

Good Vibrations

1. Introduction	9
1.1. Definition	10
1.2. History	11
1.3. Development Process.....	12
1.4. Frequency	13
1.5. Vibration.....	14
1.6. Linear Systems.....	18
2. Fatigue Break Down	21
2.1. Woehler	21
2.1.1. History.....	21
2.1.2. The Wöhler Curve.....	23
2.2. Fatigue Damage.....	26
2.3. Accelerated Test.....	29
3. The Vibration Test System	35
4. Accelerometers.....	37
4.1. Type of Sensors	37
4.1.1. Contactless Sensors	37
4.1.2. Contact Sensors.....	39
4.1.3. Piezoelectric Accelerometer	39
4.1.3.1. Piezoelectric Quartz or Ceramic:	40
4.1.3.2. Frequency Response:.....	41
4.1.3.3. Discharge Time Constant	42
4.1.3.4. Temperature:	43
4.1.3.5. Linearity:.....	44
4.1.3.6. Base Strain Sensitivity:	44
4.1.3.7. Transverse Sensitivity:.....	44
4.1.3.8. Discharge Time Constant	45
4.1.3.9. Electrical Connection:.....	45
4.1.3.10. Mounting Base:	46
4.1.3.11. Protection Class (Housing):	46
4.1.4. Types of Piezoelectric Accelerometers	46
4.1.4.1. Compression type:	47
4.1.4.2. Shear type:.....	47
4.1.4.3. Flexural or Bending type:	48
4.1.4.4. Overview and Comparison:.....	49
4.1.5. Force-Balance Servo Accelerometer	49
4.1.6. Capacitive Accelerometer.....	50
4.1.7. MEMS	52
4.1.7.1. Servo MEMS Accelerometers.....	54
4.1.7.2. Resistive Accelerometer	55
4.1.7.3. MEMS Example.....	57
5. Instrumentation and Measurement Amplifier.....	59
5.1. Charge Amplifier	59
5.1.1. Single Channel Charge Amplifier	59
5.1.2. Low Pass Filter and High Pass Filter	60

Good Vibrations

5.1.3.	Calibration Factor and Output Amplifier.....	60
5.1.4.	Multi-Channel Solutions.....	60
5.2.	Detailed Discussion	60
5.3.	IEPE, CCLD or ICP® Accelerometers.....	63
5.4.	Charge-to-IEPE Converter.....	66
5.5.	Noise.....	67
5.6.	TEDS	68
6.	Analog to Digital Conversion	70
6.1.	Analog Signals and Digital Signals – Sampling Frequency.....	70
6.2.	Analog to Digital Conversion.....	72
7.	Time Domain and Frequency Domain	74
7.1.	Why the Frequency Domain.....	74
7.2.	Fourier and the Bode Plot	75
7.3.	Reconstruction of the Time Signal	77
7.4.	Frequency Resolution.....	79
7.5.	Properties of the Fourier Transform.....	80
7.5.1.	Linearity.....	81
7.5.2.	Convolution	81
7.6.	DFT and FFT	82
7.7.	Aliasing	83
7.8.	Time Window.....	86
7.9.	Conclusion of the FFT Process.....	89
8.	Vibration Control	91
8.1.	The Vibration Controller	91
8.1.1.	The Seventies	91
8.1.2.	The Eighties	93
8.1.3.	The PC Generation	93
8.2.	Control Strategy and Transfer Function	95
8.2.1.	Self-Check and Start-up.....	97
8.2.2.	Run Schedule	99
8.2.3.	Programming the Controller.....	100
8.2.4.	Dynamic Range.....	102
8.2.5.	Conclusion.....	105
8.3.	Random	105
8.3.1.	Amplitude Distribution	106
8.3.2.	Sigma Clipping	108
8.3.3.	Power Spectral Density and DOF	110
8.3.4.	Oversampling and Overlap Processing.....	115
8.3.5.	Calculation of “g _{RMS} ”	117
8.3.6.	Calculation of the maximum Displacement	121
8.3.7.	Control or Reference Channel.....	122
8.3.8.	Kurtosis	123
8.4.	Sine	126
8.4.1.	Sine Reference Profile	126
8.4.2.	Sweep Rate and Compression Rate	130
8.4.3.	Control Signal – Tracking Filter	132
8.4.4.	COLA Output.....	134

Good Vibrations

8.4.5.	<i>Notching or Limit Channels</i>	136
8.4.6.	<i>Fatigue Cycles</i>	137
8.4.7.	<i>Resonance Search and Dwell</i>	139
8.4.8.	<i>Stepped Sine or Dwell Series</i>	145
8.4.9.	<i>Multi-Sine</i>	145
8.4.9.1.	<i>Delayed Sine Tones</i>	146
8.4.9.2.	<i>Multiple Intervals</i>	146
8.4.9.3.	<i>Multi-Sine Justification</i>	148
8.5.	Shock	150
8.5.1.	<i>Acceleration, Velocity and Displacement</i>	151
8.5.2.	<i>Compensation Technique</i>	152
8.5.3.	<i>Frequency Bandwidth</i>	155
8.5.4.	<i>Classical Shocks</i>	158
8.5.5.	<i>Functional Test</i>	159
8.5.6.	<i>Mechanical Shock Test Machines</i>	161
8.5.7.	<i>Drop Tests</i>	163
8.6	<i>Time Waveform Replication</i>	165
8.6.1	<i>Resampling</i>	165
8.6.2	<i>Filtering</i>	169
8.6.2.1	<i>High Pass Filter and Low Pass Filter</i>	169
8.6.2.2	<i>Time Window and Filtering</i>	170
8.6.2.3	<i>Trend Removal</i>	174
8.6.2.4	<i>Transient Duration</i>	174
8.6.3	<i>Control Strategy</i>	176
8.6.3.1	<i>On-Line Control</i>	176
8.6.3.2	<i>Off-Line Control</i>	178
8.7	<i>SRS – Shock Response Spectrum</i>	179
8.7.1	<i>Shock Damage</i>	179
8.7.2	<i>SRS Technique</i>	180
8.7.3	<i>SR Analysis</i>	183
8.7.4	<i>SR Synthesis</i>	186
8.8	<i>PVSRS – Pseudo Velocity Shock Response Spectrum</i>	189
8.8.1	<i>Shock Damage and Pseudo Velocity</i>	190
8.8.2	<i>PVSRS and the 4C-plot</i>	192
8.8.3	<i>Shock Response and Shock Duration</i>	196
9.	<i>Power Amplifier</i>	199
9.1.	<i>Input Stage</i>	199
9.2.	<i>Analog Power Amplifier</i>	202
9.3.	<i>Switched Mode Power Amplifier</i>	204
9.4.	<i>Control Functions and Connections</i>	208
10.	<i>Electrodynamic Shaker</i>	212
10.1.	<i>Classification</i>	212
10.2.	<i>Principle of Operation</i>	213
10.3.	<i>Construction</i>	216
10.3.1.	<i>Generalized Model</i>	216
10.3.2.	<i>Armature Guidance and Unbalance</i>	218
10.3.3.	<i>Damping</i>	222

Good Vibrations

10.3.4.	<i>Degaussing Coil</i>	224
10.3.5.	<i>Armature size and Inserts Pattern</i>	224
10.4.	Performance Chart.....	227
10.5.	Read the Specifications.....	229
10.6.	Lifetime of the Shaker Armature.....	234
10.7.	Energy Consumption and Total efficiency	235
10.8.	Shakers with Permanent Magnet	235
10.9.	Mid-Range Shakers with Air Cooling.....	236
10.10.	High-Range Shakers with Water Cooling.....	238
10.11.	Special Solutions.....	239
10.11.1.	<i>Long Stroke Shaker</i>	239
10.11.2.	<i>Induct-A-Ring</i>	240
10.11.3.	<i>Eco Shaker</i>	241
11.	<i>Servo Hydraulic Shaker</i>	247
11.1.	Principle of Operation	247
11.2.	Set-up of a Servo Hydraulic Cylinder	249
11.3.	Control Loops.....	250
11.4.	Oil Quality Inspection	251
11.5.	Compressor Unit	252
11.6.	High Frequency Servo Hydraulic Shaker	253
12.	<i>Slip Table</i>	256
12.1.	Introduction	256
12.2.	Classical Slip Table - Construction.....	257
12.3.	Moments of Inertia.....	258
12.4.	Hydrostatic Bearings.....	260
12.5.	Care of the Slip Table	264
12.6.	Slip Table with a Climatic Chamber	265
13.	<i>Head Expanders and Test Fixtures</i>	266
13.1.	<i>Head Expanders</i>	266
13.2.	Requirements.....	266
13.3.	Head Expander - Resonances.....	266
13.4.	Material Choice, Steel - Aluminum - Magnesium	268
13.5.	Breakdown Torque and Support	271
13.6.	<i>Fixtures</i>	276
13.7.	Fixing, Check and Reference Points.....	276
13.8.	Test Axes.....	277
13.9.	Standard Fixtures.....	278
13.10.	L-Type.....	279
13.11.	T-Type.....	280
13.12.	Cube.....	281
13.13.	Alternative Use of the L- and T-type Fixture	283
13.14.	Material Choice and Making	284
13.14.1.	<i>Milling</i>	285
13.14.2.	<i>Welding</i>	288
13.14.3.	<i>Bolting</i>	292
13.14.4.	<i>Wood, epoxy a.o.</i>	309
13.15.	Functional Testing	310

Good Vibrations

14. Multi-Shaker Systems	312
14.1. Theory.....	312
14.2. Force Phase Control	315
14.3. Force Phase Control Set-up.....	317
14.4. Multiple Degrees of Freedom	318
14.5. Three Axis Translation	318
14.6. 6 Degrees of Freedom	319
14.7. Mechanical Coupling	320
14.8. Control Strategy.....	324
15. Installation	327
15.1. Vibrational Isolation	327
15.2. Acoustic Isolation	330
15.3. Cooling.....	334
15.4. Preparation and Floor Plan.....	337
15.5. Electrical Installation	339
15.5.1. Electrical Power and Earthing	339
15.5.2. Signal Transmission.....	342
15.6. Other Requirements.....	348
15.7. Surveillance.....	349
15.8. Acceptance Test.....	350
16. Combined Environmental Test Systems.....	353
16.1. Functional Interface	353
16.2. Electrical Interface.....	356
16.3. Mechanical Interface (Thermal Barrier)	357
17. Maintenance and Calibration	362
17.1. Maintenance.....	362
17.2. Calibration	365
17.2.1. Calibration - Definitions	366
17.2.2. Standards and Standardization Committees.....	371
17.2.3. Calibration Template	374
17.2.4. Accelerometers.....	374
17.2.5. Measurement Amplifier	382
17.2.6. Vibration Control System.....	383
17.3. Measurement and Control Accuracy	384