Fundamentals of Control Systems

Elec 372

Lab Experiment #1

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"I certify that this submission is my original work and meets the Faculty's Expectations of Originality."

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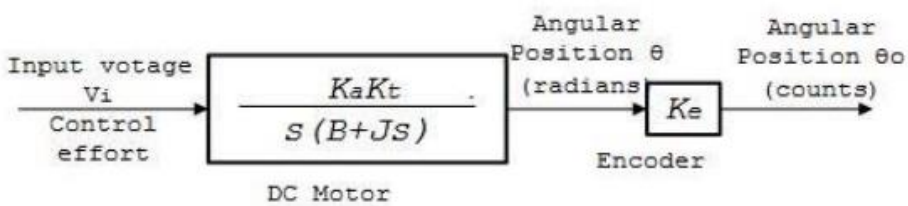
12/02/2024

1) Objectives

The primary objective of the first lab of the course Elec 372 is to familiarize ourselves with the experiment systems. For example, students will be introduced to the ECP Model 220 system as well as the software needed to produce a system response. Students will also perform basic MATLAB computation of an open-loop and closed-loop response system. As such, this allows for the student to get hands on experience on using Elec 372 laboratory equipment.

2) Theory



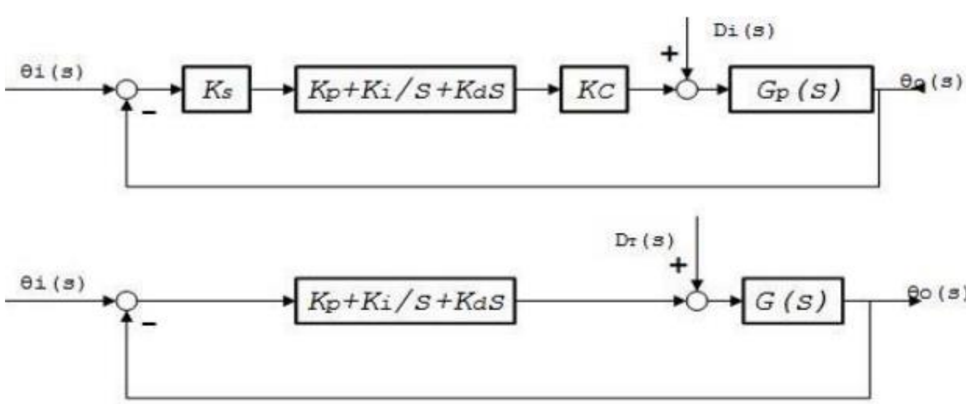
Open-Loop Diagram

K_t: Torque constant

K_a: Tran-conductance gain

J: Total inertial of turntable system

B: Viscous fiction



Closed-Loop Diagram

K_s: Controller software gain

K_c: D-to-A converter (DAC) gain

K_e: Encoder gain

K_a: Servo-amplifier gain

K_t: Servomotor torque constant

<u>3) Tasks / Results / Discussions</u>

<u>3.1) Closed-Loop Test</u>

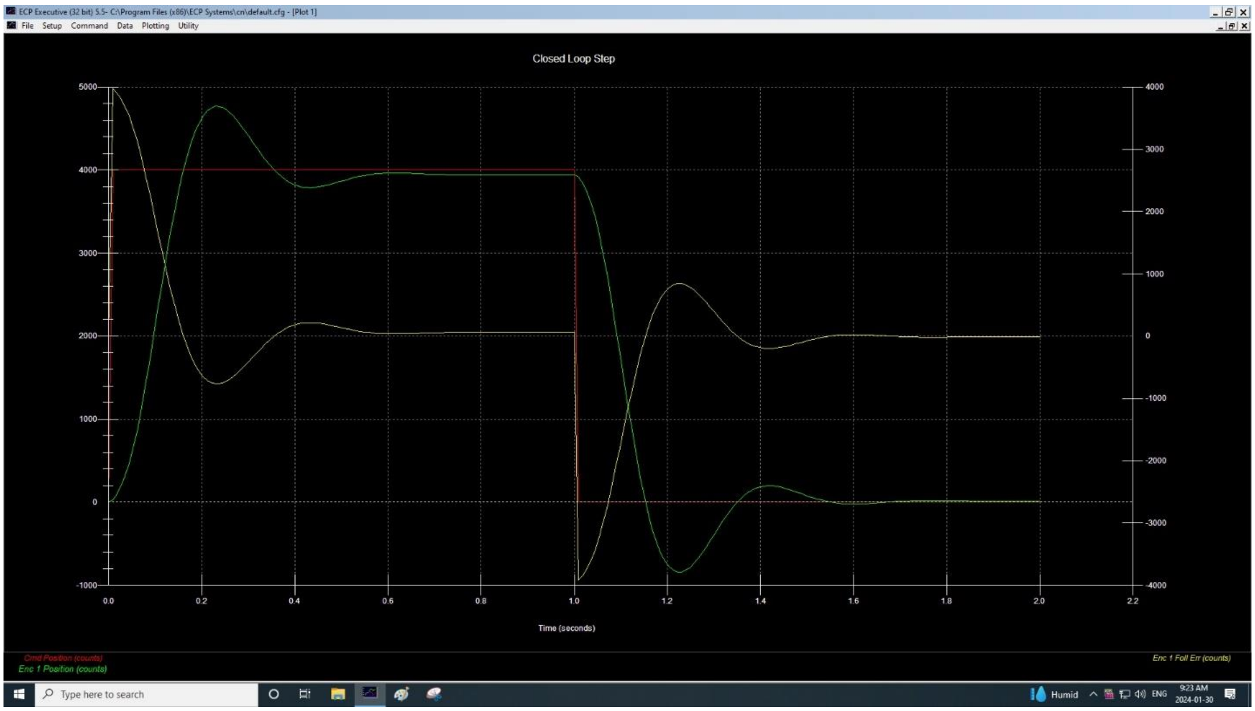


Figure 1.

This figure is the plot of Commanded Position and Encoder #1 Position in relation to Encoder #1 Error of a closed-loop system. The important point to notice is that the yellow line behaves in opposite to the green line. These represents the error and position respectively. In addition, in a steady state, the error value approaches 0 as noticed from time 0.6 and from time 1.6.

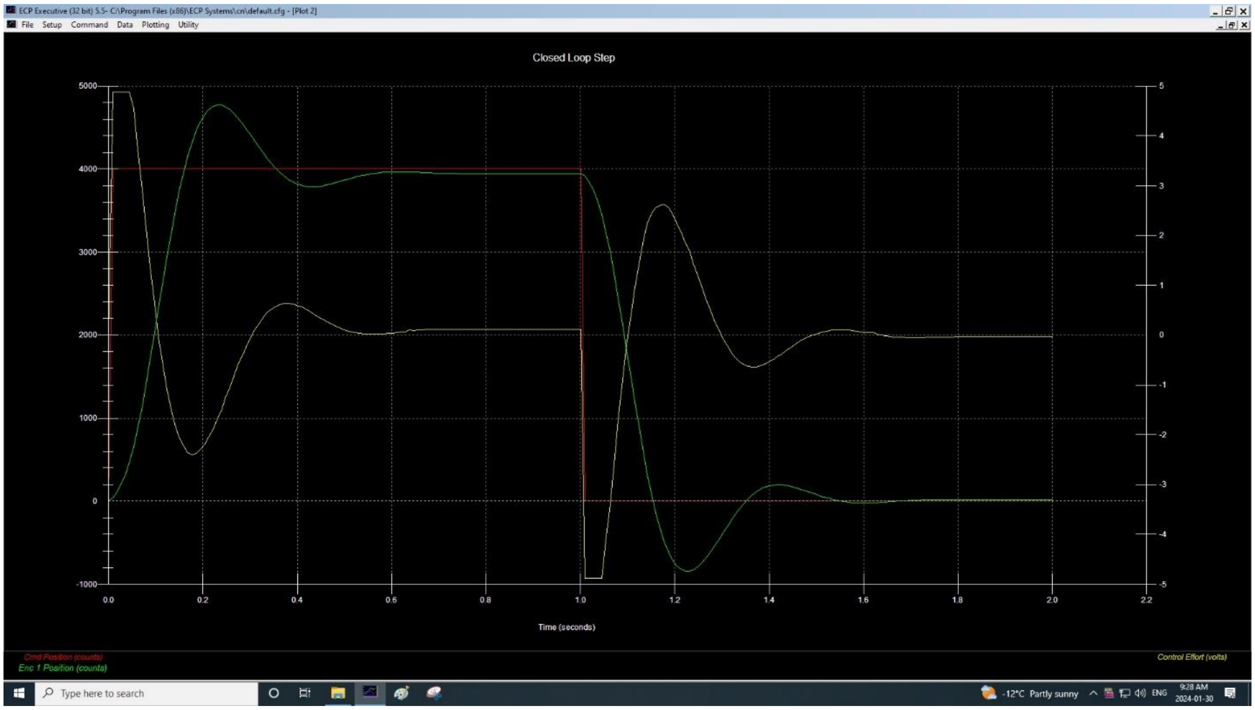
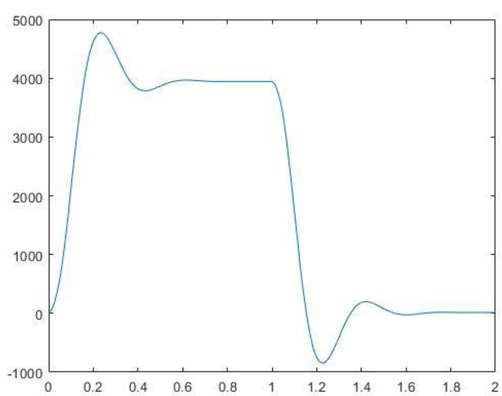


Figure 2.

This figure is the plot of Commanded Position and Encoder #1 Position in relation to Control Effort of a closed-loop system. While it looks very similar to figure 1, a difference lies in the control effort which appears to have a time shift compared to the error value. This is due to the fact that the control effort anticipates the output variation.



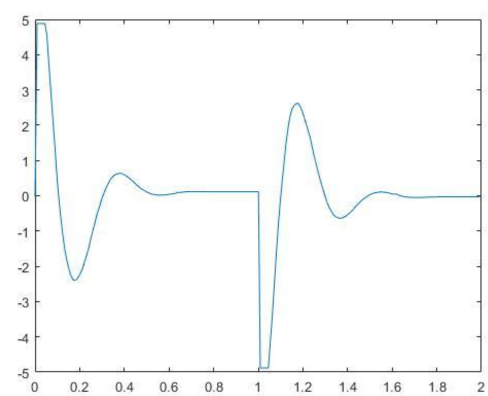
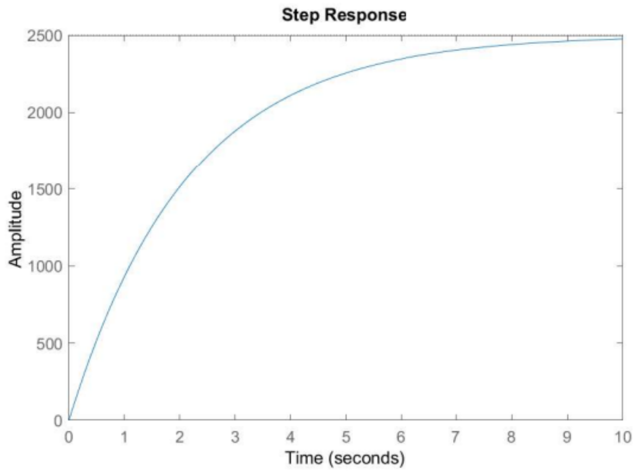


Figure 3 and Figure 4.

These two figures are MATLAB simulation that can be compared to the two ECP plots from figure 1 and figure 2. Notice that curve of figure 3 (left one) is similar to the Position while the curve of figure 4 (right one) is similar to the Control Effect.

3.2) Open-Loop Step Response MATLAB Simulation



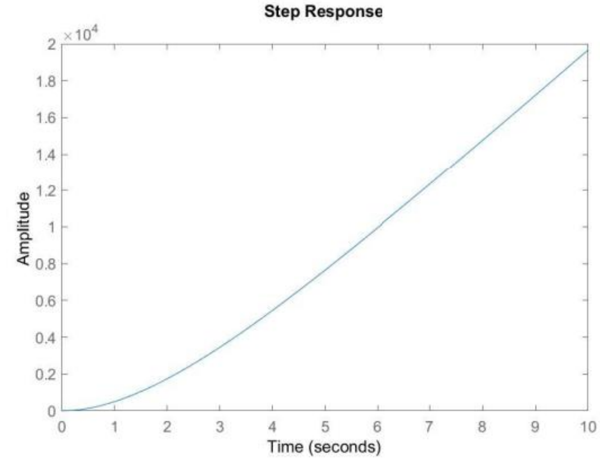


Figure 5 and Figure 6

These two figures represent the MATLAB simulation of the step response of an open-loop DC motor system. Figure 4 (left one) is velocity in terms of time, while figure 5 (right one) is the position in terms of time

3.3) Open-Loop Step Response

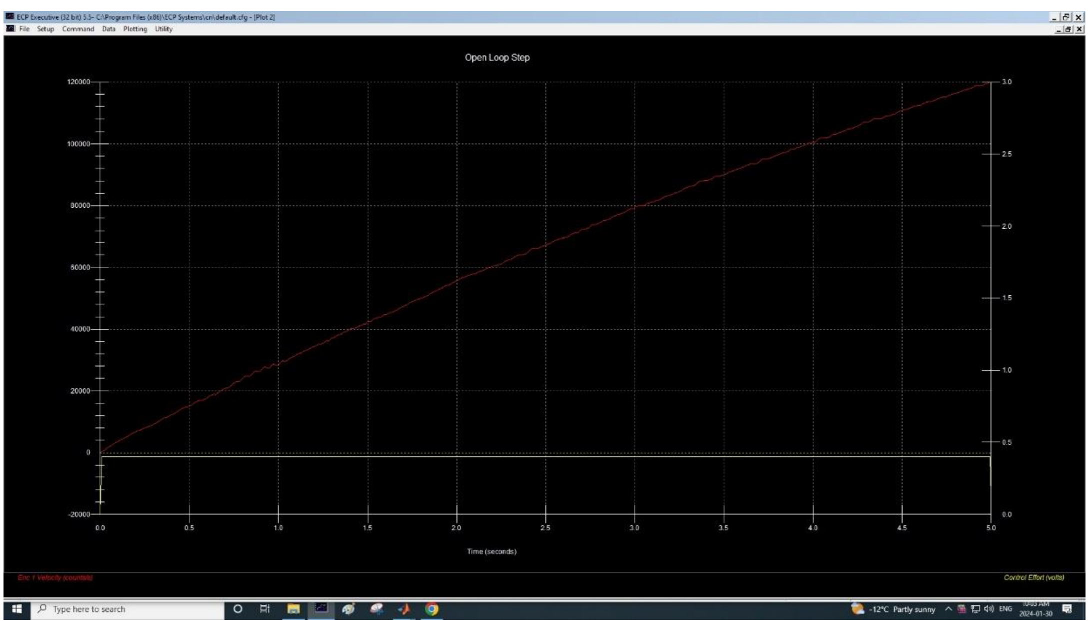


Figure 7.

This figure is a simulation of an open-loop encoder #1 velocity in relation to time using MATLAB. This corresponds to a step response of an open-loop DC motor.

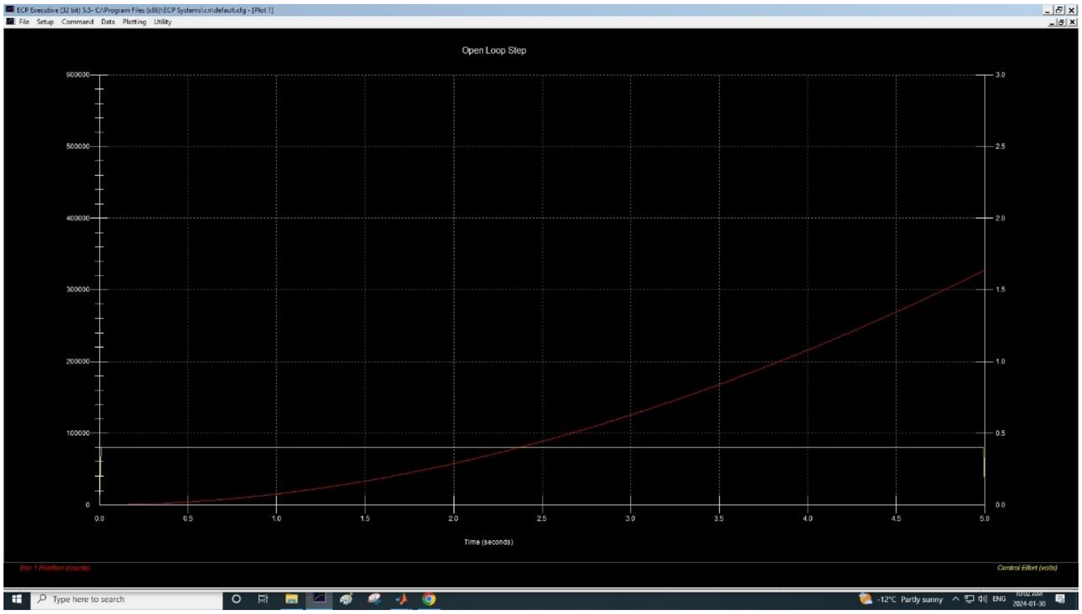


Figure 8.

This figure represents a MATLAB simulation of an open-loop encoder #1 position in relation to time. This corresponds to a step response of an open-loop DC motor.

4) Questions

4.1) Note how the error varies in the opposite direction of the output and approaches zero in the steady state. (closed-loop)

Based on figure 1, the command position refers to the red line. The encoder #1 position refers to the green line. The encoder #1 error refers to the yellow line. It can be observed based on the above plot that the error value behaves opposite to the encoder #1 position, such that when the green line increases, the yellow line decreases. Then, we also notice that given enough time, the encoder #1 error value will oscillate and approach 0 in a steady state. This happens twice, first when the command position was at value 4000 and encoder #1 error is 0 from time 0.6, second when the command position was at value of 0 and encoder #1 error is 0 from time 1.6.

4.2) Note how the CE, which is the input to the servomotor, varies in a manner similar to that of the error, but anticipates the output variation with an observable lead time. The CE is the input whenever the system is operated in the open-loop mode. (closed-loop)

Based on figure 2, it can be observed that the value and pattern of control effort is very similar to Encoder #1 error of figure 1. Their have similar behavior where they opposite the Encoder #1 position. However, a small difference is that control effort has a slight time shift where it predicts the output variation. This can be noticed by how it changes before #1 position.

5) Conclusions

In conclusion, for the first Elec 372 experiment, students achieved a fundamental understanding of control system analysis and MATLAB computation by performing tests with the ECP Model 220 system. Then, through working on an open-loop and closed-loop responses, students could analyse the effect and differences given various input parameters. In the end, this lab experiment gave students hands on experiences which will be needed for upcoming labs.

6) Appendix

6.1) sinesweep220.m MATLAB Code

```
K = 5.0;
B = 0.002;
J = 0.0043;

s = tf('s');
dcm_s = K/(J*s+B);
dcm_p = dcm_s/s;

ltiview('step', dcm_s, 0:0.1:10);

ltiview('step',dcm_p, 0:0.1:10);
```

6.2) Exported Raw MATLAB Data

```
Sample   Time     Commanded Pos   Encoder 1 Pos   Encoder 2 Pos   Control Effort

[   0    0.000         4000            14              4        -0.0275;
    1    0.009         4000            39              4         4.8840;
    2    0.018         4000           104             12         4.8840;
    3    0.027         4000           196             33         4.8840;
    4    0.035         4000           312             67         4.8840;
    5    0.044         4000           464            109         4.8840;
    6    0.053         4000           654            155         4.5488;
    7    0.062         4000           880            209         3.7283;
    8    0.071         4000          1136            273         2.9249;
    9    0.080         4000          1416            346         2.1410;
   10    0.089         4000          1712            425         1.3822;
   11    0.097         4000          2021            506         0.6361;
   12    0.106         4000          2335            586        -0.0513;
   13    0.115         4000          2646            666        -0.6105;
   14    0.124         4000          2946            743        -1.0971;
   15    0.133         4000          3232            817        -1.5104;
```

16	0.142	4000	3499	886	-1.8315;
17	0.151	4000	3742	950	-2.0611;
18	0.159	4000	3962	1007	-2.2387;
19	0.168	4000	4156	1056	-2.3584;
20	0.177	4000	4323	1096	-2.4011;
21	0.186	4000	4462	1129	-2.3755;
22	0.195	4000	4572	1157	-2.2906;
23	0.204	4000	4657	1179	-2.1874;
24	0.213	4000	4717	1195	-2.0543;
25	0.221	4000	4756	1204	-1.8950;
26	0.230	4000	4773	1208	-1.7033;
27	0.239	4000	4771	1208	-1.5177;
28	0.248	4000	4750	1203	-1.2595;
29	0.257	4000	4715	1193	-1.0397;
30	0.266	4000	4668	1180	-0.8205;
31	0.274	4000	4612	1166	-0.6087;
32	0.283	4000	4549	1149	-0.4151;
33	0.292	4000	4481	1131	-0.2326;
34	0.301	4000	4410	1113	-0.0537;
35	0.310	4000	4337	1094	0.0965;
36	0.319	4000	4266	1075	0.2332;
37	0.328	4000	4196	1057	0.3504;
38	0.336	4000	4129	1040	0.4493;
39	0.345	4000	4067	1024	0.5214;
40	0.354	4000	4010	1010	0.5763;
41	0.363	4000	3959	997	0.6129;
42	0.372	4000	3915	985	0.6337;
43	0.381	4000	3878	976	0.6368;
44	0.390	4000	3847	968	0.6276;
45	0.398	4000	3823	962	0.6007;
46	0.407	4000	3805	958	0.5672;
47	0.416	4000	3794	955	0.5311;
48	0.425	4000	3788	953	0.4780;
49	0.434	4000	3786	953	0.4353;
50	0.443	4000	3789	953	0.3816;
51	0.452	4000	3796	955	0.3248;
52	0.460	4000	3805	957	0.2814;
53	0.469	4000	3817	960	0.2332;
54	0.478	4000	3831	963	0.1911;
55	0.487	4000	3845	967	0.1551;
56	0.496	4000	3859	971	0.1215;
57	0.505	4000	3874	974	0.0910;
58	0.514	4000	3888	978	0.0684;

59	0.522	4000	3902	981	0.0501;
60	0.531	4000	3914	985	0.0379;
61	0.540	4000	3925	988	0.0293;
62	0.549	4000	3935	990	0.0195;
63	0.558	4000	3944	992	0.0201;
64	0.567	4000	3951	994	0.0189;
65	0.576	4000	3957	996	0.0232;
66	0.584	4000	3962	997	0.0244;
67	0.593	4000	3965	997	0.0330;
68	0.602	4000	3967	998	0.0433;
69	0.611	4000	3968	998	0.0488;
70	0.620	4000	3968	998	0.0623;
71	0.629	4000	3968	998	0.0623;
72	0.638	4000	3966	998	0.0983;
73	0.646	4000	3964	998	0.0940;
74	0.655	4000	3961	998	0.0971;
75	0.664	4000	3959	998	0.1062;
76	0.673	4000	3956	997	0.1111;
77	0.682	4000	3954	996	0.1117;
78	0.691	4000	3952	995	0.1190;
79	0.699	4000	3950	995	0.1172;
80	0.708	4000	3948	994	0.1197;
81	0.717	4000	3947	994	0.1197;
82	0.726	4000	3945	994	0.1197;
83	0.735	4000	3944	994	0.1160;
84	0.744	4000	3944	993	0.1129;
85	0.753	4000	3943	993	0.1184;
86	0.761	4000	3943	993	0.1166;
87	0.770	4000	3943	993	0.1111;
88	0.779	4000	3943	993	0.1111;
89	0.788	4000	3943	993	0.1111;
90	0.797	4000	3943	993	0.1111;
91	0.806	4000	3943	993	0.1111;
92	0.815	4000	3943	993	0.1111;
93	0.823	4000	3943	993	0.1111;
94	0.832	4000	3943	993	0.1111;
95	0.841	4000	3943	993	0.1111;
96	0.850	4000	3943	993	0.1111;
97	0.859	4000	3943	993	0.1111;
98	0.868	4000	3943	993	0.1111;
99	0.877	4000	3943	993	0.1111;
100	0.885	4000	3943	993	0.1111;
101	0.894	4000	3943	993	0.1111;

102	0.903	4000	3943	993	0.1111;
103	0.912	4000	3943	993	0.1111;
104	0.921	4000	3943	993	0.1111;
105	0.930	4000	3943	993	0.1111;
106	0.939	4000	3943	993	0.1111;
107	0.947	4000	3943	993	0.1111;
108	0.956	4000	3943	993	0.1111;
109	0.965	4000	3943	993	0.1111;
110	0.974	4000	3943	993	0.1111;
111	0.983	4000	3943	993	0.1111;
112	0.992	4000	3943	993	0.1111;
113	1.001	4000	3943	993	0.1111;
114	1.009	0	3918	993	-4.8840;
115	1.018	0	3849	985	-4.8840;
116	1.027	0	3751	962	-4.8840;
117	1.036	0	3625	926	-4.8840;
118	1.045	0	3457	882	-4.8840;
119	1.054	0	3246	831	-4.1361;
120	1.063	0	3007	771	-3.3901;
121	1.071	0	2741	702	-2.5830;
122	1.080	0	2447	626	-1.7143;
123	1.089	0	2134	546	-0.8974;
124	1.098	0	1814	463	-0.2027;
125	1.107	0	1496	379	0.4096;
126	1.116	0	1184	296	0.9652;
127	1.124	0	880	217	1.4670;
128	1.133	0	589	143	1.9011;
129	1.142	0	317	75	2.2479;
130	1.151	0	72	12	2.4530;
131	1.160	0	-143	-45	2.5519;
132	1.169	0	-329	-93	2.6105;
133	1.178	0	-487	-131	2.6197;
134	1.186	0	-614	-162	2.5531;
135	1.195	0	-711	-185	2.4219;
136	1.204	0	-779	-202	2.2534;
137	1.213	0	-821	-213	2.0678;
138	1.222	0	-842	-217	1.8700;
139	1.231	0	-843	-218	1.6893;
140	1.240	0	-825	-213	1.4231;
141	1.248	0	-790	-204	1.1886;
142	1.257	0	-742	-191	0.9591;
143	1.266	0	-684	-176	0.7295;
144	1.275	0	-617	-158	0.5098;

145	1.284	0	-544	-139	0.3010;
146	1.293	0	-468	-119	0.1178;
147	1.302	0	-390	-99	-0.0592;
148	1.310	0	-311	-79	-0.2155;
149	1.319	0	-235	-59	-0.3443;
150	1.328	0	-162	-41	-0.4469;
151	1.337	0	-95	-23	-0.5324;
152	1.346	0	-33	-8	-0.5879;
153	1.355	0	22	6	-0.6233;
154	1.364	0	69	18	-0.6355;
155	1.372	0	109	29	-0.6368;
156	1.381	0	141	37	-0.6166;
157	1.390	0	166	43	-0.5842;
158	1.399	0	183	47	-0.5421;
159	1.408	0	194	50	-0.4921;
160	1.417	0	198	51	-0.4353;
161	1.426	0	198	51	-0.3871;
162	1.434	0	193	51	-0.3107;
163	1.443	0	183	48	-0.2619;
164	1.452	0	170	45	-0.2057;
165	1.461	0	155	41	-0.1453;
166	1.470	0	139	37	-0.0971;
167	1.479	0	121	32	-0.0556;
168	1.488	0	104	27	-0.0171;
169	1.496	0	86	23	0.0165;
170	1.505	0	69	19	0.0415;
171	1.514	0	53	14	0.0653;
172	1.523	0	38	11	0.0830;
173	1.532	0	24	7	0.0965;
174	1.541	0	12	4	0.1001;
175	1.549	0	2	2	0.1093;
176	1.558	0	-7	-1	0.1020;
177	1.567	0	-13	-2	0.0983;
178	1.576	0	-18	-4	0.0897;
179	1.585	0	-22	-5	0.0794;
180	1.594	0	-24	-5	0.0629;
181	1.603	0	-24	-5	0.0482;
182	1.611	0	-24	-5	0.0464;
183	1.620	0	-22	-5	0.0464;
184	1.629	0	-20	-5	0.0122;
185	1.638	0	-17	-5	-0.0018;
186	1.647	0	-13	-3	-0.0177;
187	1.656	0	-9	-3	-0.0269;

188	1.665	0	-5	-1	-0.0330;
189	1.673	0	-1	-0	-0.0421;
190	1.682	0	3	1	-0.0470;
191	1.691	0	6	1	-0.0476;
192	1.700	0	9	2	-0.0482;
193	1.709	0	12	3	-0.0476;
194	1.718	0	14	3	-0.0495;
195	1.727	0	15	4	-0.0488;
196	1.735	0	16	4	-0.0440;
197	1.744	0	17	4	-0.0446;
198	1.753	0	17	4	-0.0379;
199	1.762	0	18	5	-0.0421;
200	1.771	0	18	5	-0.0354;
201	1.780	0	18	5	-0.0354;
202	1.789	0	17	5	-0.0354;
203	1.797	0	17	5	-0.0324;
204	1.806	0	17	5	-0.0324;
205	1.815	0	16	5	-0.0269;
206	1.824	0	15	5	-0.0244;
207	1.833	0	15	5	-0.0281;
208	1.842	0	15	5	-0.0299;
209	1.851	0	15	5	-0.0299;
210	1.859	0	15	5	-0.0299;
211	1.868	0	15	5	-0.0299;
212	1.877	0	15	5	-0.0299;
213	1.886	0	15	5	-0.0299;
214	1.895	0	15	5	-0.0299;
215	1.904	0	15	5	-0.0299;
216	1.913	0	15	5	-0.0299;
217	1.921	0	15	5	-0.0299;
218	1.930	0	15	5	-0.0299;
219	1.939	0	15	5	-0.0299;
220	1.948	0	15	5	-0.0299;
221	1.957	0	15	5	-0.0299;
222	1.966	0	15	5	-0.0299;
223	1.974	0	15	5	-0.0299;
224	1.983	0	15	5	-0.0299;
225	1.992	0	15	5	-0.0299]