.5.2. Acquisition of measurements . . . 213
6.6. Shock and transient control . . . 215
6.6.1. Generation in temporal form . . . 215
6.6.2. Generation and control in the shock spectrum . . . 219
6.7. Combined vibrations control . . . 223
6.7.1. Overview . . . 223
6.7.2. Methods . . . 224
6.7.3. Current and emerging needs . . . 225
6.8. Control: a few essential rules . . . 227

Chapter 7. Metrology of Measurement and Testing Methods . . . 229

7.1. Introduction to accelerometer sensors . . . 229
7.1.1. Overview . . . 229
7.1.2. Principle of operation . . . 230
7.1.3. Main features . . . 232
7.1.4. Calibration of accelerometer sensors . . . 236
7.1.5. Accuracy of accelerometers . . . 238
7.1.6. Sensor installation rules . . . 238

7.2. Measurement amplifiers . . . 239
7.2.1. Overview . . . 239
7.2.2. Equivalent circuit . . . 239
7.2.3. Voltage amplifier . . . 240
7.2.4. Charge converters . . . 241
7.3. Validation and verification of the testing means . . . 245
7.4. Control of metrology in a testing laboratory . . . 246

Chapter 8. Testing Means for Vibrations . . . 253
8.1. Electrodynamic exciters . . . 253
8.1.1. Brief description of an electrodynamic exciter . . . 253
8.1.2. Impact opportunities and performance . . . 255
8.1.3. Producing an acceleration pulse on the movable table of a shaker . . . 256
8.1.4. Modeling an electrodynamic exciter . . . 261
8.1.5. Evaluation of the modeling parameters . . . 273
8.2. Hydraulic exciters . . . 281
8.2.1. Overview . . . 281
8.2.2. Principle of operation . . . 281
8.2.3. Hydraulic operation equations . . . 283
8.2.4. Use in impact tests . . . 293
8.2.5. Conclusion . . . 295

Conclusion . . . 297

Appendices . . . 299

Appendix A. Fundamental Laws of Hydraulics – Application to the Study of Hydraulic Vibration Generators . . . 301

Appendix B. Study of the Basic Model with Damping . . . 315

Appendix C. Natural Frequencies of 1,6 mm Thick Cards Equipped with Stiffeners . . . 319

Appendix D. Resonance Frequencies of IC Cards Depending on the Mounting Conditions . . . 323

Appendix E. Concept of Cepstrum . . . 327

Appendix F. Tolerances on Vibration Fixtures . . . 329

Appendix G. Determining Measurement Uncertainty – Example of a Calibration Method for Accelerometer Sensors . . . 331

Appendix H. Example of MPE Allowances . . . 361

Appendix I. List of Testing Methods in Standard Environments . . . 367

Appendix J. Control Strategies – Simplified Summary . . . 379

Appendix K. Mathematical Elements Involved in the Estimation of Uncertainties (Supplementary) . . . 385

Bibliography . . . 403

Index . . . 407