

## Index

- accuracy grade, 181, 254
- accuracy, of
  - computation, 65, 68
  - design procedure, 71
  - finite element analysis, 72, 149
  - positioning, 89, 94 (*see also* accuracy of position control)
  - solution, 60, 63
- activation of the mechanisms at near-zero frequencies, 167, 195
- agricultural machines,
  - harvester combines, 266, 269–270
- algorithms, of
  - air-damping control, 140, 185–188, 225
  - position control, 189–192
  - stiffness control, 25, 175, 181
- antifriction composites
  - based on microplasma oxidation, 164
  - with perfluorine compounds, 163, 165
- atlases, of
  - bogie suspensions, 109, 111
  - function-generating mechanisms, 106, 108, 111
  - seat suspensions, 103, 106, 108
- beam-shaped elastic structures
  - bar systems, 29, 37
  - slender beams, 29, 36, 41
- bending moments, distribution, 68
- bending stiffness, 288
- boundary conditions, 68, 75
  - fixed, 46
  - hinged, 43–45
  - movable end-support, 218
- buckling load, 27, 42, 75–77 (*see also* critical force)
  - first or top, 47, 75
  - second or bottom, 47, 75
- buckling problem, 37
- candidates, for
  - parametric elements with negative stiffness in large, 48–49, 53, 62
  - function-generating mechanisms with no undesirable structural redundancy, 99, 101–102, 108, 111 (*see also* optimally structured FGMs)
- chaotic vibrations' study, 116–117, 124
- qualitative methods of detecting and measuring chaos, 117
  - bifurcation diagrams, 120
  - bifurcation maps, 121
  - Fourier spectra, 121
  - Poincaré sections and maps, 118
  - time charts and phase trajectories, 117
- quantitative methods of detecting and measuring chaos, 122
  - Lyapunov exponents, 125, 141
  - fractal dimensions, 124
- stability conditions for mechanisms with negative/quasi-zero stiffness, of the
  - first type, 127–131
  - second type, 131–133
- stable motion of active suspensions with the RMs, 133–141
- clearances in kinematic pairs, 153–159
- compactness of mechanisms with negative stiffness, 254
- composite parametric elements with negative/quasi-zero stiffness, 62, 210, 232, 285–291
  - based on carbon fibers, 288–290
- computer-aided test systems, 203, 221–224
  - vibration measuring equipment, 268
  - vibration simulating equipment
    - electrodynamical exciters, 220–221
    - electrohydraulic exciters, 220–221
    - fatigue testing machines, 204, 210
    - pneumo-mechanical vibrating tables and platforms, 222
- construction equipment, 2
  - Caterpillar mini excavators, 272–273
  - wheel short-chassis cranes, 270–272
- control algorithms
  - adaptive control of steady-state vibration motion, 188–191, 193 (*see also* invariant control)
  - stabilization of transient vibration motion, 190–191, 193

- control objects, 174  
 control parameters  
   acceleration, 4–6, 223–225  
   air pressure, 175–181  
   damping, 185–188, 196  
   relative position, 186–192, 196, 246, 249  
   relative velocity, 189–192  
   stiffness, 175–177, 181–185  
 criteria, of  
   quality, 4, 25, 100–101, 227–228, 240–242, 250  
   similarity, 281–282  
 stability, in  
   chaotic motion, 128–141  
   steady-state vibration motion, 5, 185, 191, 195, 250  
   transient vibration motion, 185–188, 251  
 cross forces, distribution, 152–153  
 cross section of thin-walled structures, 60, 73, 163, 286–288  
 cylindrical bending of thin-walled structures, 53, 60, 148, 286–288
- dampers (*see also* damping mechanisms)  
 external, fluid, 20, 103, 109, 135, 168, 195, 207, 230, 242, 252, 278  
 electro-rheological, 249–250  
 magneto-rheological, 249–250
- damping  
 air, with variable structure, 185–188  
 critical, 139, 153, 160  
 slip, minimization, 160, 164  
 structural, measuring and reducing, 146–148, 162–163, 212–213
- damping forces, variability, 20, 130, 177, 214, 251
- deformation problem under postbuckling, 52–55 (*see also* geometrically nonlinear deformation)
- degree-of-freedom  
 parametric, xvii, 95 (*see also* local mobility)  
 structural, xviii, 1, 85, 95 (*see also* mobility)
- design models  
 generic, 40  
 numerical, 68–71, 132
- design parameters of mechanisms with negative/quasi-zero stiffness, 66–81, 212
- development test, features in  
 dynamics, 14, 20, 230–232  
 statics, 205, 208–217, 287–291  
 the field, 10, 16, 268
- dimensioning of vibration protection mechanisms  
 with negative/quasi-zero stiffness, 36–40, 71, 77–81, 253–258
- dimensions, of  
 parametric elements with negative/quasi-zero stiffness, 28, 66, 71  
 mechanisms with negative stiffness, 29, 78, 267, 274, 278–283  
 gears, 253, 257–258  
 duality of the mechanism performance, 75–77
- effect, of  
 magnetic levitation, 13–14  
 negative stiffness, xvii, 25–28, 32, 41, 47, 68–70, 74–78, 126–136, 147, 168, 183–184, 205, 211–213, 216–217, 245, 289–290  
 quasi-zero stiffness, 25, 28, 32, 41, 136, 169, 217, 241, 289–290
- effective area, of  
 negative/quasi-zero stiffness control, 136, 140, 168–169, 212–213  
 pneumatic control system inlet/outlet orifices, 180, 188, 191–193, 243–245
- elastic limits, 67, 279
- elastic responses, operating modes, 26–28, 33, 47, 75, 168–169, 182–183, 207, 215–217, 241, 245, 279, 283–284, 287–290 (*see also* force-displacement curves)
- elasticity theory, 57–61, 146
- enumeration of a mechanism structure, 86, 91, 95–97, 101–113
- ergonomics of seats, 267, 272, 274, 280
- equations, of  
 air balance, 178–181  
 compatibility, 58–59  
 equilibrium, 59, 148–149  
 state, 59  
 vibration motion, 127–129, 140, 160, 178–179
- equilibrium  
 stable, 132, 134–136, 138, 141  
 unstable, 128–133, 138
- failures of mechanism performance, structural sources, 89–94
- fast Fourier Transform, 5 (*see also* FFT)
- fatigue testing machines, 204, 210
- finite element analysis, methods, 56, 149, 212, 287 (*see also* FE-analysis)
- finite element models (*see also* FEs)  
 basic, 62–65, 148, 152  
 gap (*see also* additional FEs)  
 node-to-line, 148–152  
 node-to-node, 148–152
- force closure of mechanisms' kinematic chains, 209, 254, 267
- form closure of mechanisms' kinematic chains, 209, 254, 267
- fractal, 119  
 dimension, 124  
 structure, 122–123
- frequency ranges of vibration  
 infra, xvii, 1–4, 208, 225, 230, 232

- frequency ranges of vibration (cont.)  
 low, xvii, 1–4, 225, 232, 273  
 middle, 1–4, 273  
 near-zero, xvii, 195–196
- frequency responses of transport vibration  
 protection systems, 8–18, 124, 195, 225,  
 230, 232, 242, 252
- friction  
 Coulomb, 130, 160–161  
 rolling, 258  
 sliding  
 extremely small, 164–165, 168, 258–259  
 lubricated, 163–166  
 viscous, 251
- function-generating mechanisms  
 atlases, 97, 103, 106–109, 111  
 methods of the type and number synthesis/  
 analysis, 29–30, 86–89
- fundamental design relations, 47–48, 71, 279
- gear ratio, 176, 208, 256
- gearings, spatial, 105–107, 213, 254–256
- gears  
 bevel, 108, 111, 167, 176, 253–255  
 mini-gears, 255–259 (*see also* mini-trains), with  
 screw-nut mechanism, 182–183  
 worm mechanism, 246–247
- generic properties of parametric elements with  
 negative/quasi-zero stiffness, 53
- generic models of parametric elements with  
 negative/quasi-zero stiffness, 41, 49, 53
- geometrically nonlinear problem of postbuckling,  
 52–55, 146
- gravity parameters, 1, 38
- hardening, of  
 gearings, 258–259  
 guiderails, 164–165, 258–259  
 slide bearings, 164–165, 258–259
- harmony operation of mechanisms with positive and  
 negative stiffness, 25, 252
- health 7, 13–16, 275, 277 (*see also* hygienic)  
 vibration standards, general and industrial
- heavy damped suspensions as vibration amplifiers,  
 8, 10–13, 20, 35, 208, 230, 232, 242,  
 248–252
- heavy trucks, inside actual vibrations and vibration  
 protection, 17–20, 276–277
- helicopters, inside actual vibrations and vibration  
 protection, 14–17, 273–275
- Hermitean family polynomials, 63, 149
- holographic interferometry, 218–219
- human operators as objects of the infra-low  
 vibration protection, xviii, 1–4, 101–103,  
 190–191, 195–196, 264–265,  
 269–278
- humans' safety and comfort providing by the  
 vibration protection systems, in  
 construction and field works, 270–273  
 flights, 273–275  
 ridings, 277–278
- idle degree-of-freedom, 184 (*see also* local DOF)
- infra-low-frequency vibrations most harmful and  
 gangrenous for humans and engineering,  
 2–4, 7–15
- infra-low-frequency vibration affecting humans  
 inside vehicles, 7–11, 16–18, 270–278  
 outside vehicles, 7, 8, 13
- instability of vibration motion  
 global, 40, 88  
 local, 40, 88–89
- invariance, of  
 design parameters, 88, 91, 281  
 mechanism characteristics, 74–76, 95, 100, 156,  
 168, 190–191
- iterative procedures in solving the postbuckling  
 problem, 54–57, 146
- joining the redundant mechanisms to vibration  
 protection mechanisms, 87–89, 95, 106,  
 111, 167–168, 209, 253–255
- joints, movable, 85–87, 91 (*see also* kinematic  
 pairs)
- kinematic chains  
 active, 91, 98 (*see also* active KC or KC with  
 actuator)  
 closed, 85  
 main, 29–30, 85  
 open, 85, 90–91  
 passive, 92 (*see also* passive KC)  
 redundant, 29–30, 85, 98, 100
- kinematic pairs (*see also* movable joints)  
 active, 90, 93 (*see also* active KP)  
 higher  
 centroid, 108, 111  
 lower  
 prismatic, 103, 105, 109, 111 (*see also* prism)  
 revolute, 97, 99, 103, 105, 108, 109,  
 111  
 spherical, 108, 109, 111  
 passive, 90, 97 (*see also* passive KP)
- kinematic structure  
 in-parallel, 90  
 redundant, 26, 29, 97
- labeled graphs, 101–103, 106, 108–109, 111
- land vehicles, inside actual vibrations and vibration  
 protection, 17–20, in  
 electromotor buses, 276–277  
 heavy trucks, 18, 276

- linear thin-shell theory,
  - key hypothesizes, 54, 58
- link mechanisms with negative/quasi-zero stiffness, 29, 37, 88, 105, 108, 111, 267, 274, 280
- local
  - buckling, 27
  - mobility, 35, 95, 103 (*see also* local DOF)
- low-cycle loading/unloading of mechanisms with negative/quasi-zero stiffness, 204–205, 210
- Lyapunov exponents,
  - largest, 125–126
  - maps, 131, 134, 138 (*see also* chaotic diagrams)
- machines
  - suspended, 275–278
  - unsuspended, 269–275
- man-machine systems, 1–4
- Maxwell-Betti theorem, 59
- mechanical  $Q$ -factor, 5, 96, 272
- mechanisms with negative/quasi-zero stiffness,
  - characteristics
    - force-displacement, 26–28, 33, 130, 133, 136, 140, 147, 151, 163, 168–169, 205, 211–213, 217, 245, 279–284, 287–290 (*see also* elastic response)
  - geometrical, 36–40, 66, 77–81, 97, 278–282
  - kinematic, 66, 69–72, 212
    - phase portrait, 130, 133, 136
    - trajectories of vibration motion, 118–119
- damping control
  - critical, 153, 169 (*see also* at lock-up behavior)
  - light, with variable structure, 138, 187, 192
  - slip 160, 164, 169 (*see also* sliding)
  - structural, 162–163, 212–213
- motion control, 186–192
  - criteria, 185, 188, 196–197
  - features, 173
  - methods, of
    - adaptive control, 186–191
    - stabilization, 187–189, 191–192
  - stability conditions, 133, 138–141
  - stiffness-displacement, 183
  - stiffness control, xvii, 25–27, 175–177, 183–185, 216–217, 243–245
    - minimization of positive stiffness, 181–185, 216, 243 (*see also* quasi-zero stiffness)
  - structural conditions, 85
- mechanisms with negative/quasi-zero stiffness,
  - types
    - link, 29, 88, 105, 111, 128
    - cam, 30, 38–39, 89, 105
    - electromagnetic, 14, 28, 30, 39–40
    - membrane forces, distribution, 58–60
    - microarc oxidation, 164–165, 257–259
  - models of stress-strain state of parametric elements with negative/quasi-zero stiffness, 55, 73–76, 287
  - nanopowders use, 164–165
  - near-zero frequency vibration motion, 160–162, 232
  - negative stiffness,
    - in rotation, 26, 30, 105, 108, 111, 128–129
    - in translation, 26–30, 88–89, 105, 108, 111
  - neutral
    - axis, 42, 148
    - position, 33, 37, 191
  - node displacements, equations, 54–56, 63–65
  - Novozhilov, theory of the shells, 57–60
  - number synthesis of a mechanism, 85, 91, 97, 101, 104–105, 108, 110–111 (*see also* enumeration of the mechanisms)
- objects of transport infrastructure, 13–14, 281–283
- overall dimensions of the vibration protection mechanisms with negative/quasi-zero stiffness, 29–30, 78, 98, 209, 254, 267, 274, 280, 283–284, 290
- packaging of parametric elements with negative/quasi-zero stiffness, 62, 73
- parametric elements, load-bearing,
  - selection of type, 181–182, 207–208, 238–242
- path-linearization, 77–78, 168, 183, 217, 290
- payload capacity of vibration isolating mechanisms, 168, 207, 217
- perfluorine compounds, multilayered and incompressible, 163–166
- performance of vibration protection mechanisms with negative/quasi-zero stiffness
  - degradation, sources and reasons, 33, 90–93
  - duality, 75–77
  - failures, 39, 89, 94
  - inversion, 26–27, 140
  - loss, sources and reasons, 94
  - sensitivity to parameter change, 71–76, 125, 211
- phase
  - portrait, 130, 133, 136
  - trajectory, 118–120
- Poisson's ratio, 48, 59, 286, 288
- Poincare sections and maps of a vibration motion, 118–120, 134, 139
- potential energy of elastic deformation, 56–63, 146
- postbuckling
  - in large, 47, 53, 75–78, 105, 108, 111, 289
  - in small, 28, 33, 36–40, 76, 88–89, 105, 111, 289
- precompressed parametric elements of the mechanisms with negative/quasi-zero stiffness, 29–30, 41, 53, 128, 210 (*see also* springs)
- prototypes of mechanisms with quasi-zero stiffness, 14, 28–30, 73, 167, 209, 254, 280

- quality of vibration protection systems criteria, 4–6, 100, 227–228
  - absolute effectiveness, 227, 242, 250
  - crest factor, 5, 235, 250–251
  - relative effectiveness, 195, 227–230
  - transmissibility, 5, 167, 227, 230, 232, 250, 268
- quasi-zero stiffness
  - in rotation, 25–26, 30, 111
  - in translation, 14, 25–30, 88–89, 108, 111, 128
- railroad vibration protection systems with negative/quasi-zero stiffness
  - engineer seats, 30, 280
  - infrastructural objects, floating track bed elements, 284
  - rolling stock, regular, cars and locomotives, 29, 111, 283
  - rolling stock, high-speed, maglev, 14, 111
- redundant
  - constrains, structural, 85–87, 95, 104, 105, 108, 110–111 (*see also* RCs)
  - kinematic chains, xviii, 29–30, 85, 88–89, 98–99, 111 (*see also* RKCs)
  - kinematic pairs, 85, 95, 103–105, 110–111 (*see also* redundant KPs)
  - mechanisms with negative stiffness, xviii, 96, 105–106, 108, 111, 281–283 (*see also* RMs)
    - first type, in translation, 126–128
    - second type, in rotation, 126–128
  - parametric elements, xviii, 96, 99, 101
- relative
  - damping ratio, 5, 129, 138, 166, 203, 208, 217
  - displacements, 187–189, 191–192, 246
  - velocities, 187–189, 192
- resonance amplifiers, 20, 33, 35, 232, 242, 252
- Reuleaux definition for coupling, 101
- ride comfort conditions, 5, 9, 189, 192, 268, 277
- rigid loop, 112, 156 (*see also* motionless structure)
- rod-shaped structures with negative/quasi-zero stiffness, 29, 88–89, 105, 111, 128
- seat suspensions, type selection, 20, 103, 106, 206–209, 267, 280
- selection of accelerometers, 223, 247
- sensitivity to the parameters change, 71–76, 212–213
- shape function formulation, 43–47, 54, 60–61, 149
- shear buckling, 28, 244–245
- sign-changing stiffness, xvii, 25–28, 33, 47, 88–89
- similarity criteria for mechanisms with negative stiffness, 281
- spring materials
  - nonmetal composites, 210, 287–288
  - rubbers, 28, 241
  - rubber-metals, 28–30, 241
  - spring steels, 29, 163, 210, 219, 241, 287
  - wire ropes, 29
- springs with negative/quasi-zero stiffness, shapes
  - air-bags, rodless, 28, 174, 242
  - bar systems, 29
  - elastic rods, 28
  - electromagnet sets, 14, 28, 30
  - slender beams, 28, 29, 41
  - thin plate sets, 49, 53, 73
  - thin shallow shells, 53
- sprung mass, 3, 160, 179 (*see also* suspended mass)
- stability of motion of mechanisms with negative/quasi-zero stiffness
  - at nearly-zero frequencies, 133, 162
  - under minimal damping, 138, 141, 162, 185, 192
- static-geometric analogy, 60
- steady-state vibration motion, 195, 225, 230, 232
- stiffness control methods, 25–28, 41, 175, 243–245
- stiffness matrix, 56, 64, 146
- strain energy, 56–61, 63, 146
- stress maximum in parametric elements with negative/quasi-zero stiffness, 48, 67–68, 74–76, 78, 150–151, 163, 279, 283–284, 287
- structural
  - complexity, 102, 106, 108, 111
  - conditions of a mechanism, 85
  - damping, 146–147, 163, 212–213
  - elements, 86, 88–89, 103, 105–106, 108–109, 111
    - fixed, 29, 30, 103, 105, 108
    - input, 29, 30, 88–89, 103, 105, 108, 111
    - intermediate, 88–89, 103, 105, 108–109, 111
    - movable, 29, 30
    - output, 103, 105–106, 108–109, 111
    - real, 153–154
    - virtual, 153–154
  - formulae, 91, 95, 103 (*see also* structural equations)
  - identity, 100–101
  - invariance, 100, 156
  - numbers, 85, 91, 97, 101, 104–105, 108, 110–111
  - redundancy, xviii, 85, 96–97, 101, 104–106, 110
    - undesirable, 85, 95, 103
  - synthesis, methods, 86, 93, 101 (*see also* structural design)
- suspension end-stops, 215–216, 249
- suspensions with negative/quasi-zero stiffness, for
  - cabin mountings, 78
  - cargo containers, 78, 259
  - measuring instrument platforms and tables, 29
  - railroad floating track bed elements, 14, 284
  - regular and high-speed railroad cars and locomotives, 14, 29, 111, 283
  - seats for human operators, staff and passengers, of
    - caterpillar excavators, 78, 108, 209, 267
    - city buses, 78, 108, 209, 267
    - harvester combines, 78, 108, 209, 267

- heavy trucks, 78, 108, 209, 267
- helicopters, 108, 209, 267
- railroad cars and locomotives, 30, 78, 108, 209, 267, 280
- wheel cranes, 78, 108, 209, 267
- vehicle bodies, 78 (*see also* chassis)
- suspension parametric control, methods
  - active, 14, 167, 184, 193, 209, 222, 267
  - passive, 28–30, 209, 267, 274, 280
  - semiactive, 249
- suspensions softening, other methods
  - direct, 242–245
  - with no elastic elements, 245–248
- suspensions, types
  - combined, 11, 109, 111 (*see also* hybrid)
  - electromagnetic, 14, 30
  - mechanical, 29–30, 111, 209, 267, 274, 280, 284
  - pneumatic, 106, 167, 209, 222, 242, 267
- synthesis of mechanisms
  - geometrical, 66–67, 71, 77 (*see also* dimensioning)
  - dynamic, 97, 129, 140, 160–162, 178–180
  - kinematic, 154–159, 282
  - number, 91, 97, 101, 105, 108, 111
  - type, 29–30, 86–89, 97, 105–106, 108, 111, 209
- tensor equations, 57–60
- test conditions
  - city streets and motor company testing areas, 275
  - construction works, 270–272
  - farm operations, 269
  - helicopter flights, 273–274
  - lab development, 208, 216, 218, 228
- test equipment
  - general-purpose, 203–204, 210, 221, 268 (*see also* standard)
  - nonstandard, 164, 210, 221–222, 268
- thickness of thin-walled structures postbuckled, 48, 59, 66, 73, 149, 288
- thin-walled elastic structures under postbuckling
  - approximation method, 54–55
  - fundamental design relations, 48, 71, 279
  - generic models
    - thin plates, 49, 53, 62–65, 73, 128, 148, 286
    - packaging, 49, 62, 73, 148
    - lamination, 62, 73, 128
    - shallow cylindrical shells, 48, 53
    - shallow spherical shells, 53
- time history, 118, 225
- transfer functions, 25, 121, 176, 194, 213, 280–281
- transverse-longitudinal bending of parametric elements with negative/quasi-zero stiffness, 41
- type diagrams of mechanisms, 29–30, 88–90, 97, 103, 105, 108–109, 111, 284
- undamped systems, 5 (*see also* undamped VPS)
- unsprung mass, 3 (*see also* unsuspended parts)
- unsuspended vehicles, 77, 269
- urban electric buses, 276–278 (*see also* trolley buses)
- variable air-damping, 138, 177, 187, 192, 196, 242
- vibration dose value, 6
- vibration excitation, computer-aided equipment
  - electrodynamic exciters, 221–222 (*see also* EDEs)
  - electrohydraulic exciters, 221–222 (*see also* EHEs)
  - pneumo-mechanical exciters, 222
- vibration exposure time, 6
- vibration limits, 7–13, 16, 33, 275–277
- vibration measured parameters
  - relative accelerations, 225
  - relative displacements, 187–192, 246
  - relative velocities, 187–189, 192
- vibration measurement systems
  - automotive, one/two-channel, 268
  - stationary, multi-channel, 268
- vibration motion, types
  - chaotic, 116–118, 124 (*see also* chaotic vibration)
  - deterministic, 118, 124
- vibration protection mechanisms, with negative/quasi-zero stiffness
  - selection of type, 104–106, 126–128
- vibration protection, methods
  - external heavy damping, 248–252
  - structural damping, 146–147, 163, 212, 217
  - vibration absorbing, 15–17, 242
  - vibration isolation, xviii, 21
- working travel with negative/quasi-zero stiffness
  - effective, 27–28, 33, 40, 168, 184, 212–213, 287, 290 (*see also* effective area)
  - total, 26–28, 33, 47, 68, 74–78, 130, 133, 136, 140, 147, 151, 163, 168, 183, 184, 211–213, 217, 245, 279, 283, 284, 287, 289, 290
- Young's modulus, 48, 59, 149, 286–288