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1 !*****
2 ! etmsus.mac
3 !*****
4 ! macro to analyse natural frequencies of an ETM quad suspension
5 !
6 !Dennis Coyne 28-nov-2005
7 !
8 finish
9 /CLEAR,START
10 /COM,ANSYS MODEL OF A SINGLE ETM QUAD SUSPENSION CHAIN
11 /PREP7
12 /TITLE,ETM QUAD SUSPENSION
13 !*****
14 !*      GEOMETRIC PARAMETERS
15 !*****
16 ! values of parameters
17 ! SI units (m,N)
18 ! naming per T040072-01, plus extensions explained below
19 ! coordinate system per T040072-02 with origin at center of top blades
20
21 ! top blades (D040298)
22 lnb=0.480
23 anb=0.095
24 bnb=0.010 ! blade tip width
25 cnb=7.5*3.14159/180 ! blade centerline angle to y-axis (rad)
26 hnb=0.00429
27 nn0=0.25
28 !*
29 ! middle blades (D040297)
30 llb=0.4207
31 alb=0.059
32 blb=0.010 ! blade tip width
33 clb=7.5*3.14159/180 ! blade centerline angle to y-axis (rad)
34 hlb=0.0046
35 n0=0.200
36 !*
37 ! bottom blades (D040296)
38 llb=0.370
39 a2b=0.049
40 b2b=0.010 ! blade tip width
41 c2b=7.5*3.14159/180 ! blade centerline angle to y-axis (rad)
42 h2b=0.0042
43 n2=0.140
44 !*
45 ! Top Wires
46 ! zw1 is the height coordinate of the top wire attachment to the top mass
47 ! zcg1 is the height coordinate of the c.g. of the top mass
48 ! zbl is the height coordinate of the neutral axis of the middle blades
49 nn1=0.090
50 ln=0.450
```

```
51 rn=0.00052
52 dm=0.001
53 dn=0.001
54 zw1=-SQRT(ln**2-(nn0-nn1)**2)
55 zcg1=zw1-dm
56 zbl=zcg1-dn
57 !*
58 ! Middle Wires
59 ! zw2 is the height coordinate of the middle wire attachment to the UI mass
60 ! zcg2 is the height coordinate of the c.g. of the UI mass
61 ! zb2 is the height coordinate of the neutral axis of the bottom blades
62 n1=0.060
63 l1=0.3085
64 r1=0.00035
65 d0=0.001
66 d1=0.001
67 su=0.003
68 zw2=zbl-SQRT(l1**2-(n0-n1)**2)
69 zcg2=zw2-d0
70 zb2=zcg2-d1
71 !*
72 ! Penultimate Wires
73 ! zw3 is the height coordinate upper (penultimate) wire attachment to the PM
74 ! zcg3 is the height coordinate of the c.g. of the PM
75 ! zb3 is the height coordinate of lower (TM) wire attachment to the PM
76 n3=0.1635
77 l2=0.3400
78 r2=0.00031
79 d2=0.001
80 d3=0.001
81 si=0.003
82 zw3=zb2-SQRT(l2**2-(n2-n3)**2)
83 zcg3=zw3-d2
84 zb3=zcg3-d3
85 !*
86 ! Test Mass Wires/Ribbons
87 ! zw4 is the height coordinate TM wire attachment to the TM
88 ! zcg4 is the height coordinate of the c.g. of the TM
89 n4=0.1585
90 n5=0.1585
91 l3=0.6020
92 r3=0.00022
93 d4=0.001
94 sl=0.015
95 zw4=zb3-SQRT(l3**2-(n4-n5)**2)
96 zcg4=zw4-d4
97
98 !*****
99 !*      MASS PARAMETERS
100 !*****
```

```
101 !* N.B.: The moments of inertia below (Inx, Iny, Inz) are values without
102 !           the blade springs included.
103 !   Top Mass
104 mn=22.1
105 Inx=0.0670
106 Iny=0.4289
107 Inz=0.4309
108 !*
109 !   UI Mass
110 m1=21.8
111 I1x=0.0581
112 I1y=0.5005
113 I1z=0.4988
114 !*
115 !   PM
116 m2=38.4
117 I2x=0.2765
118 I2y=0.2752
119 I2z=0.4704
120 !*
121 !   TM
122 m3=39.61
123 I3x=0.2692
124 I3y=0.2679
125 I3z=0.4556
126
127 !*****
128 !*      MATERIAL PROPERTIES
129 !*****
130 maryoung=1.76e11
131 marpoiss=0.3
132 mardens=7800
133 wireyoung=2.0e11
134 wirepoiss=0.3
135 wiredens=7800
136
137 !MPTEMP,,,,,,,,
138 !MPTEMP,1,0
139 !MPDATA,EX,1,,maryoung
140 !MPDATA,PRXY,1,,marpoiss
141 !MPDATA,DENS,1,,mardens
142 !MPTEMP,,,,,,,,
143 !MPTEMP,1,0
144 !MPDATA,EX,2,,wireyoung
145 !MPDATA,PRXY,2,,wirepoiss
146 !MPTEMP,,,,,,,,
147 !MPTEMP,1,0
148 !MPDATA,DENS,2,,wiredens
149 MP,EX,1,maryoung
150 MP,EY,1,maryoung
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```
151 MP,EZ,1,maryoung
152 MP,PRXY,1,marpoiss
153 MP,DENS,1,mardens
154 MP,EX,2,wireyoung
155 MP,EY,2,wireyoung
156 MP,EZ,2,wireyoung
157 MP,PRXY,2,wirepoiss
158 MP,DENS,2,wiredens
159
160 !*****
161 !*      GENERATE GEOMETRY
162 !*****
163 !*      BLADES
164 !*****
165 ! Top Blade, Right
166 K,1,0,nn0,0,
167 K,2,-bnb*cos(cnb)/2,nn0-bnb*sin(cnb)/2,0,
168 K,3,bnb*cos(cnb)/2,nn0+bnb*sin(cnb)/2,0,
169 K,4,lnb*sin(cnb),nn0-lnb*cos(cnb),0,
170 K,5,lnb*sin(cnb)-anb*cos(cnb)/2,nn0-lnb*cos(cnb)-anb*sin(cnb)/2,0,
171 K,6,lnb*sin(cnb)+anb*cos(cnb)/2,nn0-lnb*cos(cnb)+anb*sin(cnb)/2,0,
172 LSTR, 1, 4 ! line 1
173 LSTR, 4, 6 ! line 2
174 LSTR, 6, 3 ! line 3
175 LSTR, 3, 1 ! line 4
176 LSTR, 4, 5 ! line 5
177 LSTR, 5, 2 ! line 6
178 LSTR, 2, 1 ! line 7
179 AL,1,2,3,4 ! area 1
180 AL,1,5,6,7 ! area 2
181 !*
182 ! Top Blade, Left
183 K,7,0,-nn0,0,
184 K,8,bnb*cos(cnb)/2,-nn0+bnb*sin(cnb)/2,0,
185 K,9,-bnb*cos(cnb)/2,-nn0-bnb*sin(cnb)/2,0,
186 K,10,-lnb*sin(cnb),-nn0+lnb*cos(cnb),0,
187 K,11,-lnb*sin(cnb)+anb*cos(cnb)/2,-nn0+lnb*cos(cnb)+anb*sin(cnb)/2,0,
188 K,12,-lnb*sin(cnb)-anb*cos(cnb)/2,-nn0+lnb*cos(cnb)-anb*sin(cnb)/2,0,
189 LSTR, 7,10 ! line 8
190 LSTR,10,12 ! line 9
191 LSTR, 9,12 ! line 10
192 LSTR, 7, 9 ! line 11
193 LSTR,10,11 ! line 12
194 LSTR, 8,11 ! line 13
195 LSTR, 7, 8 ! line 14
196 AL,8,9,10,11 ! area 3
197 AL,8,12,13,14 ! area 4
198 !*
199 ! Middle Blade, Right
200 K,13,0,n0,zb1,
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201 K,14,-b1b*cos(c1b)/2,n0-b1b*sin(c1b)/2,zb1,
202 K,15,b1b*cos(c1b)/2,n0+b1b*sin(c1b)/2,zb1,
203 K,16,l1b*sin(c1b),n0-l1b*cos(c1b),zb1,
204 K,17,l1b*sin(c1b)-a1b*cos(c1b)/2,n0-l1b*cos(c1b)-a1b*sin(c1b)/2,zb1,
205 K,18,l1b*sin(c1b)+a1b*cos(c1b)/2,n0-l1b*cos(c1b)+a1b*sin(c1b)/2,zb1,
206 LSTR, 13,16 ! line 15
207 LSTR, 16,18 ! line 16
208 LSTR, 18,15 ! line 17
209 LSTR, 15,13 ! line 18
210 LSTR, 16,17 ! line 19
211 LSTR, 17,14 ! line 20
212 LSTR, 14,13 ! line 21
213 AL,15,16,17,18 ! area 5
214 AL,15,19,20,21 ! area 6
215 !*
216 ! Middle Blade, Left
217 K,19,0,-n0,zb1,
218 K,20,b1b*cos(c1b)/2,-n0+b1b*sin(c1b)/2,zb1,
219 K,21,-b1b*cos(c1b)/2,-n0-b1b*sin(c1b)/2,zb1,
220 K,22,-l1b*sin(c1b),-n0+l1b*cos(c1b),zb1,
221 K,23,-l1b*sin(c1b)+a1b*cos(c1b)/2,-n0+l1b*cos(c1b)+a1b*sin(c1b)/2,zb1,
222 K,24,-l1b*sin(c1b)-a1b*cos(c1b)/2,-n0+l1b*cos(c1b)-a1b*sin(c1b)/2,zb1,
223 LSTR, 19,22 ! line 22
224 LSTR, 22,24 ! line 23
225 LSTR, 21,24 ! line 24
226 LSTR, 19,21 ! line 25
227 LSTR, 22,23 ! line 26
228 LSTR, 20,23 ! line 27
229 LSTR, 19,20 ! line 28
230 AL,22,23,24,25 ! area 7
231 AL,22,26,27,28 ! area 8
232 !*
233 ! Bottom Blade, Right
234 K,25,0,n2,zb2,
235 K,26,-b2b*cos(c2b)/2,n2-b2b*sin(c2b)/2,zb2,
236 K,27,b2b*cos(c2b)/2,n2+b2b*sin(c2b)/2,zb2,
237 K,28,l2b*sin(c2b),n2-l2b*cos(c2b),zb2,
238 K,29,l2b*sin(c2b)-a2b*cos(c2b)/2,n2-l2b*cos(c2b)-a2b*sin(c2b)/2,zb2,
239 K,30,l2b*sin(c2b)+a2b*cos(c2b)/2,n2-l2b*cos(c2b)+a2b*sin(c2b)/2,zb2,
240 LSTR, 25,28 ! line 29
241 LSTR, 28,30 ! line 30
242 LSTR, 30,27 ! line 31
243 LSTR, 27,25 ! line 32
244 LSTR, 28,29 ! line 33
245 LSTR, 29,26 ! line 34
246 LSTR, 26,25 ! line 35
247 AL,29,30,31,32 ! area 9
248 AL,29,33,34,35 ! area 10
249 !*
250 ! Bottom Blade, Left
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251 K,31,0,-n2,zb2,
252 K,32,b2b*cos(c2b)/2,-n2+b2b*sin(c2b)/2,zb2,
253 K,33,-b2b*cos(c2b)/2,-n2-b2b*sin(c2b)/2,zb2,
254 K,34,-l2b*sin(c2b),-n2+l2b*cos(c2b),zb2,
255 K,35,-l2b*sin(c2b)+a2b*cos(c2b)/2,-n2+l2b*cos(c2b)+a2b*sin(c2b)/2,zb2,
256 K,36,-l2b*sin(c2b)-a2b*cos(c2b)/2,-n2+l2b*cos(c2b)-a2b*sin(c2b)/2,zb2,
257 LSTR, 31,34 ! line 36
258 LSTR, 34,36 ! line 37
259 LSTR, 33,36 ! line 38
260 LSTR, 31,33 ! line 39
261 LSTR, 34,35 ! line 40
262 LSTR, 32,35 ! line 41
263 LSTR, 31,32 ! line 42
264 AL,36,37,38,39 ! area 11
265 AL,36,40,41,42 ! area 12
266 !*****
267 !*          MASSES
268 !*****
269 !*
270 ! Top Mass
271 K,100,0,0,zcg1,
272 K,101,0,nn1,zw1,
273 K,102,0,-nn1,zw1,
274 K,103,su,n0,zb1,
275 K,104,-su,n0,zb1,
276 K,105,su,-n0,zb1,
277 K,106,-su,-n0,zb1,
278
279 !*
280 ! Upper Intermediate (UI) Mass
281 K,200,0,0,zcg2,
282 K,201,su,n1,zw2,
283 K,202,-su,n1,zw2,
284 K,203,su,-n1,zw2,
285 K,204,-su,-n1,zw2,
286 K,205,si,n2,zb2,
287 K,206,-si,n2,zb2,
288 K,207,si,-n2,zb2,
289 K,208,-si,-n2,zb2,
290
291 !*
292 ! Penultimate Mass (PM)
293 K,300,0,0,zcg3,
294 K,301,si,n3,zw3,
295 K,302,-si,n3,zw3,
296 K,303,si,-n3,zw3,
297 K,304,-si,-n3,zw3,
298 K,305,s1,n4,zb3,
299 K,306,-s1,n4,zb3,
300 K,307,s1,-n4,zb3,
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301 K,308,-s1,-n4,zb3,
302
303 !*
304 ! Test Mass (TM)
305 K,400,0,0,zcg4,
306 K,401,s1,n5,zw4,
307 K,402,-s1,n5,zw4,
308 K,403,s1,-n5,zw4,
309 K,404,-s1,-n5,zw4,
310
311 !*****
312 !*           WIRES
313 !*****
314 !*
315 ! Top Wires
316 LSTR,1,101      ! line 43
317 LSTR,7,102      ! line 44
318 !*
319 ! UI Wires
320 LSTR,103,201     ! line 45
321 LSTR,104,202     ! line 46
322 LSTR,105,203     ! line 47
323 LSTR,106,204     ! line 48
324 !*
325 ! PM Wires
326 LSTR,205,301     ! line 49
327 LSTR,206,302     ! line 50
328 LSTR,207,303     ! line 51
329 LSTR,208,304     ! line 52
330 !*
331 ! TM Wires
332 LSTR,305,401     ! line 53
333 LSTR,306,402     ! line 54
334 LSTR,307,403     ! line 55
335 LSTR,308,404     ! line 56
336
337 !*****
338 !*           RIGID LINKS
339 !*****
340 !*
341 ! Top Mass
342 LSTR,100,101     ! line 57, top wire 1
343 LSTR,100,102     ! LINE 58, top wire 2
344 LSTR, 15,103     ! LINE 59, middle blade to wire 1
345 LSTR, 14,104     ! LINE 60, middle blade to wire 2
346 LSTR, 20,105     ! LINE 61, middle blade to wire 3
347 LSTR, 21,106     ! LINE 62, middle blade to wire 4
348 LSTR,100, 16     ! LINE 63, c.g. to blade root 1
349 LSTR,100, 17     ! LINE 64, c.g. to blade root 2
350 LSTR,100, 18     ! LINE 65, c.g. to blade root 3
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351 LSTR,100, 22      ! LINE 66, c.g. to blade root 4
352 LSTR,100, 23      ! LINE 67, c.g. to blade root 5
353 LSTR,100, 24      ! LINE 68, c.g. to blade root 6
354 !*
355 ! UI Mass
356 LSTR,200,201      ! line 69, UI wire 1
357 LSTR,200,202      ! LINE 70, UI wire 2
358 LSTR,200,203      ! LINE 71, UI wire 3
359 LSTR,200,204      ! LINE 72, UI wire 4
360 LSTR, 27,205      ! LINE 73, bottom blade to wire 1
361 LSTR, 26,206      ! LINE 74, bottom blade to wire 2
362 LSTR, 32,207      ! LINE 75, bottom blade to wire 3
363 LSTR, 33,208      ! LINE 76, bottom blade to wire 4
364 LSTR,200, 28      ! LINE 77, c.g. to blade root 1
365 LSTR,200, 29      ! LINE 78, c.g. to blade root 2
366 LSTR,200, 30      ! LINE 79, c.g. to blade root 3
367 LSTR,200, 34      ! LINE 80, c.g. to blade root 4
368 LSTR,200, 35      ! LINE 81, c.g. to blade root 5
369 LSTR,200, 36      ! LINE 82, c.g. to blade root 6
370 !*
371 ! PM
372 LSTR,300,301      ! LINE 83, c.g. to PM wire 1
373 LSTR,300,302      ! LINE 84, c.g. to PM wire 2
374 LSTR,300,303      ! LINE 85, c.g. to PM wire 3
375 LSTR,300,304      ! LINE 86, c.g. to PM wire 4
376 LSTR,300,305      ! LINE 87, c.g. to TM wire 1
377 LSTR,300,306      ! LINE 88, c.g. to TM wire 2
378 LSTR,300,307      ! LINE 89, c.g. to TM wire 3
379 LSTR,300,308      ! LINE 90, c.g. to TM wire 4
380 !*
381 ! TM
382 LSTR,400,401      ! LINE 91, c.g. to TM wire 1
383 LSTR,400,402      ! LINE 92, c.g. to TM wire 2
384 LSTR,400,403      ! LINE 93, c.g. to TM wire 3
385 LSTR,400,404      ! LINE 94, c.g. to TM wire 4
386 !*
387 ! Plot Areas
388 aplot
389
390 !*****
391 !*      MESH GEOMETRY
392 !*****
393 !*
394 !*****
395 !      Blade Springs
396 !*****
397 !ET,1,SHELL63,0,0,1,,0,0
398 !ET,1,SHELL43,,,2
399 !ET,1,SHELL181,1
400 !ET,1,SHELL93
```



```
401 ET,1,SHELL63
402 TYPE,1      ! shell elements
403 MAT,1      ! maraging steel
404 !          Top Blades
405 R,1,hnb          !for the blade
406 REAL,1
407 ESIZE,anb/4,0
408 amesh,1,4
409 !          Middle Blades
410 R,2,h1b          !for the blade
411 REAL,2
412 ESIZE,a1b/4,0
413 amesh,5,8
414 !          Bottom Blades
415 R,3,h2b          !for the blade
416 REAL,3
417 ESIZE,a2b/4,0
418 amesh,9,12
419
420 !*****
421 !          Suspension Masses
422 !*****
423 ET,2,MASS21,0,0,0
424 TYPE,2      ! discrete mass elements
425 !          Top Mass
426 R,4,mn,mn,mn,Inx,Iny,Inz
427 REAL,4
428 KMESH,100
429 !          UI Mass
430 R,5,m1,m1,m1,I1x,I1y,I1z
431 REAL,5
432 KMESH,200
433 !          PM
434 R,6,m2,m2,m2,I2x,I2y,I2z
435 REAL,6
436 KMESH,300
437 !          TM
438 R,7,m3,m3,m3,I3x,I3y,I3z
439 REAL,7
440 KMESH,400
441
442 ! Wire Clamps
443 !R,8,mc,mc,mc,Icx,Icy,Icz
444 !REAL,8
445 !kmesh,?
446
447 !*****
448 !          Wires
449 !*****
450 ET,3,BEAM4,,0,,,0
```

```
451 TYPE,3      ! beam elements
452 MAT,2
453 !           Top Wires
454 wAn=3.14159*rn**2
455 wIn=(3.14159*rn**4)/4
456 wJn=(3.14159*rn**4)/2
457 R,9,wAn,wIn,wIn,rn,rn,0
458 RMORE,0,wJn
459 REAL,9
460 ESIZE,0.005
461 LMESH,43,44
462 !           UI Wires
463 wA1=3.14159*r1**2
464 wI1=(3.14159*r1**4)/4
465 wJ1=(3.14159*r1**4)/2
466 R,10,wA1,wI1,wI1,r1,r1,0
467 RMORE,0,wJ1
468 REAL,10
469 ESIZE,0.005
470 LMESH,45,48
471 !           PM Wires
472 wA2=3.14159*r2**2
473 wI2=(3.14159*r2**4)/4
474 wJ2=(3.14159*r2**4)/2
475 R,11,wA2,wI2,wI2,r2,r2,0
476 RMORE,0,wJ2
477 REAL,11
478 ESIZE,0.005
479 LMESH,49,52
480 !           TM Wires
481 wA3=3.14159*r3**2
482 wI3=(3.14159*r3**4)/4
483 wJ3=(3.14159*r3**4)/2
484 R,12,wA3,wI3,wI3,r3,r3,0
485 RMORE,0,wJ3
486 REAL,12
487 ESIZE,0.005
488 LMESH,53,56
489
490 !*****
491 !           Rigid Links
492 !*****
493 ET,4,MPC184,1,0
494 TYPE,4      ! rigid body constraint elements
495 ESIZE,,1
496 LMESH,57,94
497
498 NUMMRG,NODE,0.00001
499
500 !*****
```

```
501 !*          BOUNDARY CONDITIONS
502 !*****
503 !*
504 ! Clamp the upper blade roots
505 DL, 2, ,ALL,0
506 DL, 5, ,ALL,0
507 DL, 9, ,ALL,0
508 DL,12, ,ALL,0
509 EPLOT
510
511 FINISH
512
513 !*****
514 !   Static Preload Analysis
515 !*****
516 /SOL
517 ANTYPE,STATIC
518 PSTRES,ON
519 G=9.84
520 ACEL,0,0,G
521 SOLVE
522 FINISH
523 !/POST1
524 !PLDIST,0
525 !FINISH
526 !*****
527 !   Eigenvalue Analysis
528 !*****
529 /SOL
530 ANTYPE,MODAL
531 MSAVE,0
532 !*
533 MODOPT,LANB,60
534 EQSLV,JCG
535 !MXPAND,0, , ,0
536 LUMPM,OFF
537 PSTRES,ON
538 !*
539 /STATUS,SOLU
540 SOLVE
541 FINISH
542 /POST1
543 /output,etmsus,out,,
544 !*Status,argx
545 SET,LIST
546 /output
547 *get,freq1,mode,1,freq
548 *get,freq2,mode,2,freq
549 *get,freq3,mode,3,freq
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