

## LISTING OF COMPUTER PROGRAMS

### FIRST PART. TRACK AND TRAIN DYNAMICS

N°	Prog.	Page
1	1.1	Matlab. Damped vibrations. .... 38
2	1.2	Matlab. Beating. .... 42
3	1.3	Matlab. Impulse response of a linear system. .... 45
4	1.4	Matlab. Longitudinal profile used as example. .... 49
5	1.5	Visual C++. Movement of one mass running on the longitudinal profile. No damping. .... 52
6	1.6	Matlab. Movement of one mass. Finite differences, Visual C++. .... 54
7	1.7	Matlab. One mass, ode 45 routines. No damping. .... 57
8	1.8	Simulink. One mass, no damping. .... 60
9	1.9	Matlab. Graph of the Simulink output. .... 61
10	1.10	Matlab. System response, impulse and step functions. .... 64
11	1.11	Matlab. One mass movement. Laplace transform. Command "lsim" for linear systems. .... 66
12	1.12	Matlab. One mass movement. State space, direct solution with Matlab. .... 73
13	1.13	Matlab. One mass movement. State space solution, command lsim. .... 76
14	1.14	Matlab. Static and dynamic forces on the track. .... 80
15	1.15	Matlab. Examples of differentiation and integration in Matlab of a longitudinal profile. .... 80
16	1.16	Matlab. Exponential longitudinal profile as an example. .... 82
17	1.17	Matlab. One mass-spring-damper system. Movement with ode45 routines. .... 85
18	1.18	Simulink. One mass-spring-damper system. Movement with Simulink . .... 88
19	1.19	Matlab. One mass-spring-damper system. Movement with Laplace transform and lsim. .... 89
20	1.20	Matlab. Simulink input for the transfer function. .... 90
21	1.21	Simulink. One mass-spring-damper system. Movement with Laplace transform. .... 91
22	1.22	Matlab. Processing of Simulink output. .... 91
23	1.23	Visual C++. One mass-spring-damper system. Movement with state space equation. .... 93
24	1.24	Matlab. Processing of Visual C++ output. .... 97
25	1.25	Matlab. One mass-spring-damper system. Movement with state space direct solution. .... 98
26	1.26	Matlab. Static and dynamic forces on the track. .... 100
27	1.27	Matlab. Mass oscillations, frequency of the system and excitation frequency. .... 103
28	2.1	Visual C++. Two masses system with springs and dampers. Finite differences solution. .... 114
29	2.2	Matlab. Processing of the Visual C++ output. .... 116
30	2.3	Matlab. Two masses system. Finite differences solution, iterative. .... 118
31	2.4	Visual C++. Two masses system. State space solution. .... 122
32	2.5	Matlab. Processing of Visual C++ output. .... 124
33	2.6	Matlab. Two masses. State space direct solution. .... 126
34	2.7	Matlab. Transfer function of the system obtained from the state space equation. .... 128
35	2.8	Matlab. Two masses system. Ode45 routines. .... 130
36	2.9	Matlab. Processing of the Simulink output for two masses. .... 132

LISTING OF COMPUTER PROGRAMS

Nº	Prog.		Page
37	2.10	Simulink. Movement of two masses linear system. ....	133
38	2.11	Matlab. Movement of two masses. State space equation and lsim command. ....	135
39	2.12	Matlab. Two masses. Laplace transfer function and lsim command. ....	139
40	2.13	Matlab. Two masses. Laplace series of transfer functions and lsim command. ....	142
41	2.14	Matlab. Frequencies of the system of two masses. ....	144
42	2.15	Matlab. Static and dynamic forces on the track. ....	145
43	3.1	Matlab. Three masses system. Ode45 routines. ....	151
44	3.2	Matlab. Three masses system. State space equation, direct solution. ....	154
45	3.3	Simulink. Three masses system. ....	156
46	3.4	Matlab. Processing of the simout output from Simulink. ....	156
47	3.5a	Simulink. Block, lower mass. ....	157
	3.5b	Simulink. Block, middle mass. ....	158
	3.5c	Simulink. Block, upper mass. ....	158
48	3.6	Simulink. Complete diagram with 3 blocks. ....	159
49	3.7	Matlab. Three masses. Series Laplace transfer function and lsim. ....	163
50	3.8	Matlab. Three masses, accelerations and dynamic forces on the track. ....	165
51	3.9	Matlab. Four masses system, ode45 routines. ....	168
52	3.10	Matlab. Four masses system, Laplace transfer function. ....	170
53	3.11	Matlab. Frequencies of the systems of three and four masses. ....	172
54	4.1	Visual C++. Half-truck. Finite differences, iterative explicit solution. ....	184
55	4.2	Matlab. Processing of Visual C++ output. Finite differences, explicit matrix solution. ....	187
56	4.3	Matlab. Explicit matrix solution. ....	188
57	4.4	Matlab. Direct state space solution. ....	192
58	4.5	Matlab. State space solution, commands lsim and ss. ....	195
59	4.6	Matlab. Graph of the rolling movement. ....	197
60	4.7	Matlab. Graph of all degrees of freedom. ....	197
61	4.8	Matlab. Graph of all system variables directly with command sim. ....	198
62	4.9	Matlab. System transfer function with command tf. ....	199
63	4.10	Visual C++. Rigid axle model. Finite differences matrix solution. ....	205
64	4.11	Matlab. Rigid axle system. State space solution, commands lsim and ss. ....	211
65	5.1	Matlab. Simplified full truck. Finite differences, matrix explicit solution. ....	226
66	5.2	Matlab. Full truck, state space direct solution. ....	233
67	5.3	Matlab. Full truck. State space solution, commands ss and lsim. ....	235
68	5.4	Matlab. Input profiles for right and left wheels. ....	237
69	5.5	Matlab. State space variables as output from command lsim. ....	238
70	6.1	Matlab. Full truck with rigid axles. State space direct solution, commands ss and lsim. ....	251
71	7.1	Matlab. Track settlements under two axles. Zimmermann-Timoshenko method. ....	274
72	7.2	Matlab. Bending moments under two axles. Zimmermann-Timoshenko method. ....	275
73	7.3	Matlab. Track settlements under 3 axles. Zimmermann-Timoshenko method. ....	277
74	8.1	Matlab. Wheel on a sleeper. Loads and settlements, Lorente-Unold method. ....	302
75	8.2	Matlab. Settlements by a 12.63 t wheel on an sleeper. Lorente and Zimmermann methods. ....	304
76	9.1	Matlab. Global vertical stiffness of the track given the measured settlement under the wheel. Movement of the unsprung mass between sleepers. ....	310

Nº	Prog.		Page
77	9.2	Matlab. Dynamic forces due to rail bending. ....	312
78	9.3	Matlab. Frequencies of the sprung and unsprung masses. ....	314
79	9.4	Matlab. Vertical acceleration of the unsprung mass as vertical track stiffness varies. ....	320
80	9.5	Matlab. Sudden change in the vertical track stiffness. Change in the vertical accelerations of the unsprung mass. ....	324
81	9.6	Matlab. Length of transition needed to avoid the jump of vertical accelerations. ....	327
82	9.7	Matlab. Three masses model at 350 km/h speed. ....	330
83	9.8	Matlab. Energy loss in the track due to vibration of the unsprung mass. ....	337
84	9.9	Matlab. Profile for simulation of a wheel flat. ....	340
85	9.10	Matlab. Wheel flat simulation. Axle vertical accelerations. ....	341
86	10.1	Matlab. Slab track test zones in Benicassim. Unold-Lorente method. ....	382
87	13.1	Matlab. IRI transfer function for road pavements. ....	440
88	13.2	Matlab. Dynamic forces of the unsprung mass for different defect wavelengths with an amplitude of 1 mm . ....	442
89	13.3	Matlab. Example of the Matlab command "reshape". ....	445
90	13.4	Matlab. Vertical Quality Index of a track. ....	446
91	13.5	Matlab. Transfer function of a dynamic model of two masses. ....	448

## SECOND PART. DIGITAL SIGNALS IN RAILWAYS

101	2.1	Matlab. Rectangle function as a sine series. ....	556
102	2.2	Matlab. Gibbs phenomenon. ....	558
103	2.3	Visual C++. DTF routine. ....	565
104	2.4	Matlab. Longitudinal profile composed by 4 sine curves. ....	567
105	2.5	Matlab. Graph of longitudinal profile. ....	567
106	2.6	Matlab. DTF routine for the longitudinal profile. ....	568
107	2.7	Matlab. Graph of the periodogram. ....	568
108	2.8	Matlab. Sum and average of the elevations of the profile points. ....	569
109	2.9	Matlab. Alternate sum and average of the elevations of the profile points. ....	570
110	2.10	DTF routine, Visual Basic in Excel. ....	570
111	2.11	Matlab. Parseval theorem and the variance of the profile elevations. ....	573
112	2.12	Matlab. Longitudinal slope. ....	579
113	3.1	DTF routine in Visual C++. Prof. Puy. ....	586
114	3.2	FFT routine in Visual C++. Prof. Puy. ....	592
115	3.3	Matlab. Periodogram with command fft. ....	594
116	3.4	Matlab. Sum and variance of the profile point elevations. Parseval theorem with FFT. ....	594
117	3.5	Matlab. FFT, graph of the periodogram. ....	595
118	4.1	Matlab. Profile input, FFT and graph of the periodogram. ....	608
119	4.2	Matlab. Analysis of part of a file. ....	612
120	5.1	Matlab. Solution of a frequency response equation. ....	632
121	5.2	Matlab. Solution of frequency response equation, moving average, 2 points. ....	633
122	5.3	Matlab. Graph of frequency response of moving averages. ....	634
123	5.4	Matlab. Zeros of the frequency response, sliding rule 3 m. ....	636

LISTING OF COMPUTER PROGRAMS

Nº	Prog.		Page
124	5.5	Matlab. Transfer function, sliding rule 3 m. ....	636
125	5.6	Matlab. Zeros of the frequency response, viagraph. ....	639
126	5.7	Matlab. Transfer function, viagraph. ....	639
127	5.8	Matlab. Assumed transfer function for a tamping machine, $\Delta x = 3.31$ m. ....	642
128	5.9	Matlab. Assumed transfer function for a tamping machine, $\Delta x = 1.0$ m. ....	644
129	5.10	Matlab. Transfer function, first difference of a series. ....	645
130	5.11	Matlab. Transfer function, second difference of a series. ....	646
131	5.12	Matlab. Transfer functions for some low pass filters. ....	653
132	5.13	Matlab. Transfer functions for some high pass filters. ....	654
133	5.14	Matlab. Graph. Butterworth sine filters. ....	657
134	6.1	Matlab. Spectral density. ....	676
135	7.1	Matlab. Longitudinal profile and profile filtered by Butterworth. ....	684
136	7.2	Matlab. Graph of original and filtered periodograms. ....	685
137	7.3	Matlab. Chebyshev filters. ....	687
138	7.4	Matlab. Elliptic filters. ....	687
139	7.5	Matlab. High pass filters. ....	688
140	7.6	Matlab. Band pass filters. ....	688
141	7.7	Matlab. Frequency filtering, Butterworth. ....	690
142	7.8	Matlab. Frequency filtering by convolution. ....	695
143	7.9	Matlab. Comparison, convolution and Butterworth filtering. ....	696
144	7.10	Matlab. Matlab. Filtering by erasing in the periodogram. ....	699
145	7.11	Matlab. Lateral acceleration filtering, measurements in high speed line Madrid-Barcelona. ....	703
146	8.1	Matlab. Unsprung mass movement, One mass model. ....	710
147	8.2	Matlab. Unsprung mass movement. Frequencies. ....	711
148	8.3	Matlab. Unsprung and sprung masses movement. Frequencies. ....	713
149	8.4	Matlab. Frequencies of the system of two masses, FFT. ....	715
150	8.5	Matlab. Movement of the unsprung and sprung masses. ....	716
151	8.6	Matlab. Frequencies of the system of three masses, FFT. ....	718
152	9.1	Matlab. Waterfall diagram, periodograms of lateral accelerations along 500 km track high speed line Madrid to Tarragona, in parts of 5 km.. ....	723
153	9.2	Matlab. Waterfall diagram, periodograms of lateral accelerations measured on the high speed line Madrid to Tarragona along the 100 km zone of the high embankments Guadalajara to Calatayud. Parts 1 km long. ....	725
154	9.3	Matlab. Waterfall diagram, periodograms of lateral accelerations measured on the high speed line Madrid to Tarragona, zone of the high embankments pk 101 and 179. ....	727
155	10.1	Matlab. Inertial plane. Integration of the vertical accelerations of the laser lamp. ....	738
156	11.1	Transfer function, UNE-ENV 12299 Standard. ....	752
157	11.2	Averaging of measured accelerations, standard UNE-ENV 12299. ....	753
158	11.3	Comfort index, standard UNE-ENV 12299, frequency domain. ....	753
159	11.4	Comfort index, standard UNE-ENV 12299, time domain. ....	756
160	12.1	Two mass model. Elastic layer under the ballast. ....	768