Supporting information

Detection of engine misfire using characteristic harmonics of angular acceleration

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§1 Figures (The data are acquired from cylinder 1)

1.1 In-cylinder pressure traces

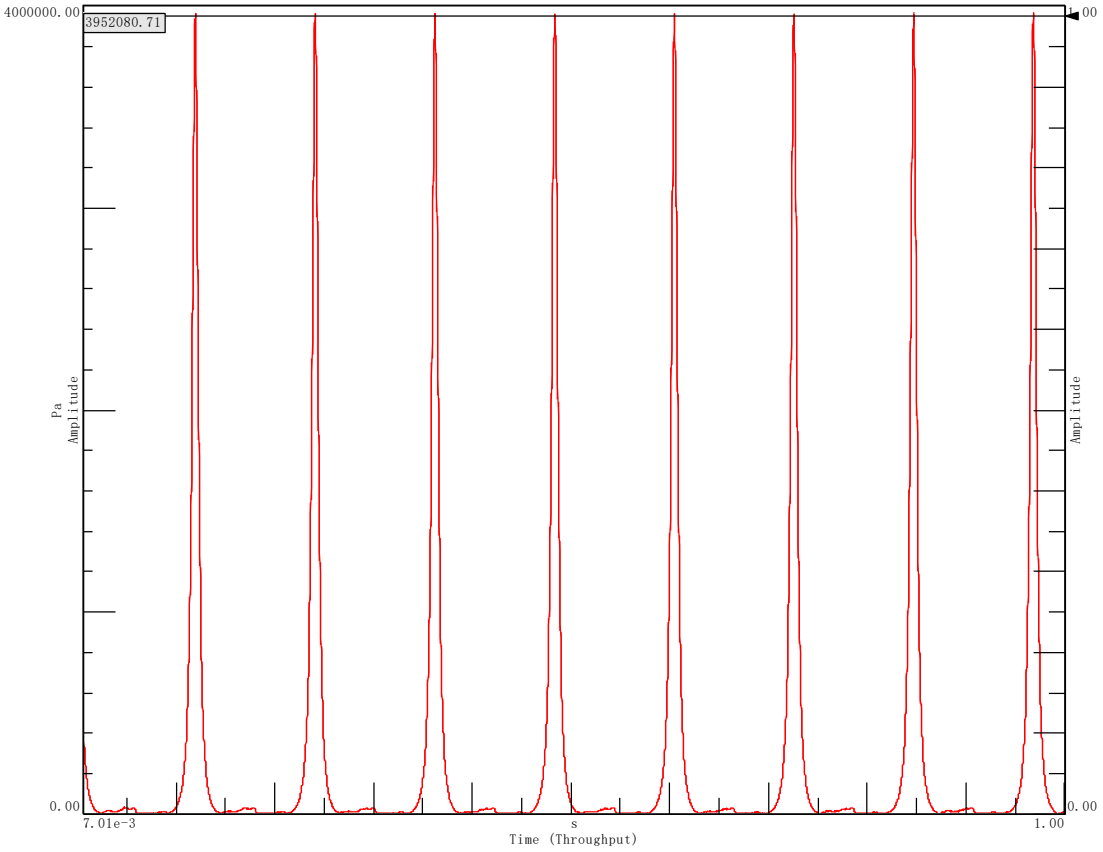

Figure SI1-1. In-cylinder pressure trace at 1000 rpm/no load, misfire.

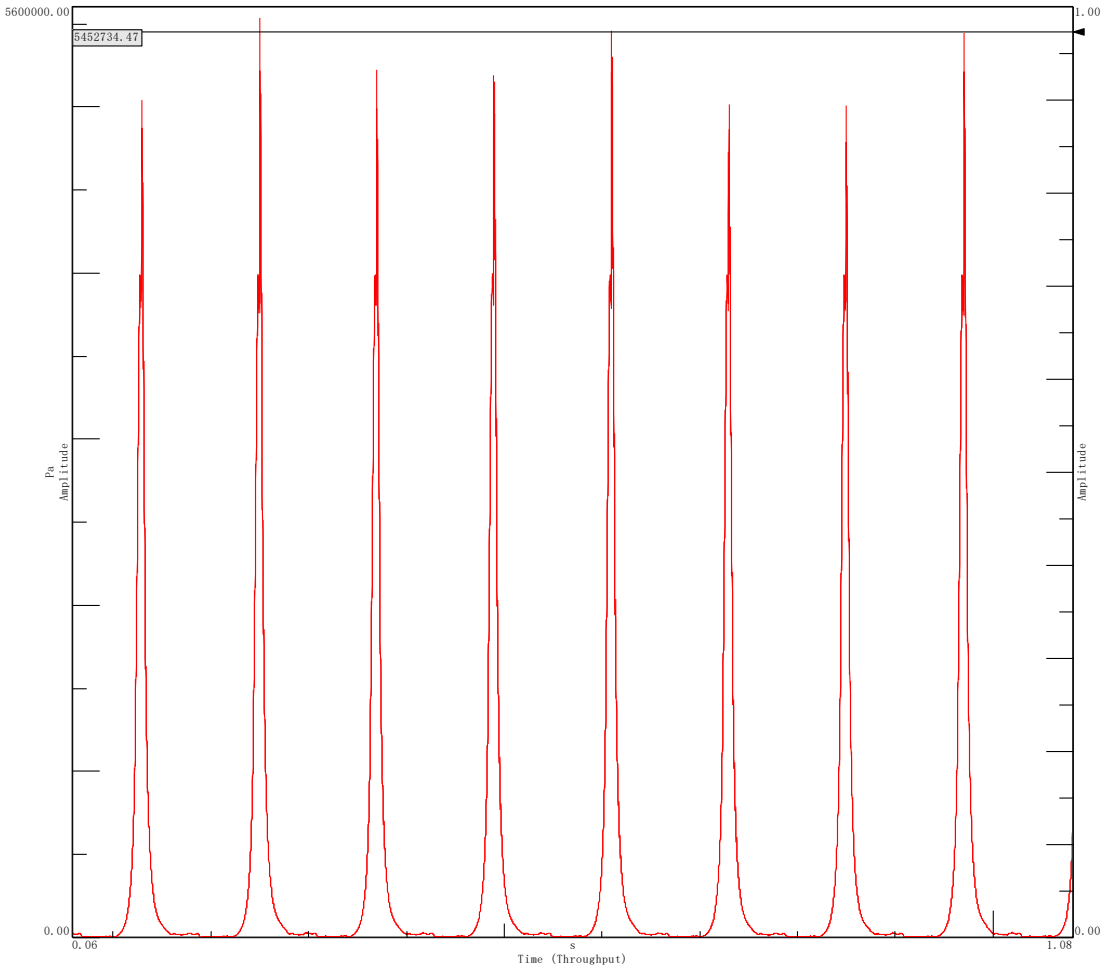

Figure SI1-2. In-cylinder pressure trace at 1000 rpm/no load, normal.

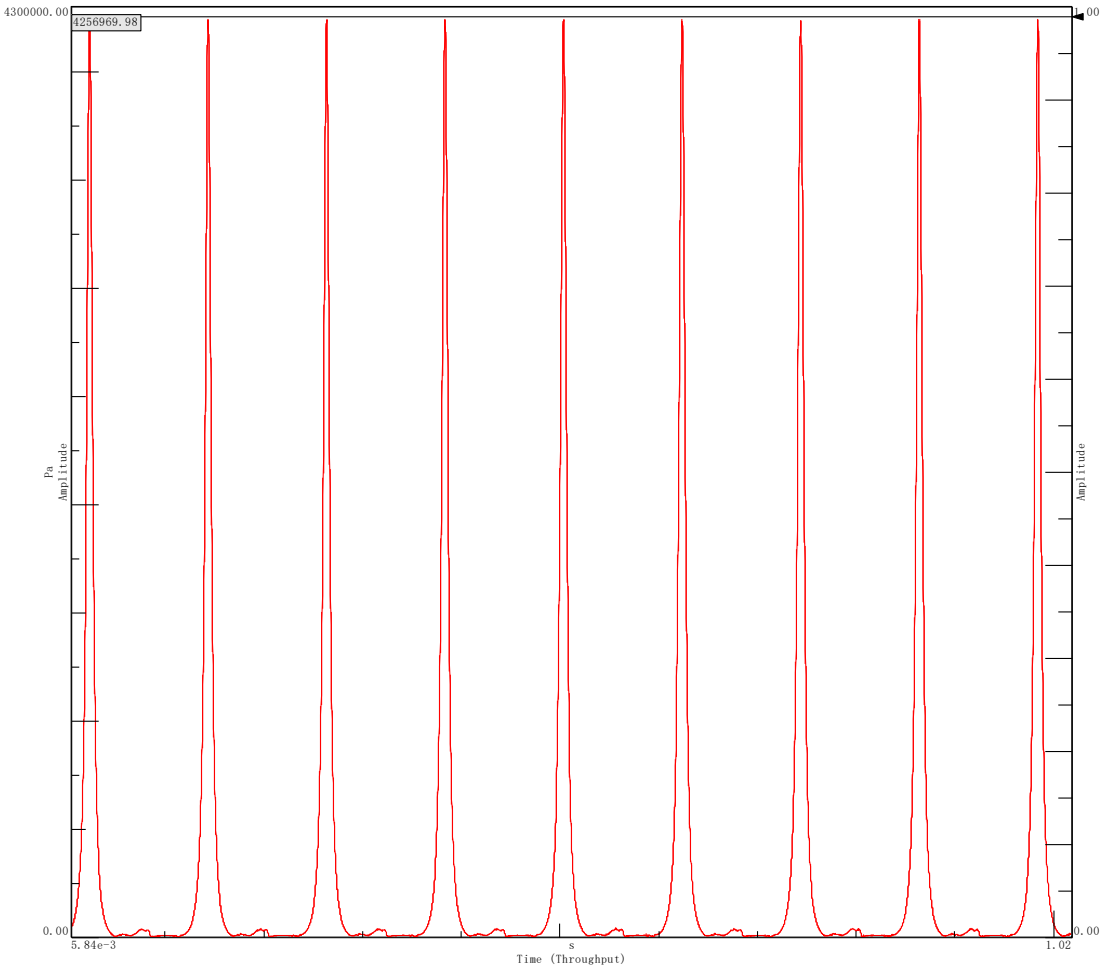

Figure SI1-3. In-cylinder pressure trace at 1000 rpm/200 Nm, misfire.

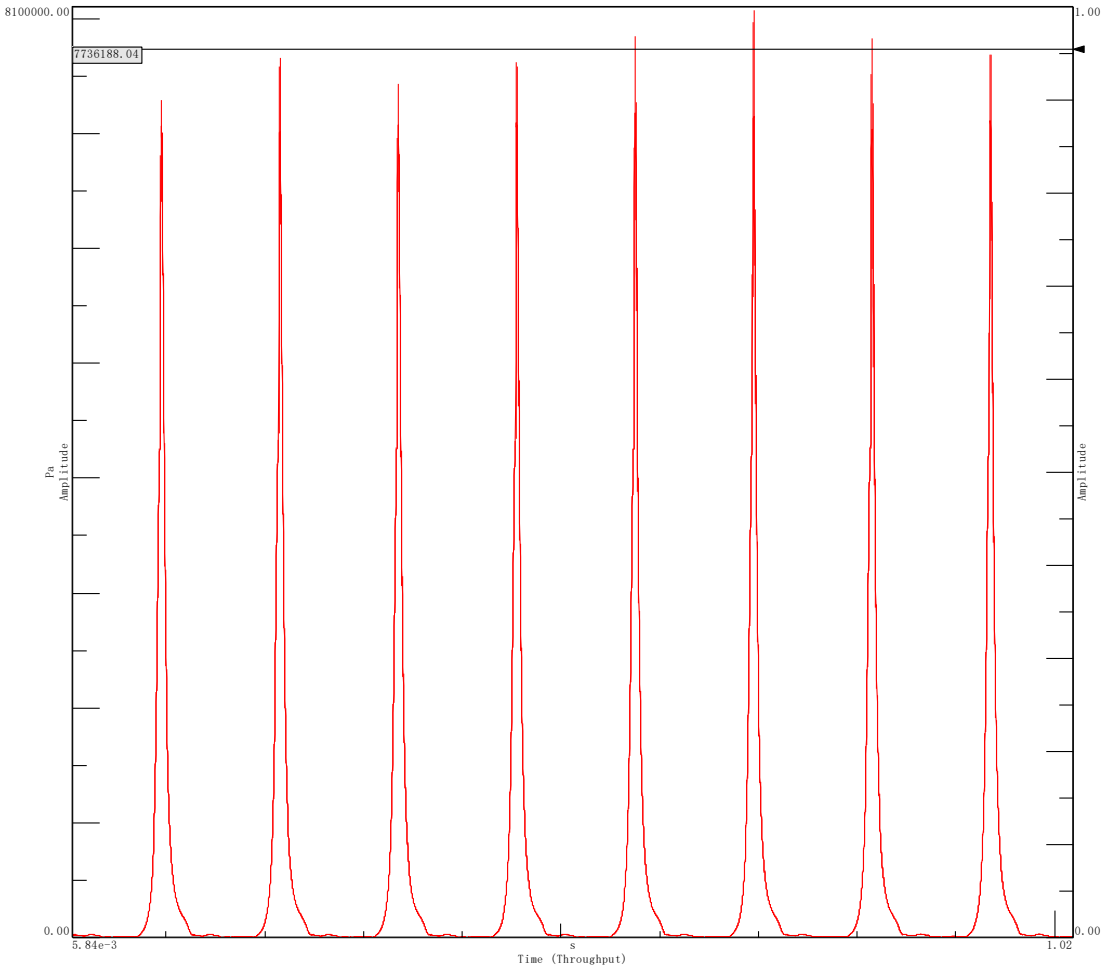

Figure SI1-4. In-cylinder pressure trace at 1000 rpm/200 Nm, normal.

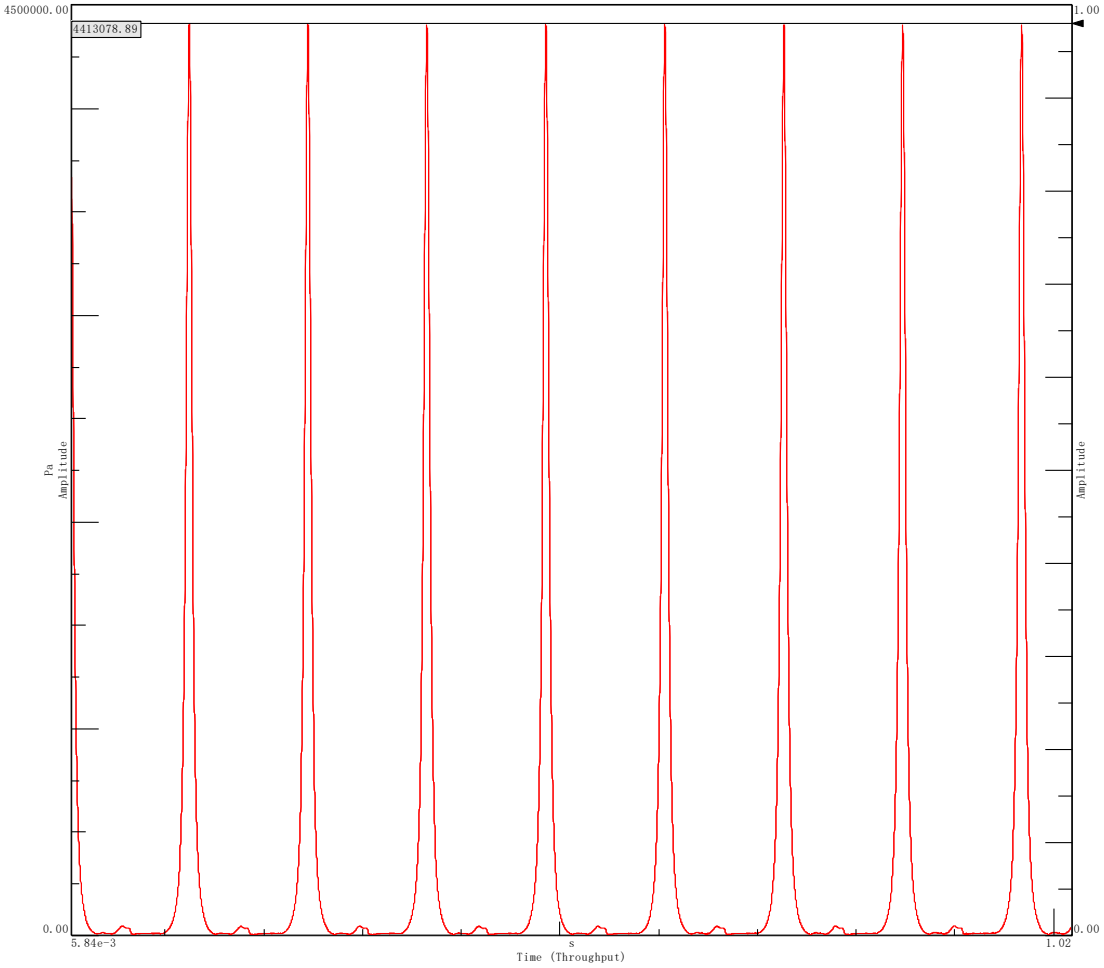

Figure SI1-5. In-cylinder pressure trace at 1000 rpm/300 Nm, misfire.

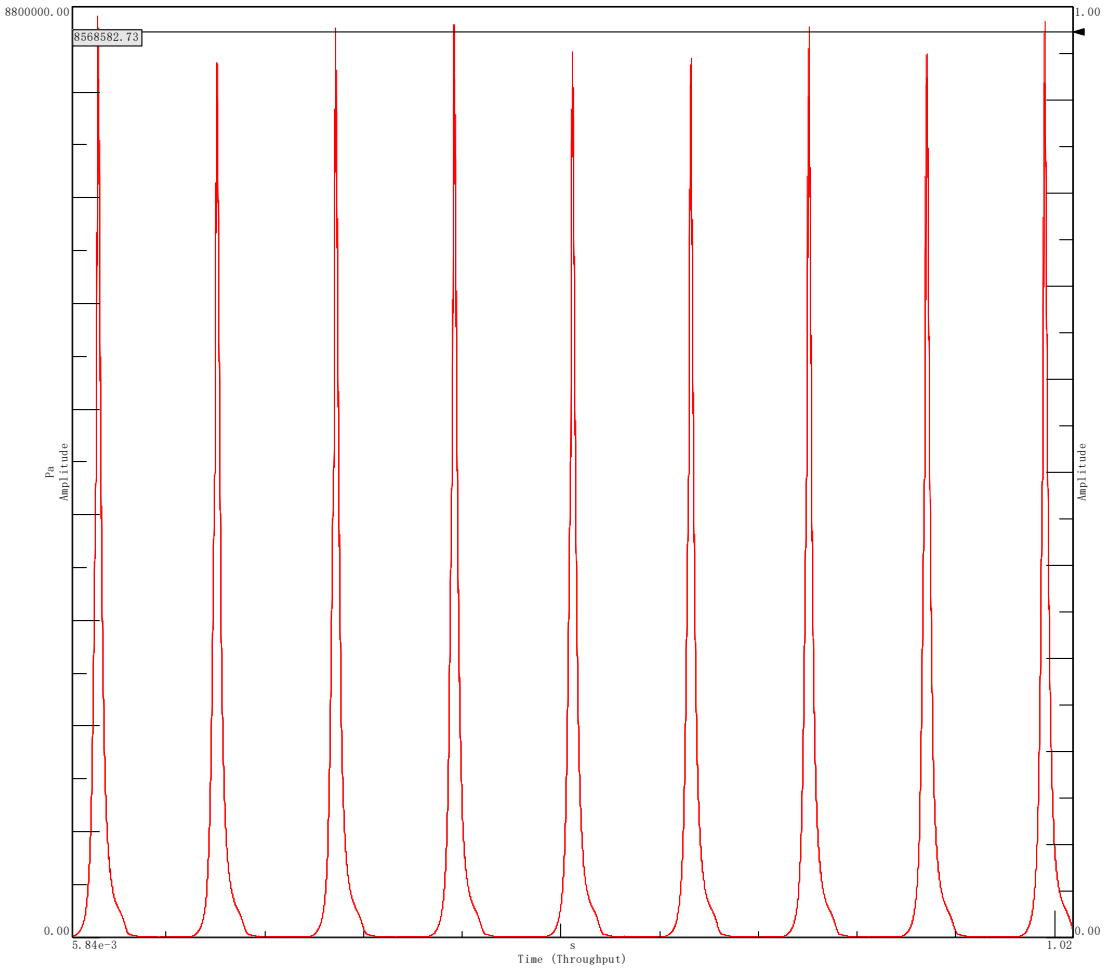

Figure SI1-6. In-cylinder pressure trace at 1000 rpm/300 Nm, normal.

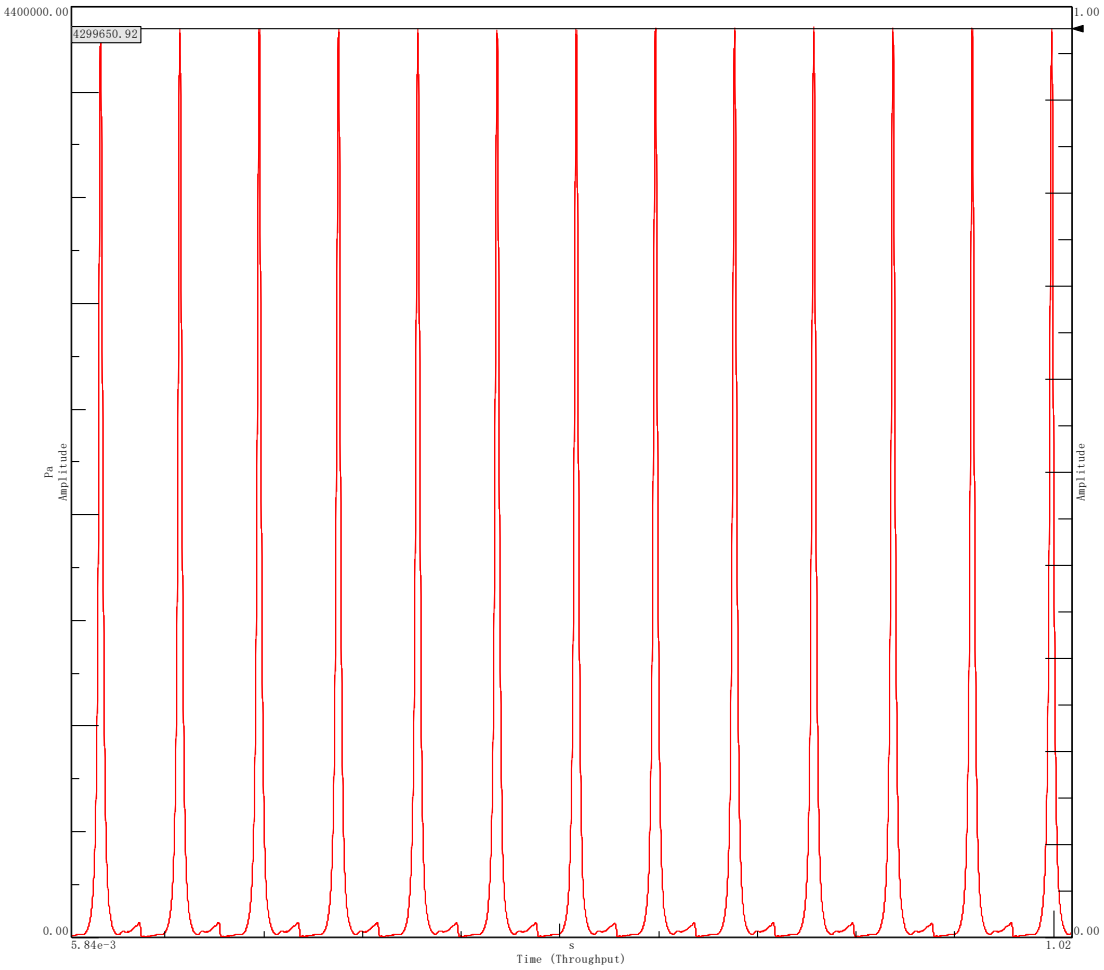

Figure SI1-7. In-cylinder pressure trace at 1500 rpm/no load, misfire.

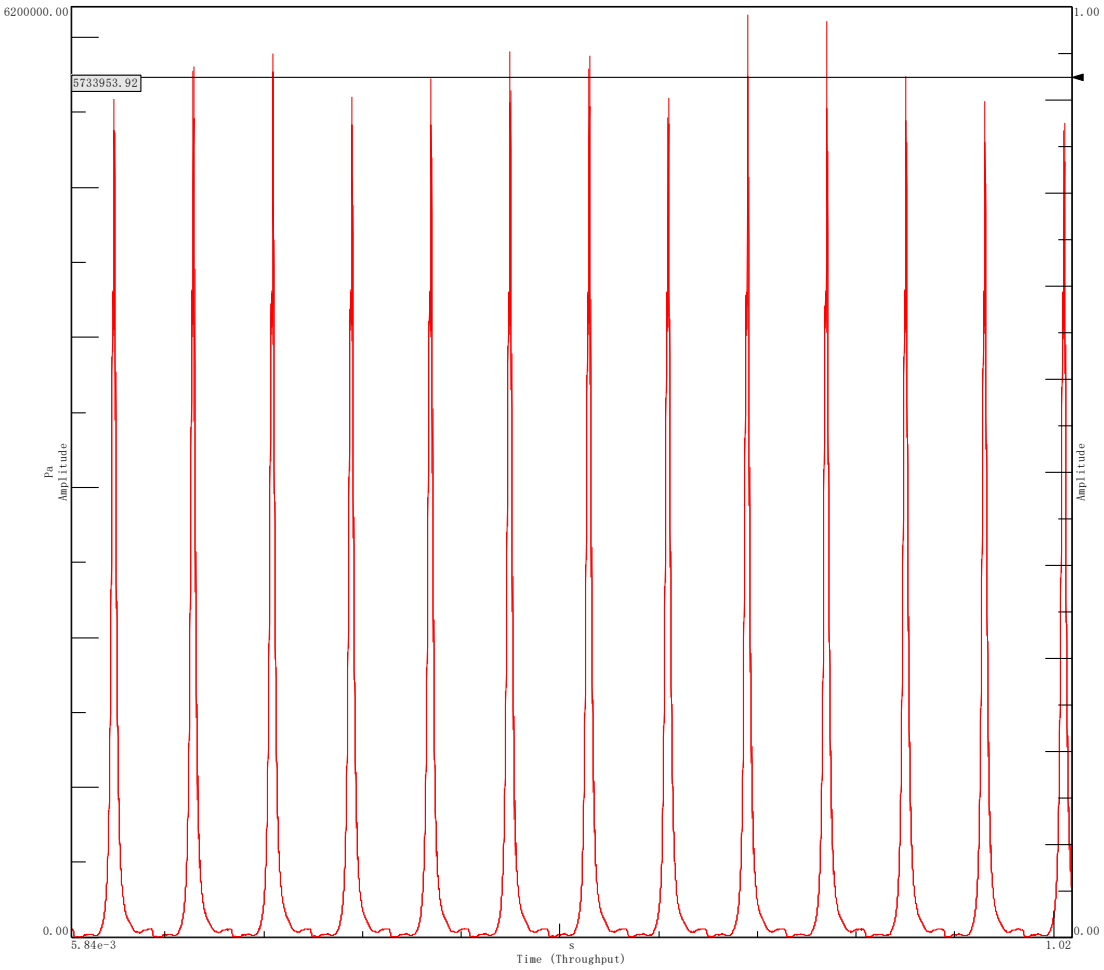

Figure SI1-8. In-cylinder pressure trace at 1500 rpm/no load, normal.

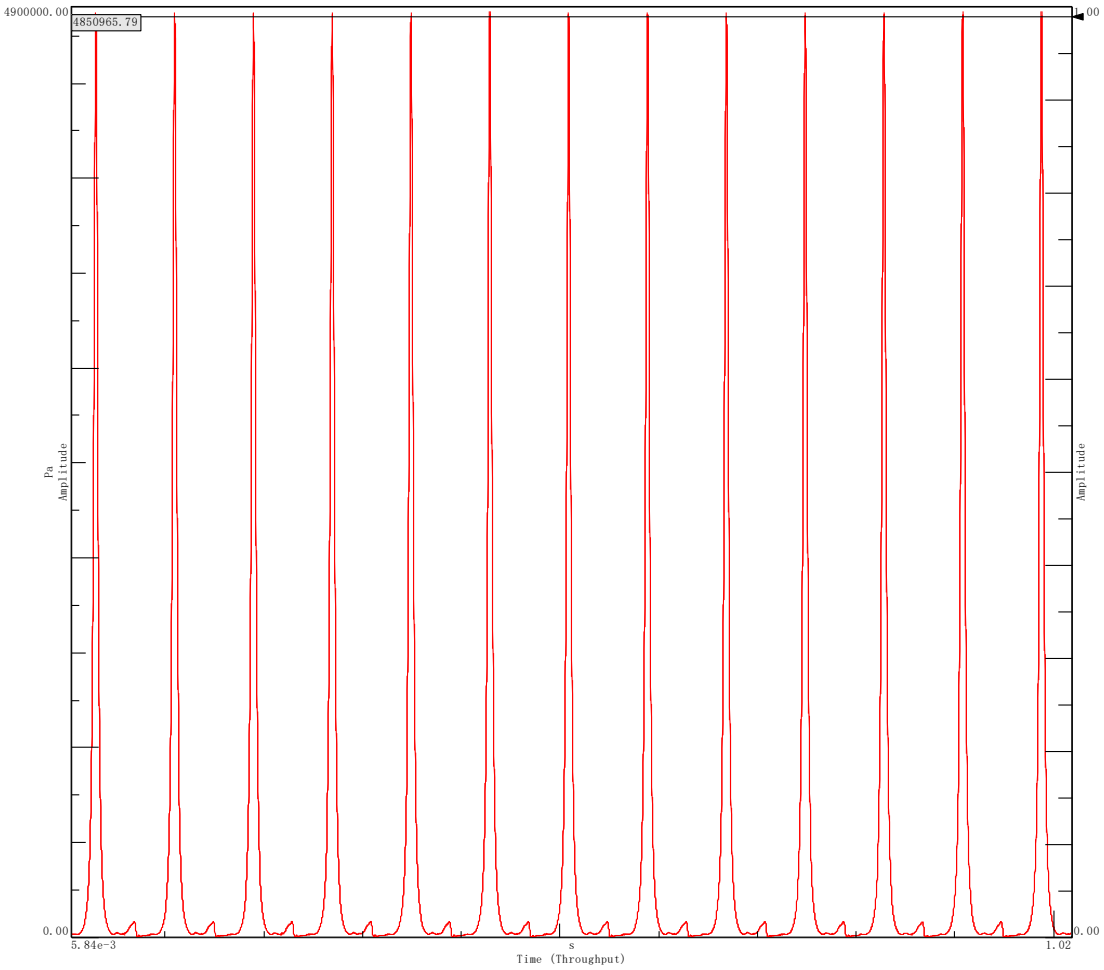

Figure SI1-9. In-cylinder pressure trace at 1500 rpm/200 Nm, misfire.

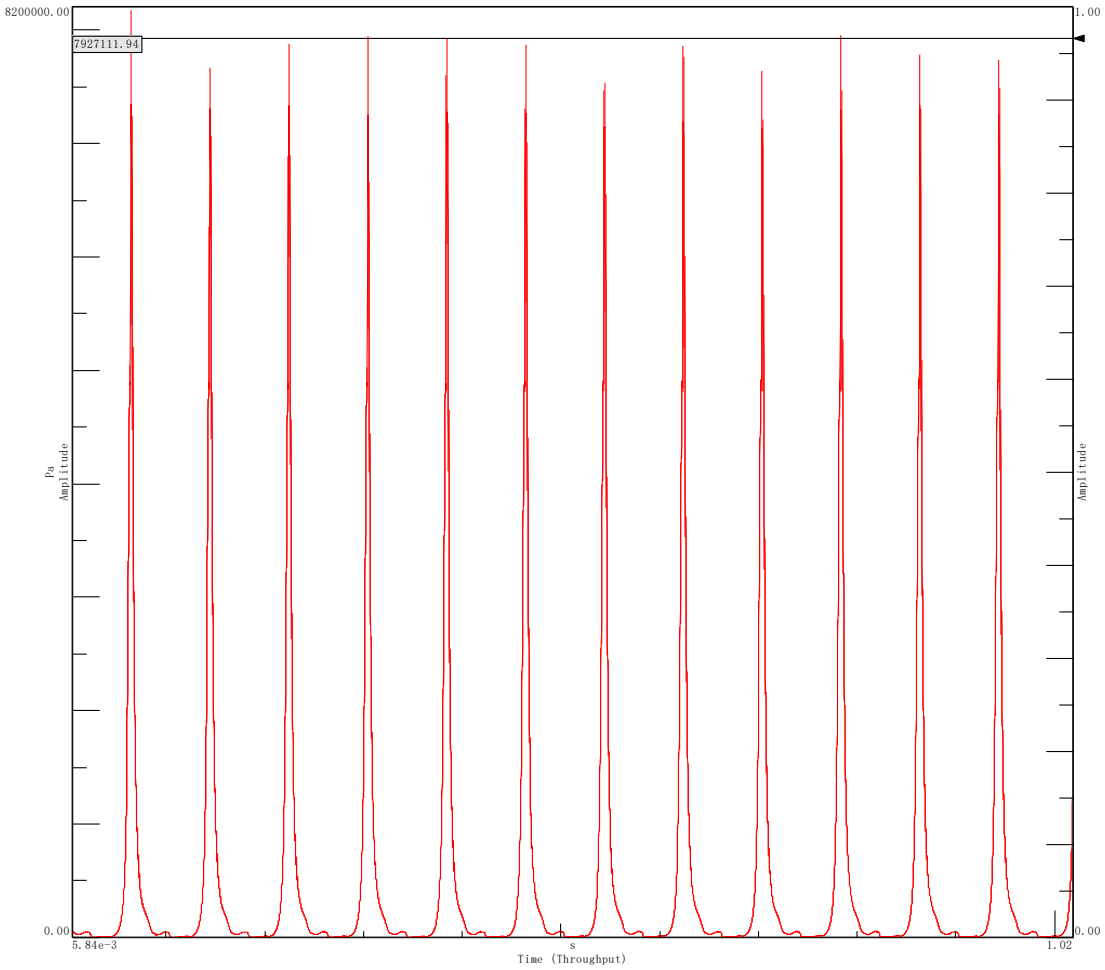

Figure SI1-10. In-cylinder pressure trace at 1500 rpm/200 Nm, normal.

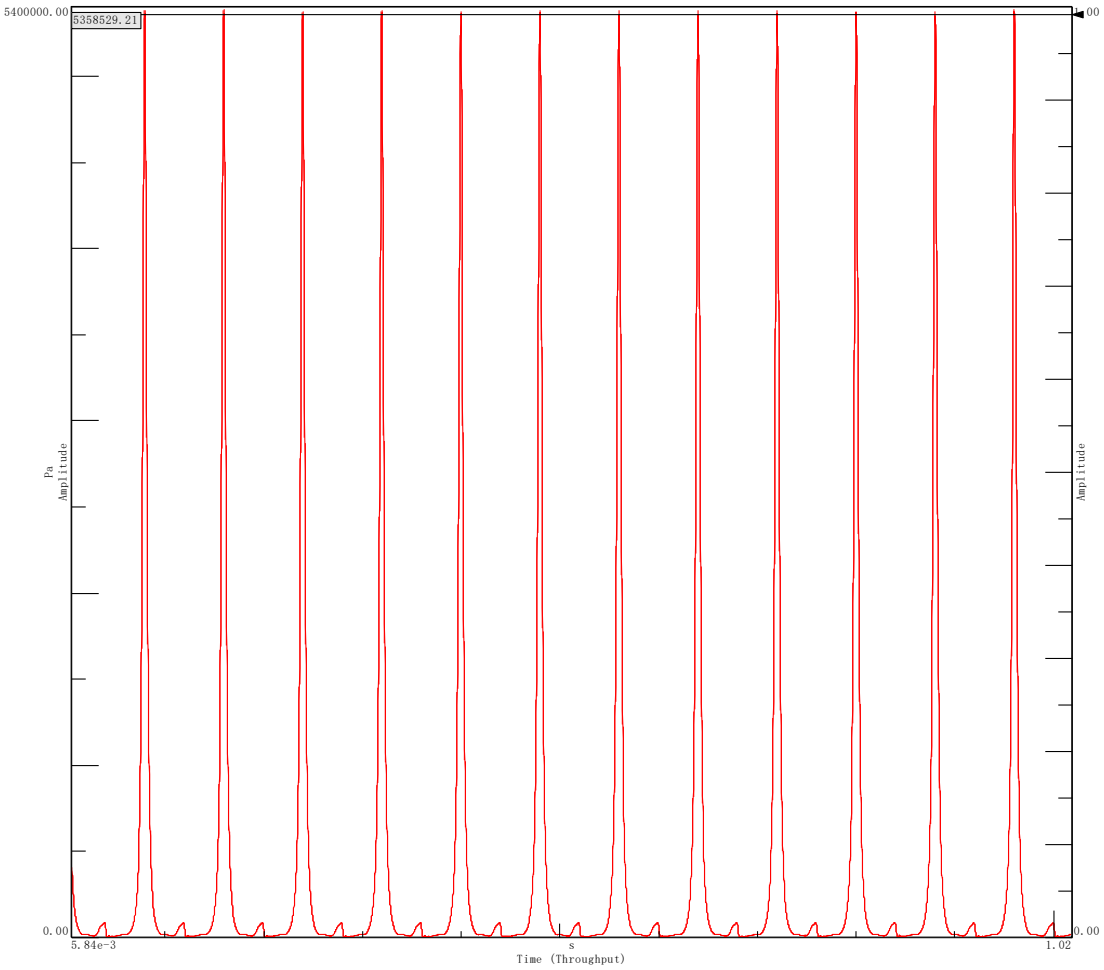

Figure SI1-11. In-cylinder pressure trace at 1500 rpm/300 Nm, misfire.

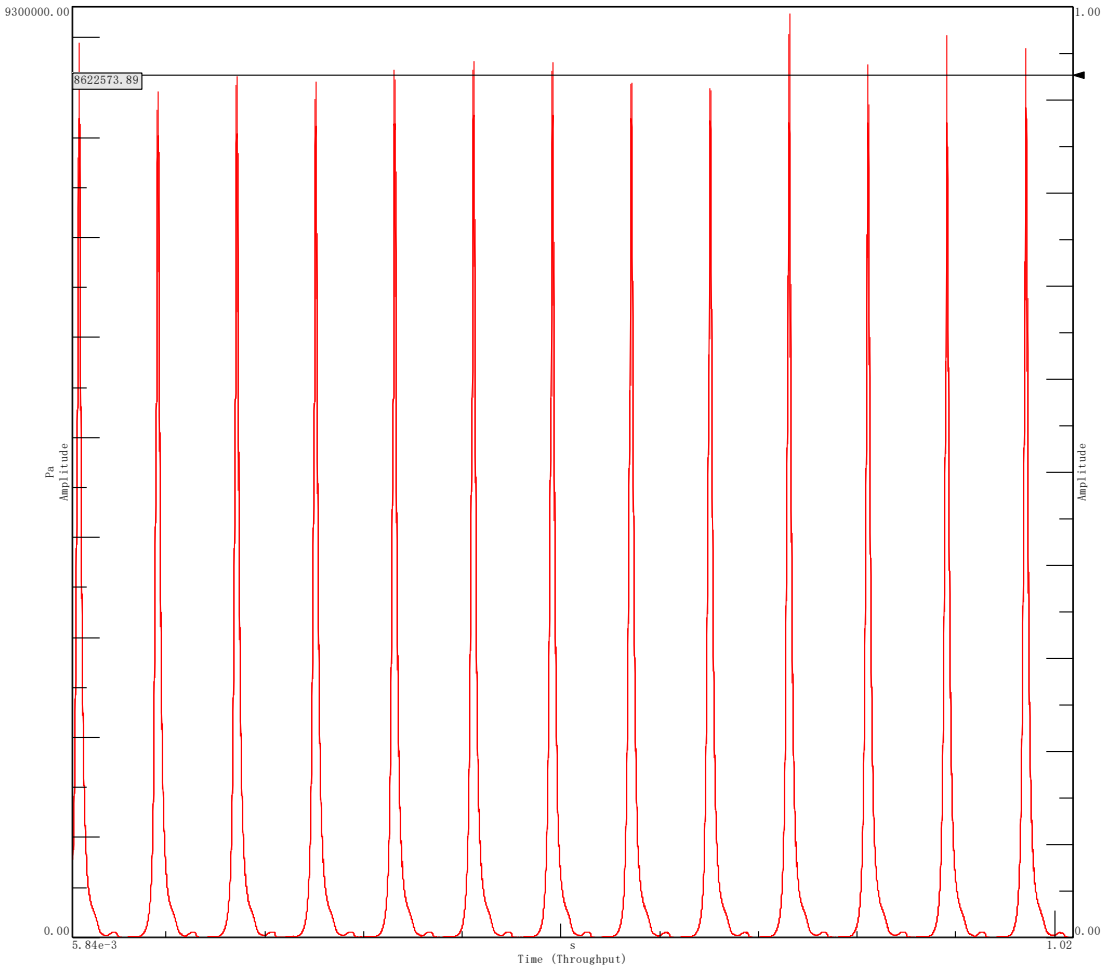

Figure SI1-12. In-cylinder pressure trace at 1500 rpm/300 Nm, normal.

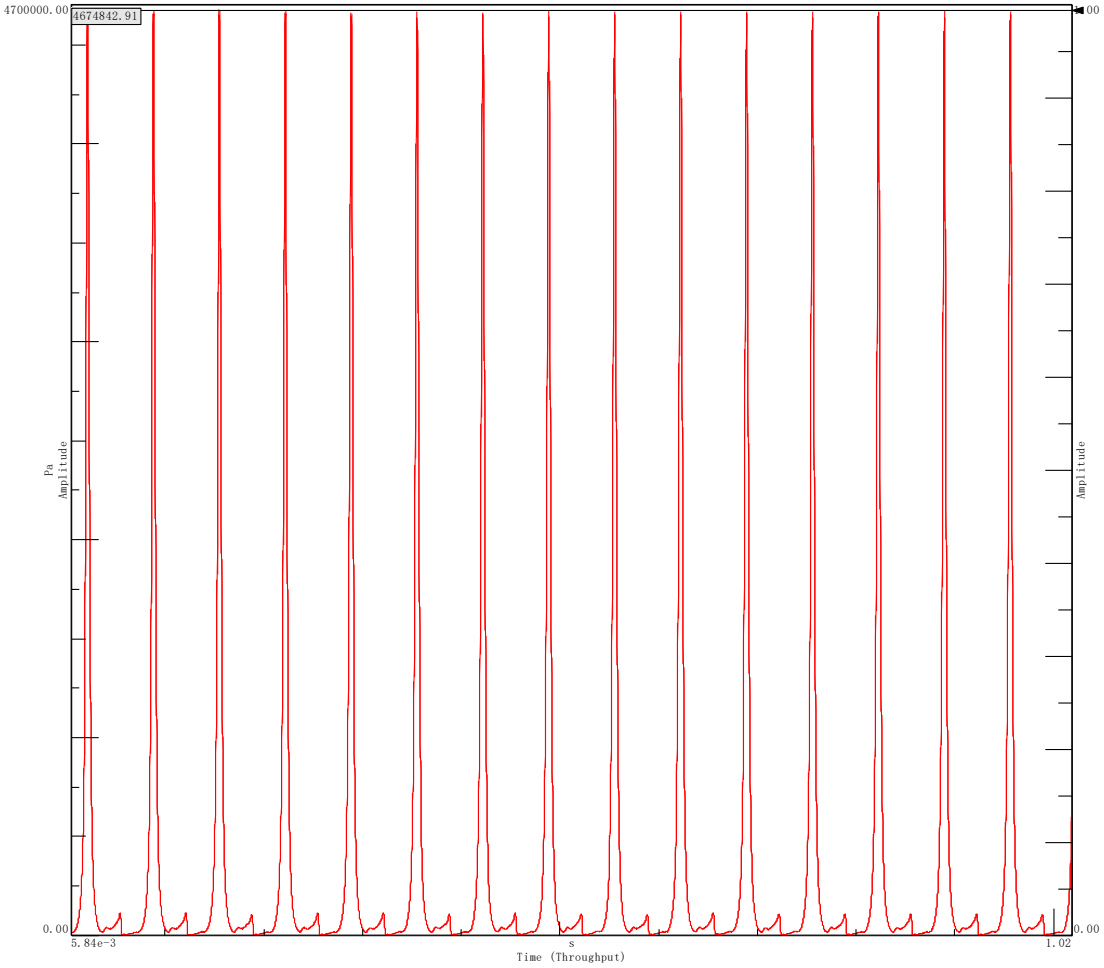

Figure SI1-13. In-cylinder pressure trace at 1800 rpm/no load, misfire.

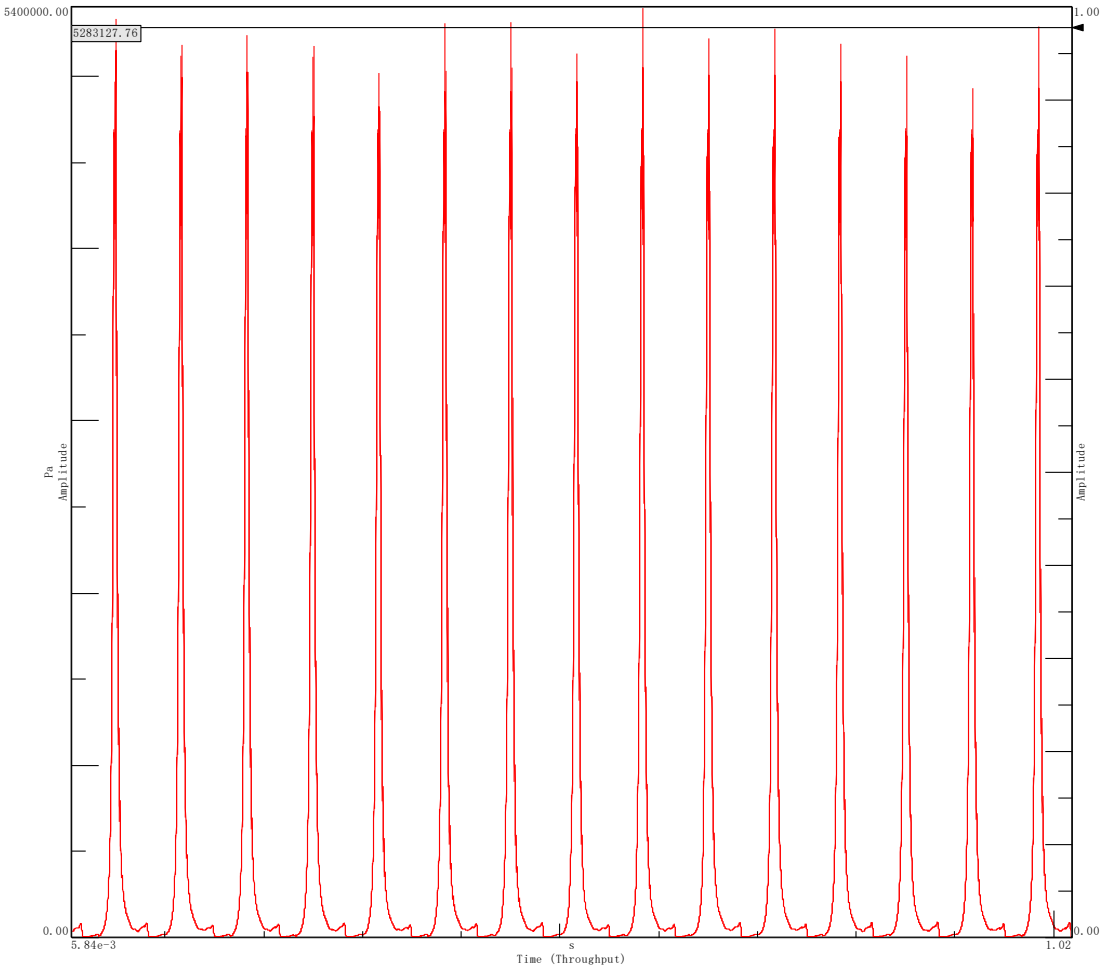

Figure SI1-14. In-cylinder pressure trace at 1800 rpm/no load, normal.

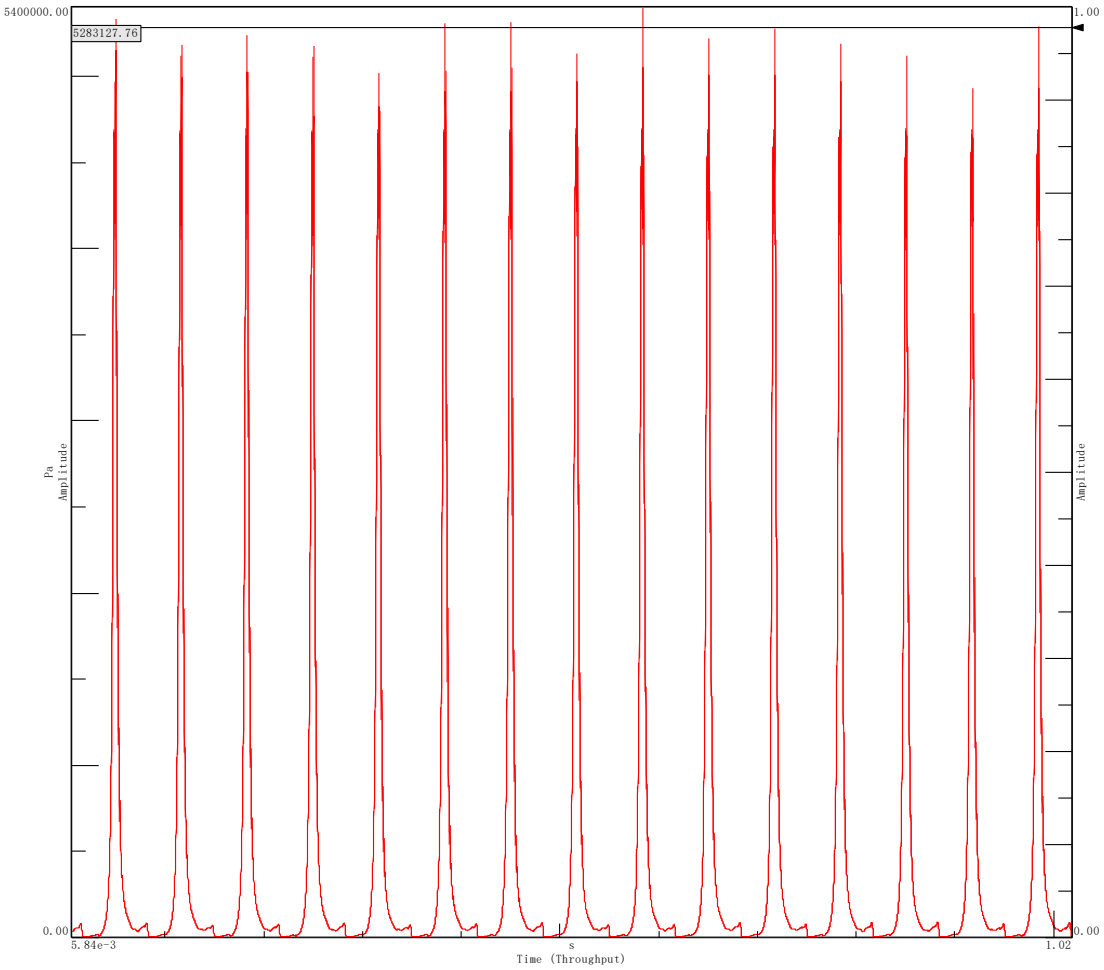

Figure SI1-15. In-cylinder pressure trace at 1800 rpm/200 Nm, misfire

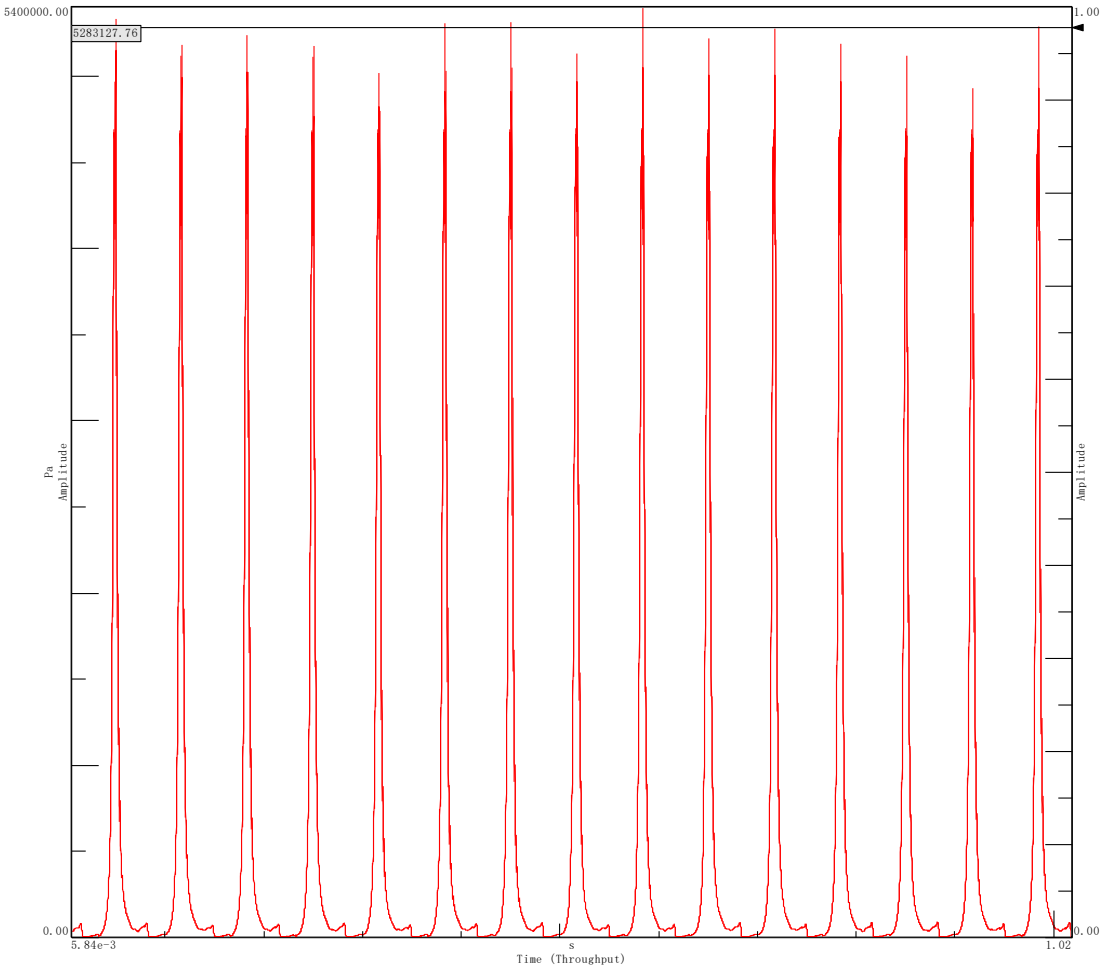

Figure SI1-16. In-cylinder pressure trace at 1800 rpm/200 Nm, normal.

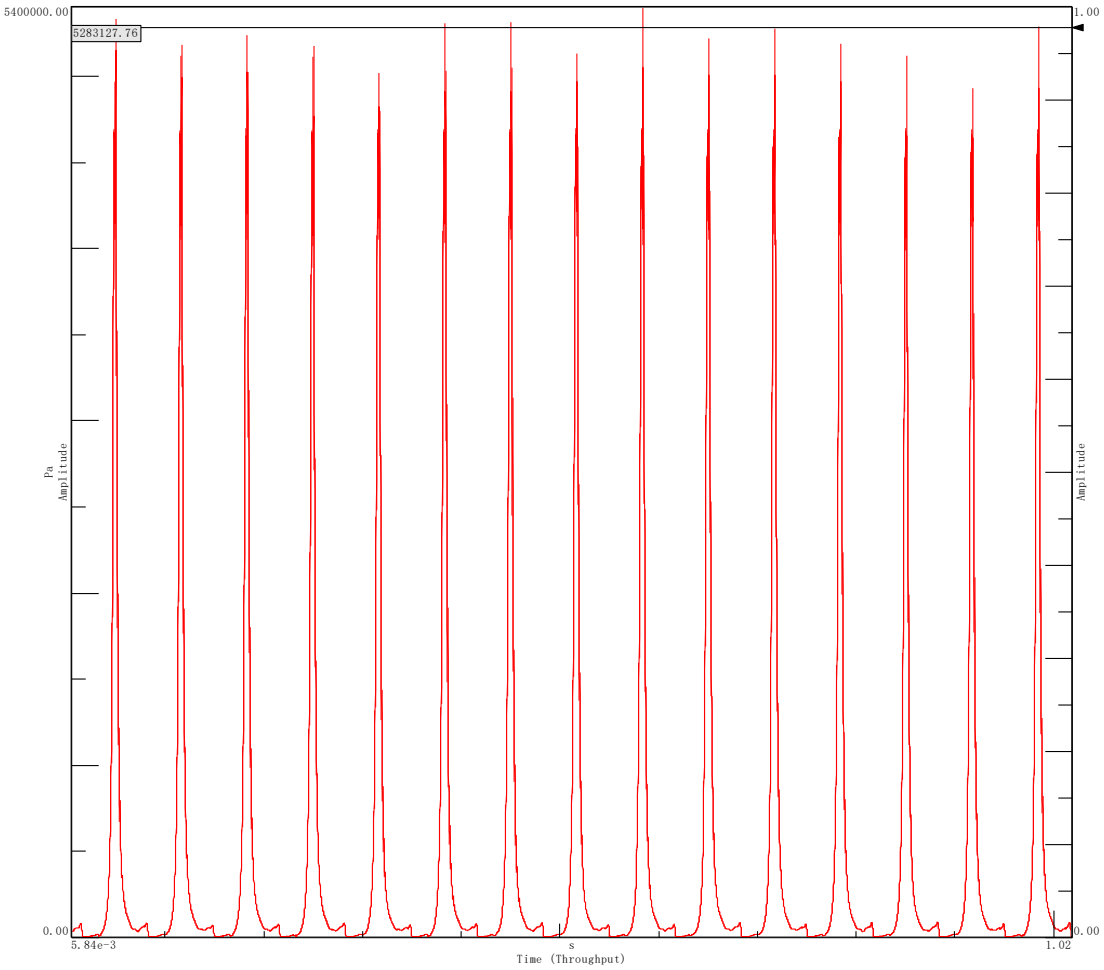

Figure SI1-17. In-cylinder pressure trace at 1800 rpm/300 Nm, misfire.

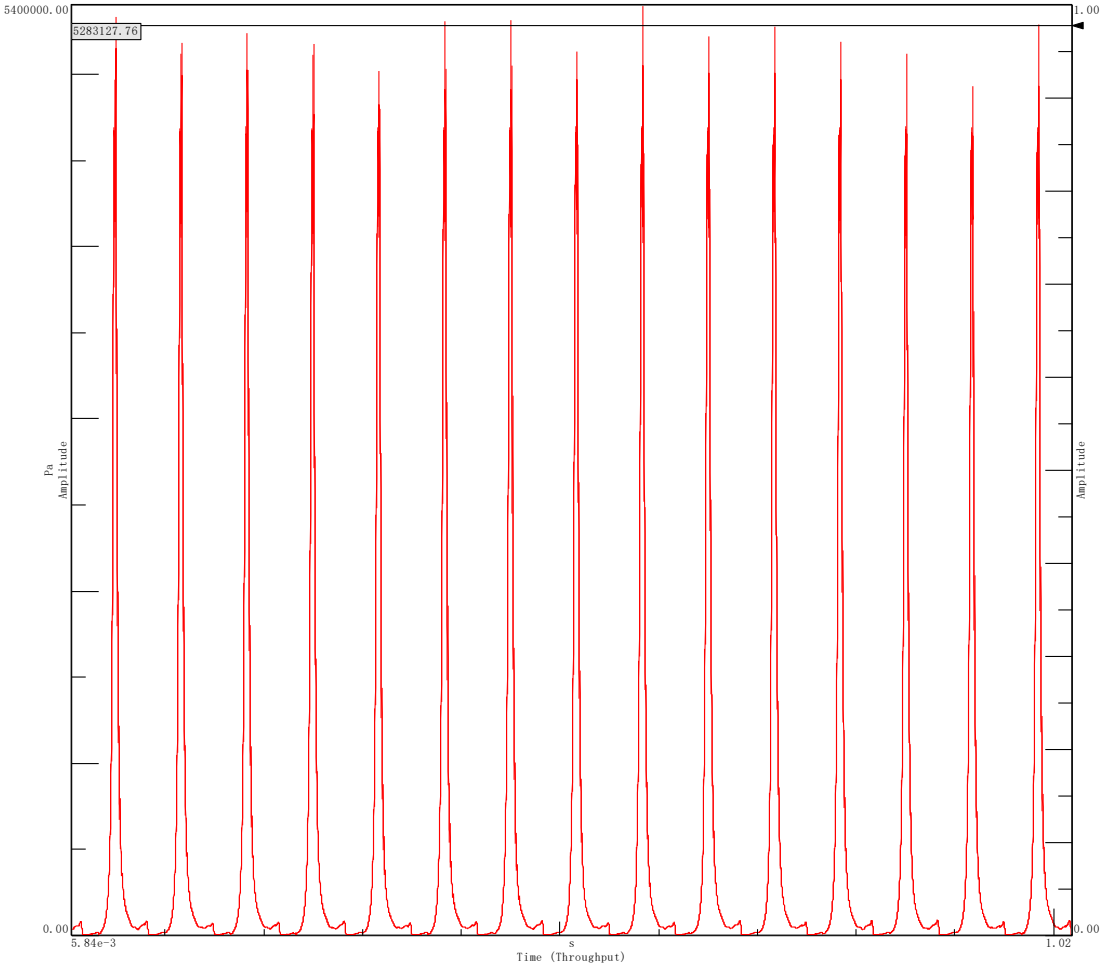

Figure SI1-18. In-cylinder pressure trace at 1800 rpm/300 Nm, normal.

1.2 Original data of instantaneous speed acquired from the measurement sensors

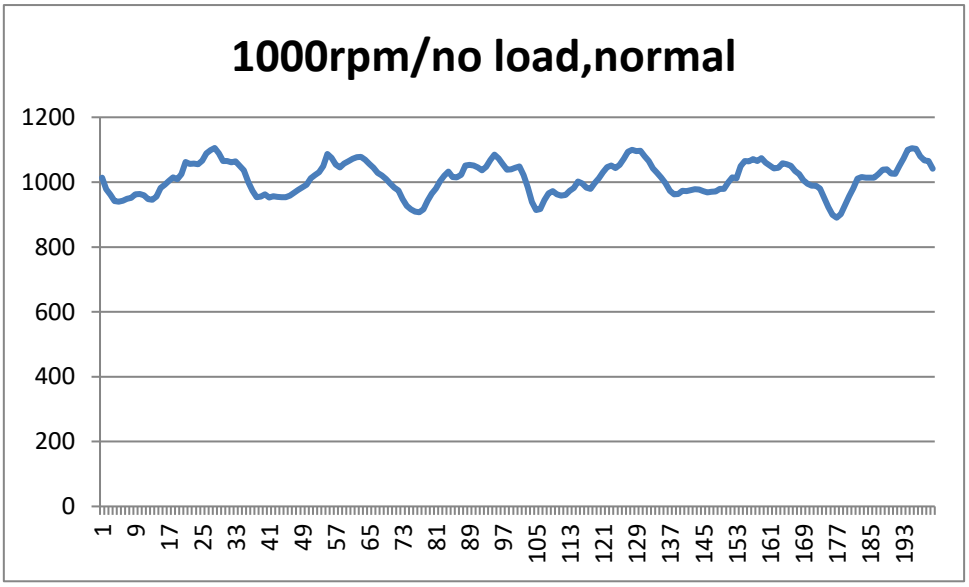

Figure SI2-1. 1000 rpm/no load, normal.

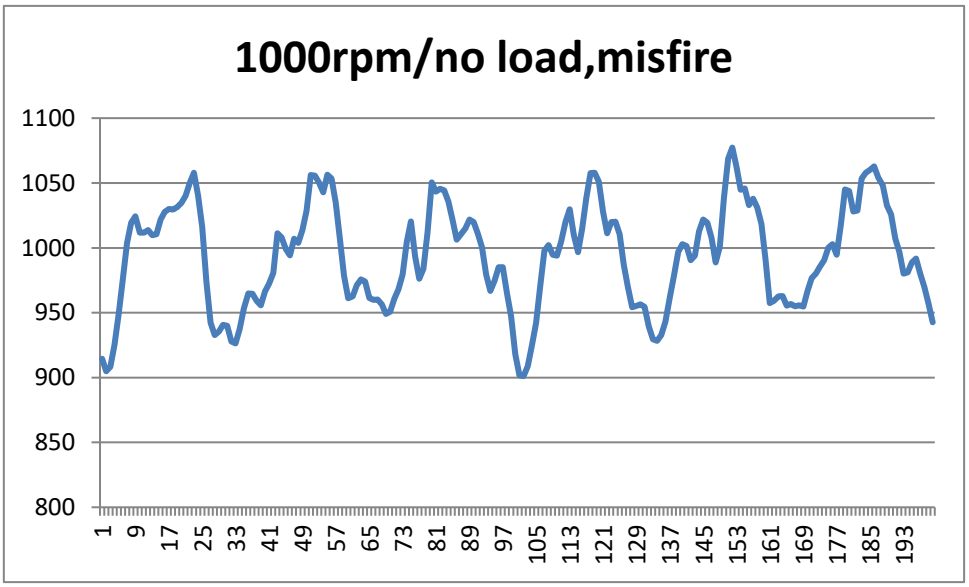

Figure SI2-2. 1000 rpm/no load, misfire.

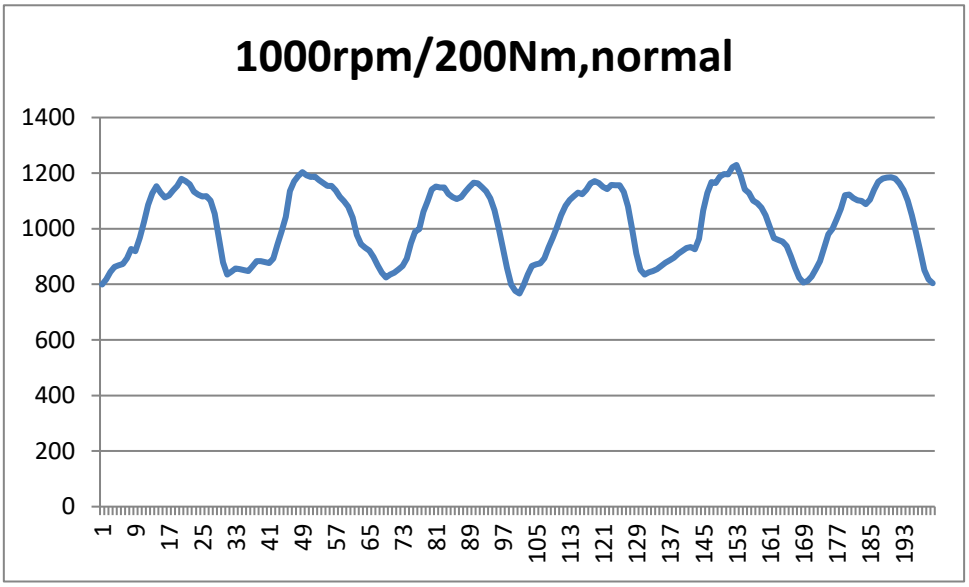

Figure SI2-3. 1000 rpm/200 Nm, normal.

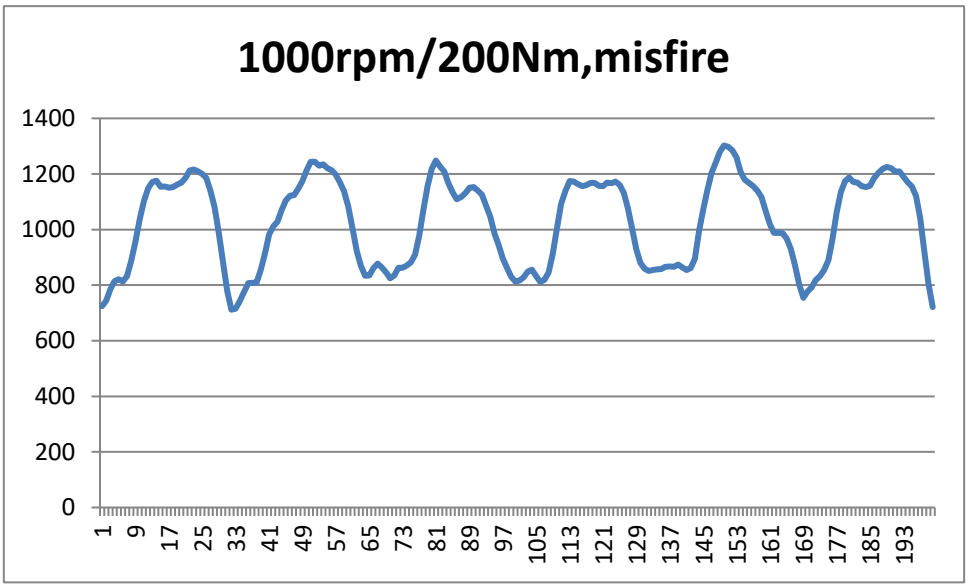

Figure SI2-4. 1000 rpm/200 Nm, misfire.

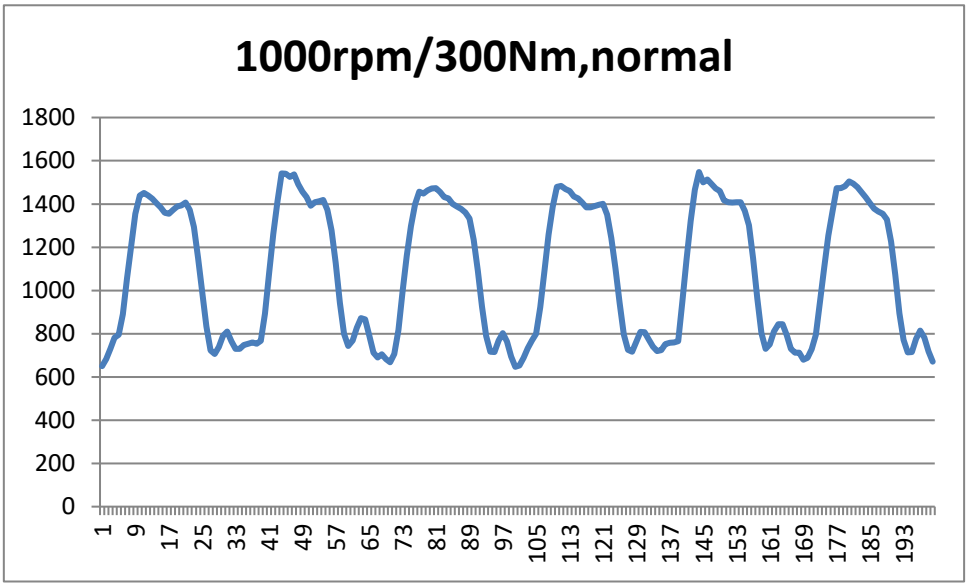

Figure SI2-5. 1000 rpm/300 Nm, normal.

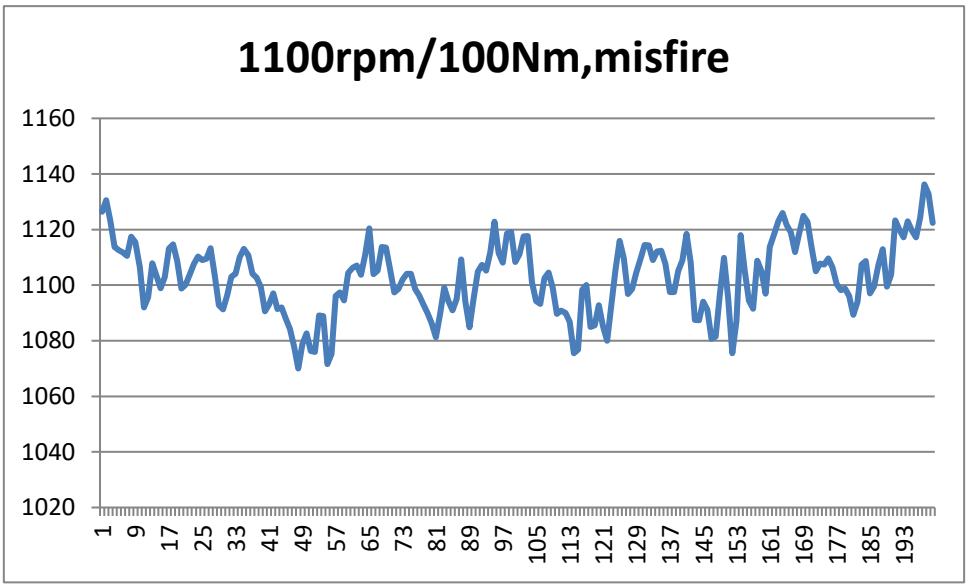

Figure SI2-6. 1100 rpm/100 Nm, misfire.

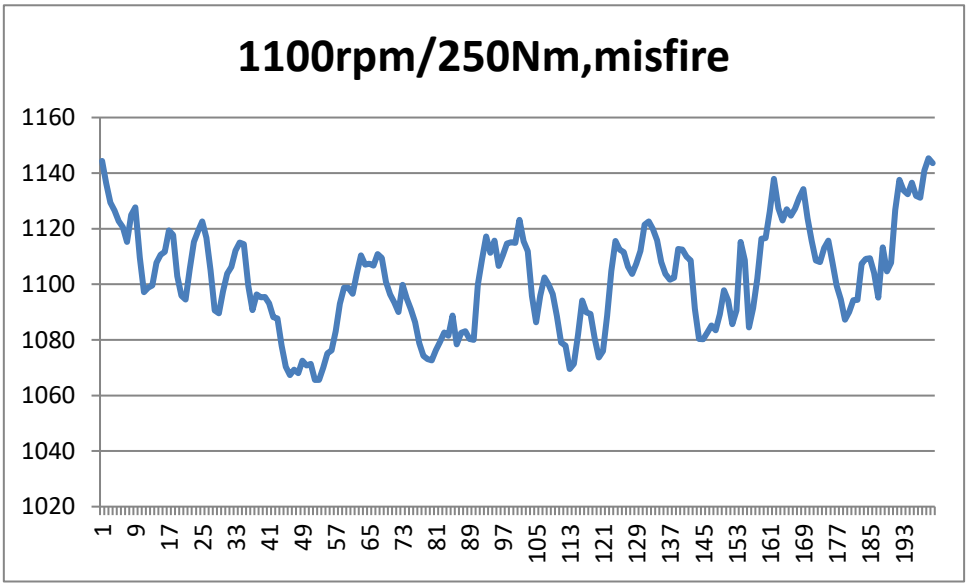

Figure SI2-7. 1100 rpm/250 Nm, misfire.

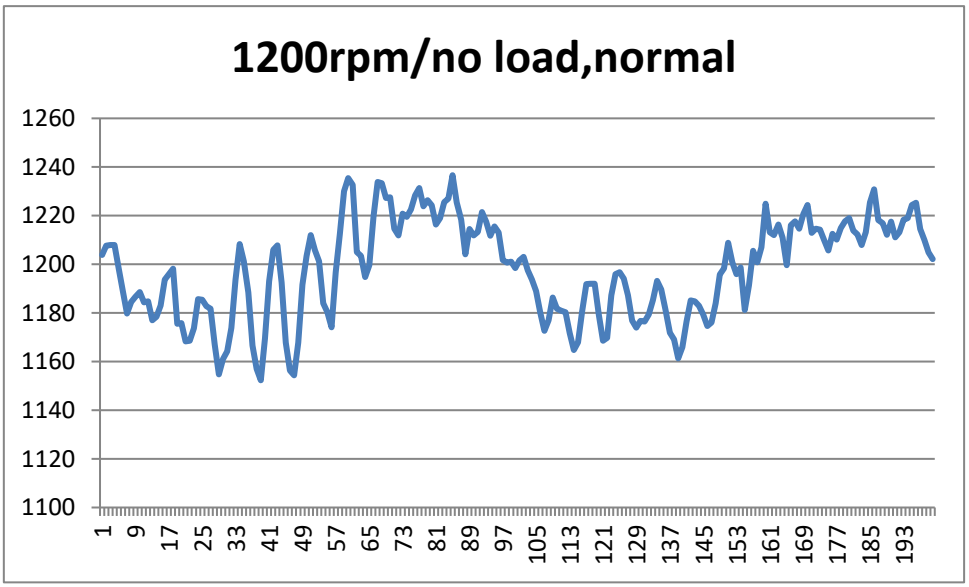

Figure SI2-8. 1200 rpm/no load, normal.

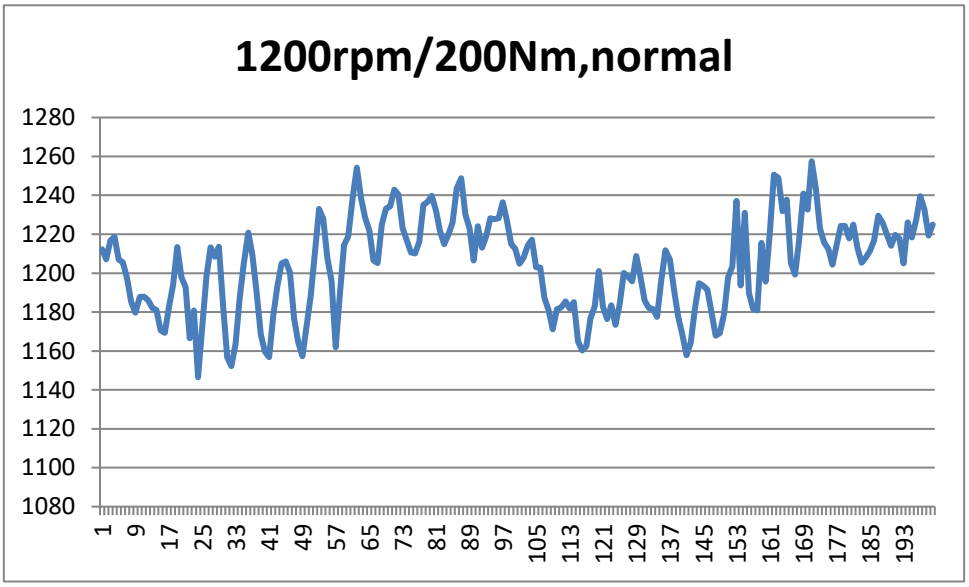

Figure SI2-9. 1200 rpm/200 Nm, normal.

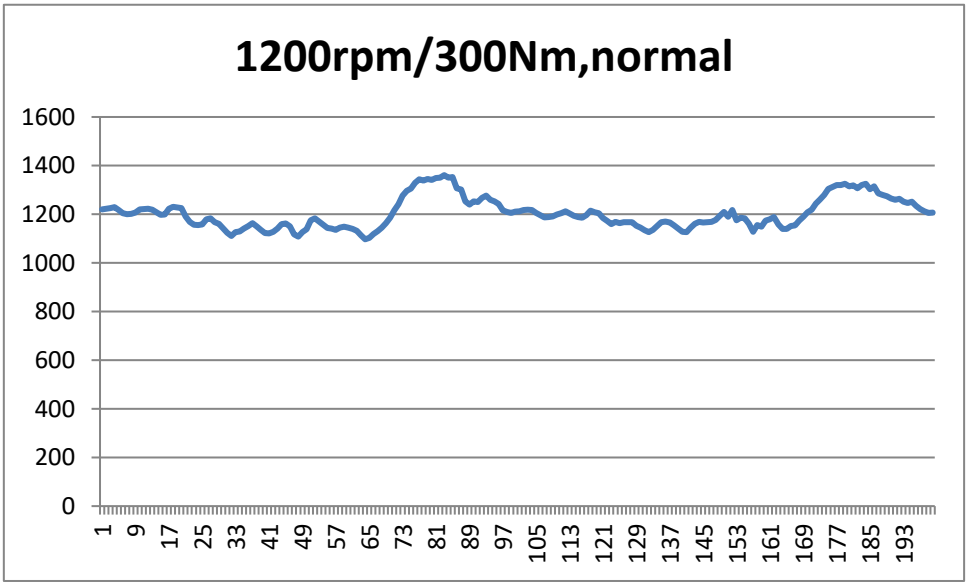

Figure SI2-10. 1200 rpm/300 Nm, normal.

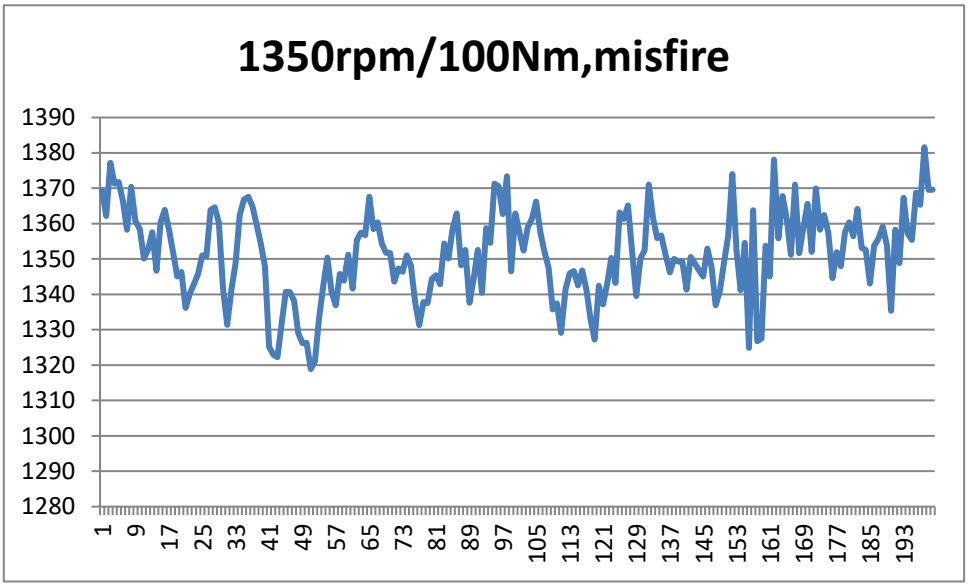

Figure SI2-11. 1350 rpm/100 Nm, misfire.

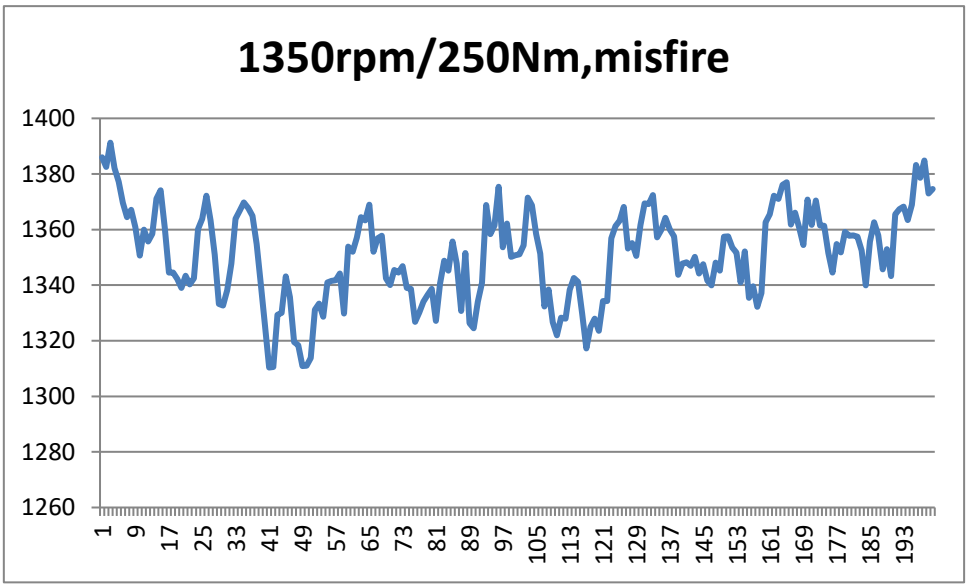

Figure SI2-12. 1350 rpm/250 Nm, misfire.

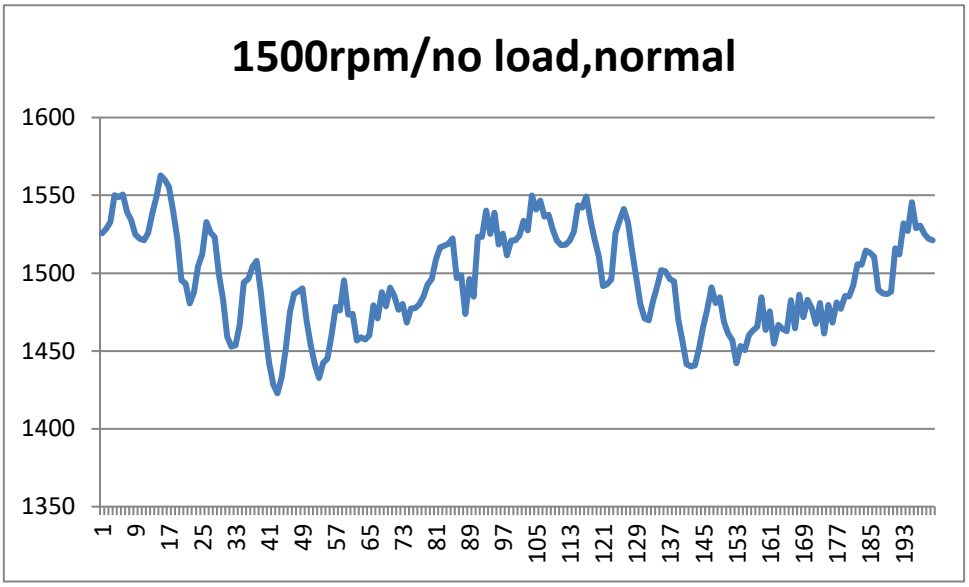

Figure SI2-13. 1500 rpm/no load, normal.

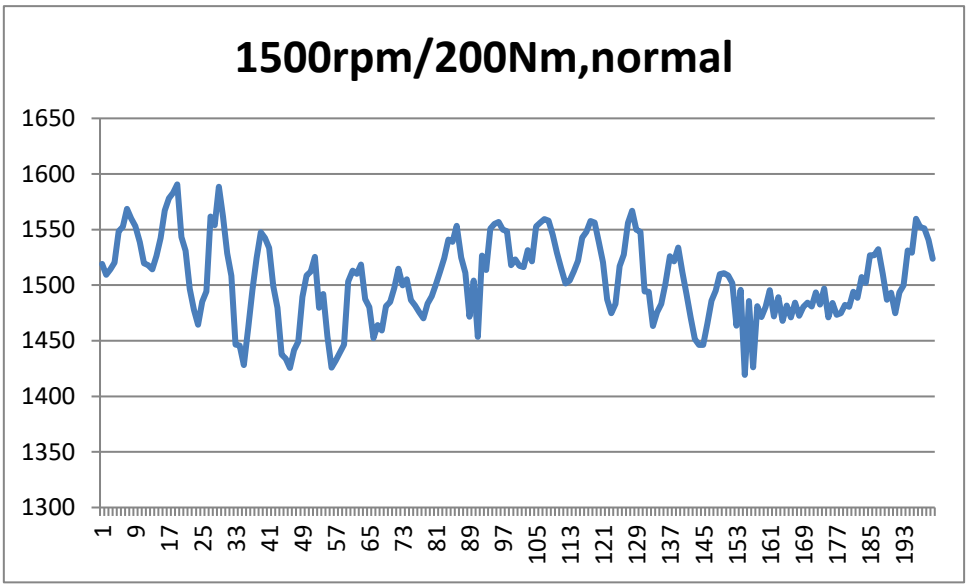

Figure SI2-14. 1500 rpm/200 Nm, normal.

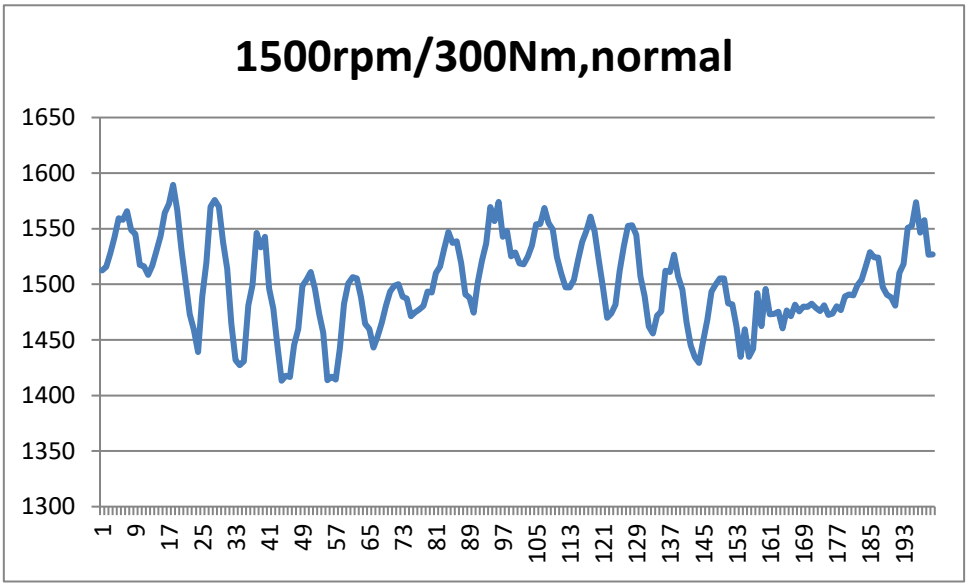

Figure SI2-15. 1500 rpm/300 Nm, normal.

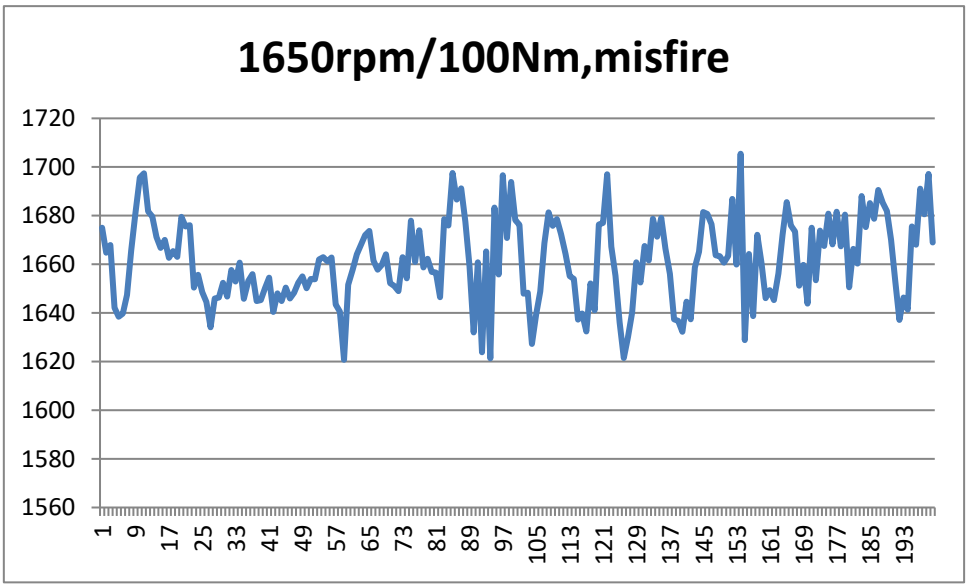

Figure SI2-16. 1650 rpm/100 Nm, misfire.

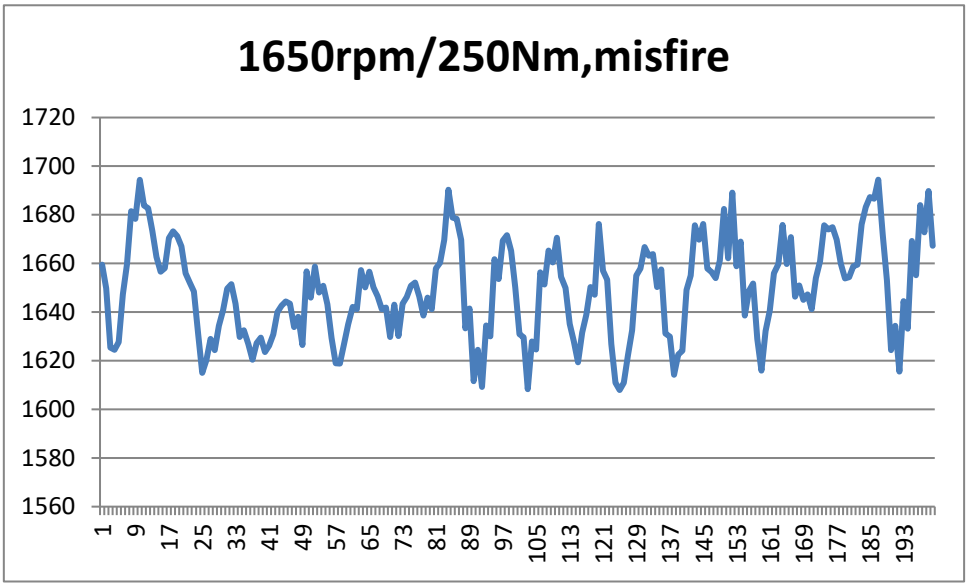

Figure SI2-17. 1650 rpm/250 Nm, misfire.

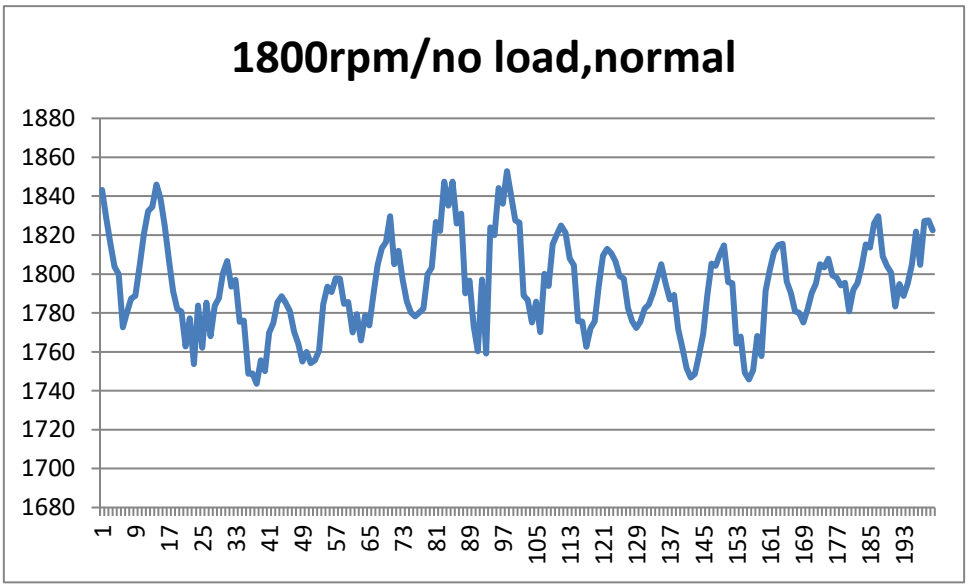

Figure SI2-18. 1800 rpm/No load, normal.

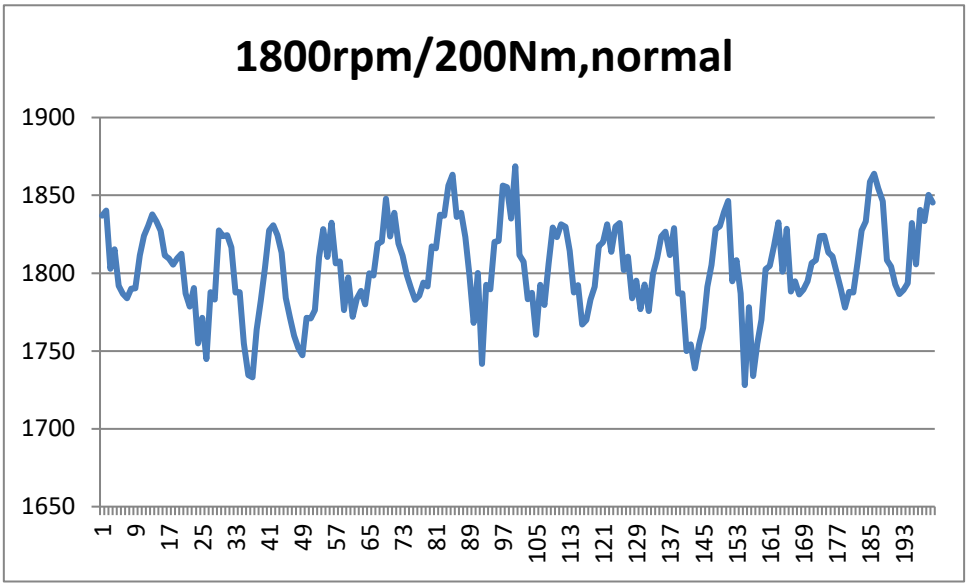

Figure SI2-19. 1800 rpm/200 Nm, normal.

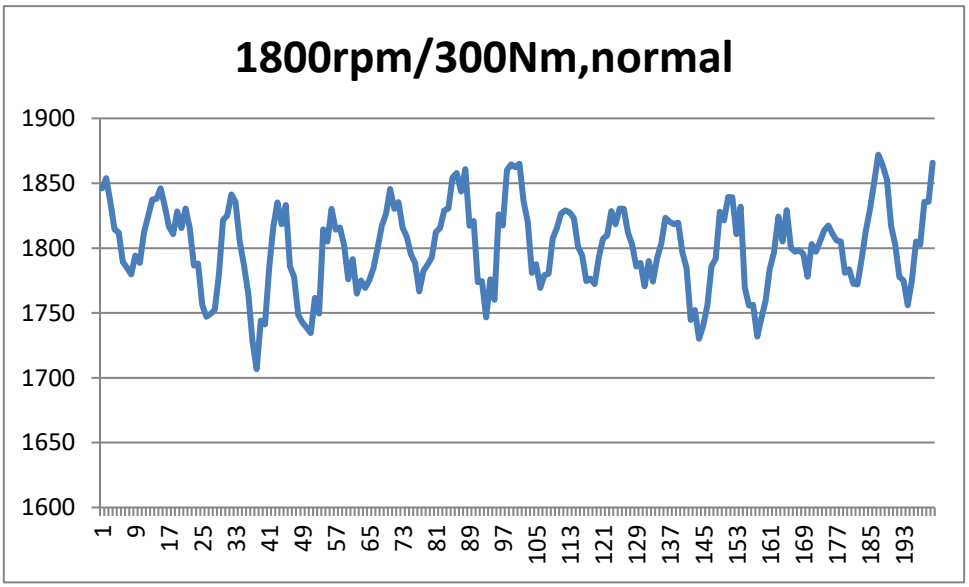

Figure SI2-20. 1800 rpm/300 Nm, normal.

1.3 Conversion of instantaneous speed data in frequency domain

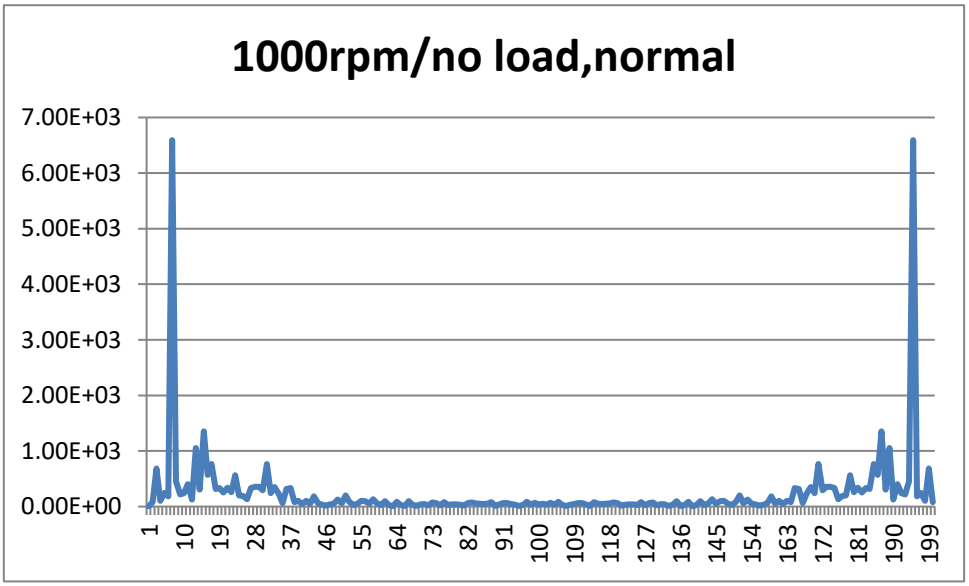

Figure SI3-1. 1000 rpm/No load, normal.

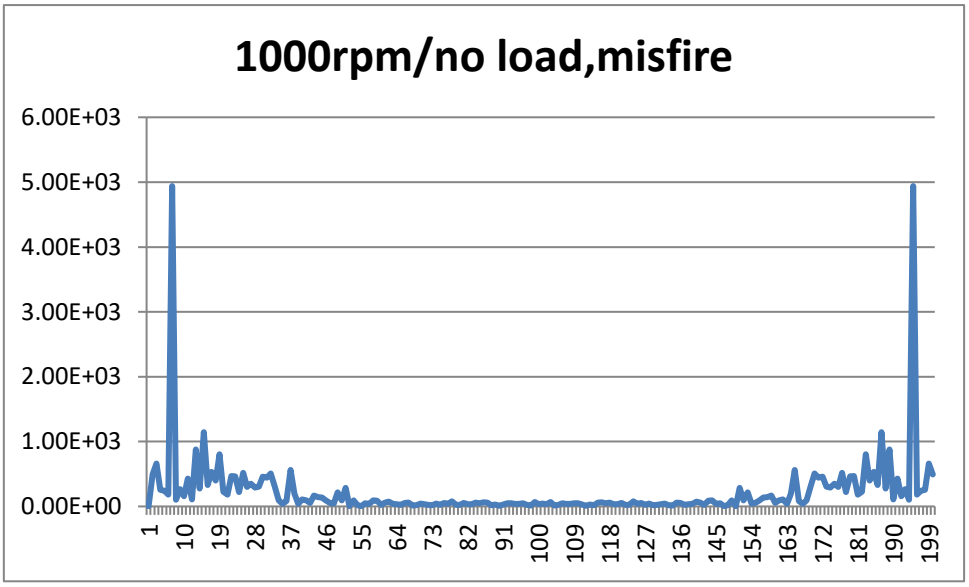

Figure SI3-2. 1000 rpm/No load, misfire.

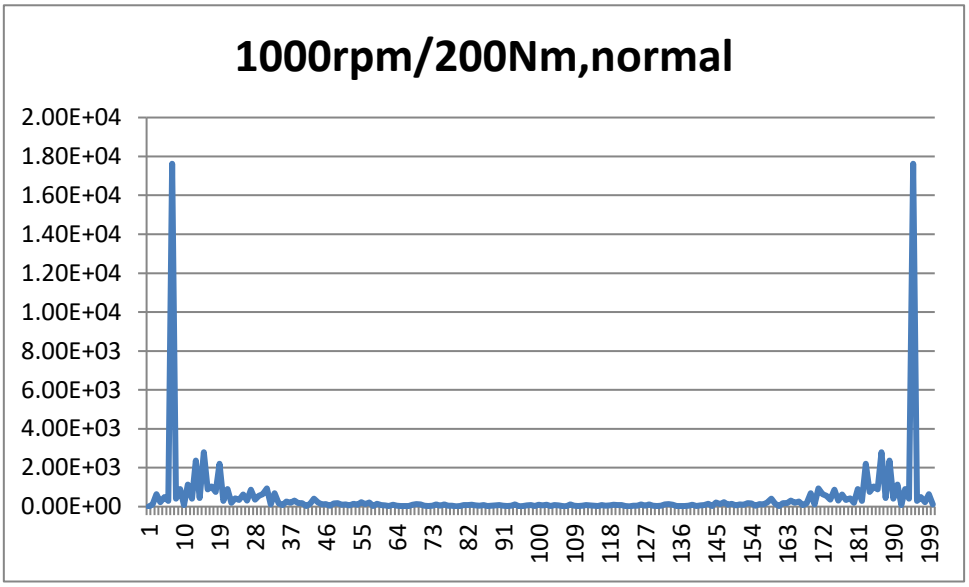

Figure SI3-3. 1000 rpm/200 Nm, normal.

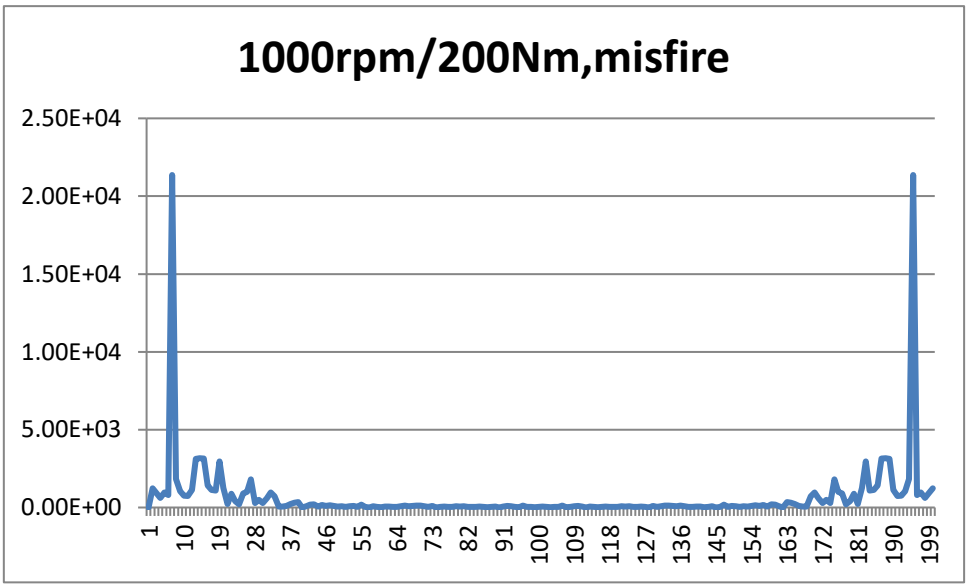

Figure SI3-4. 1000 rpm/200 Nm, misfire.

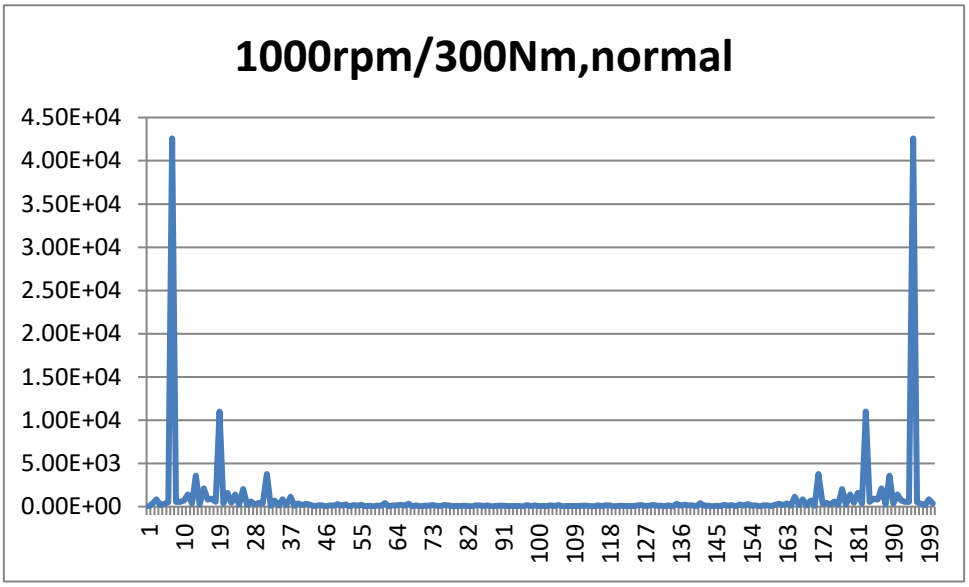

Figure SI3-5. 1000 rpm/300 Nm, normal.

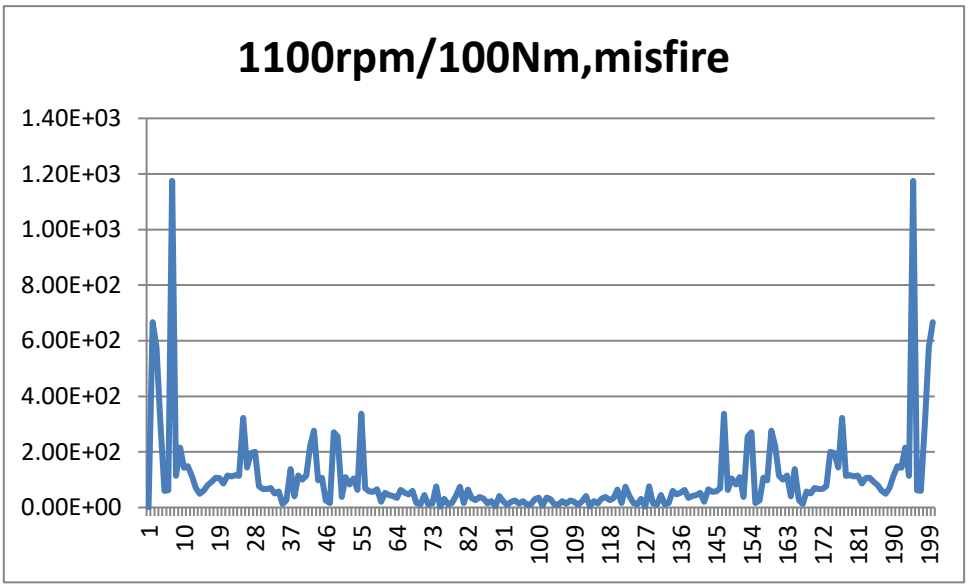

Figure SI3-6. 1100 rpm/100 Nm, misfire.

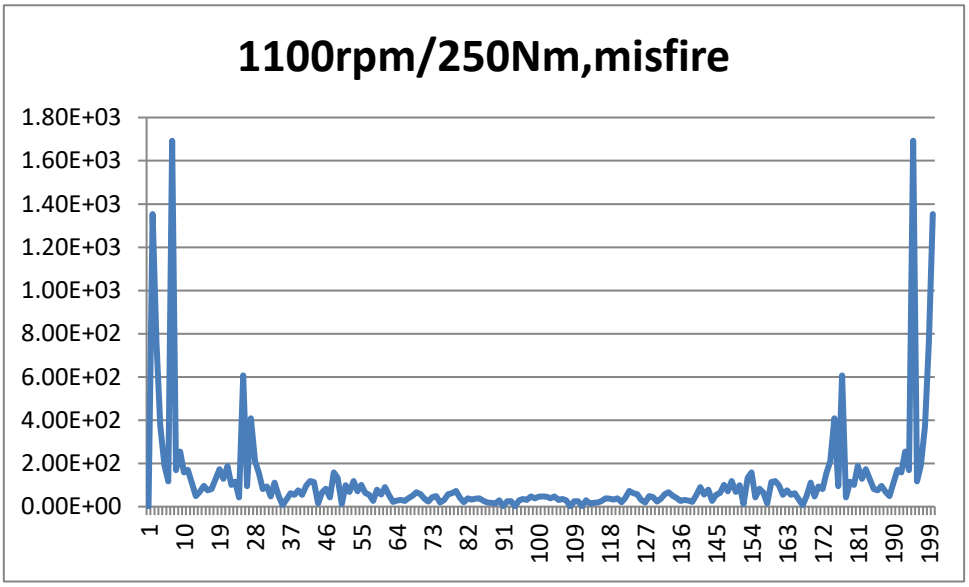

Figure SI3-7. 1100 rpm/250 Nm, misfire.

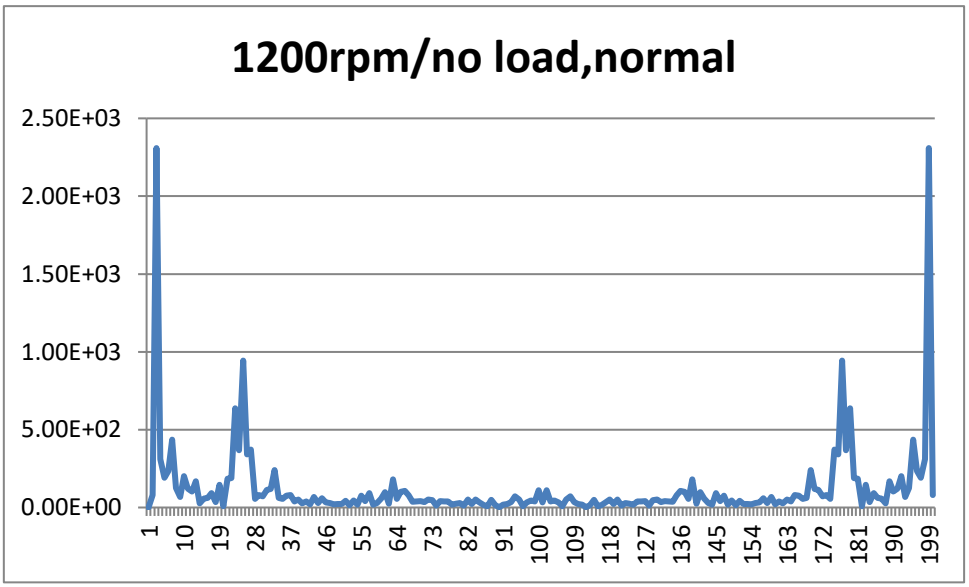

Figure SI3-8. 1200 rpm/No load, normal.

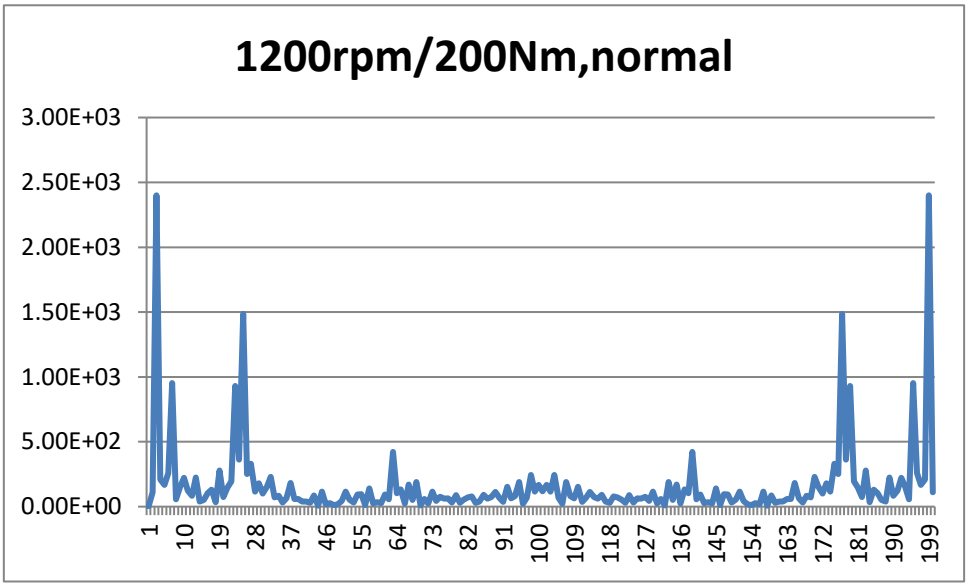

Figure SI3-9. 1200 rpm/200 Nm, normal.

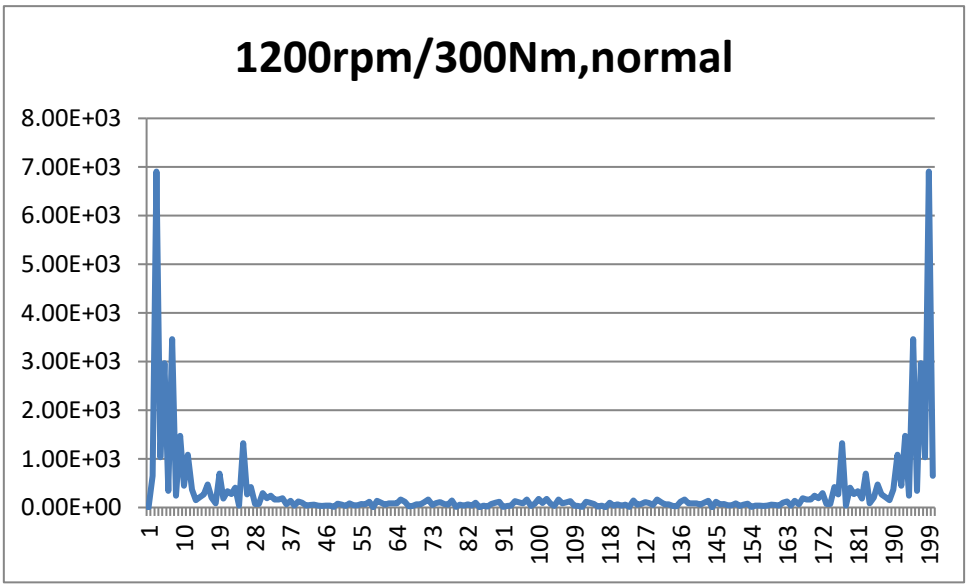

Figure SI3-10. 1200 rpm/300 Nm, normal.

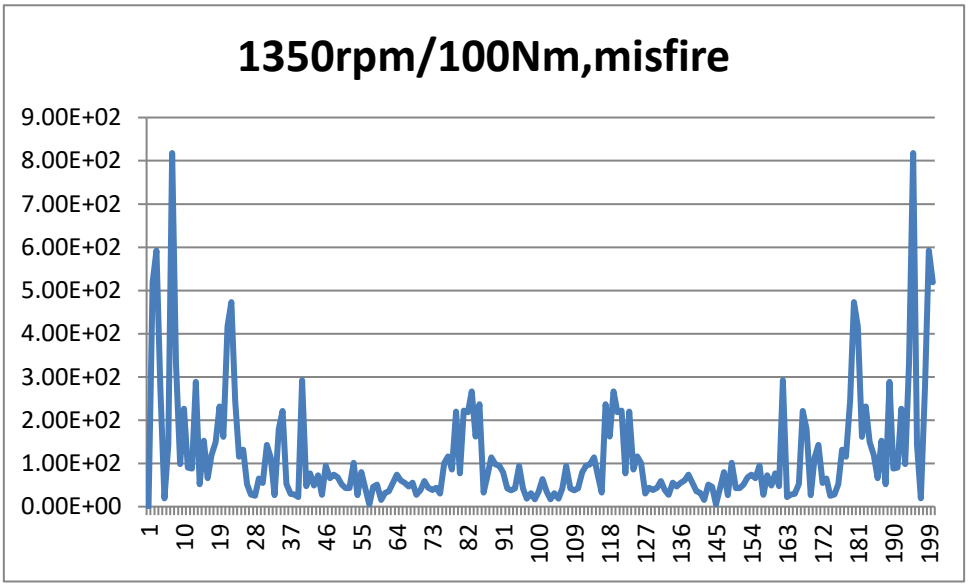

Figure SI3-11. 1350 rpm/100 Nm, misfire.

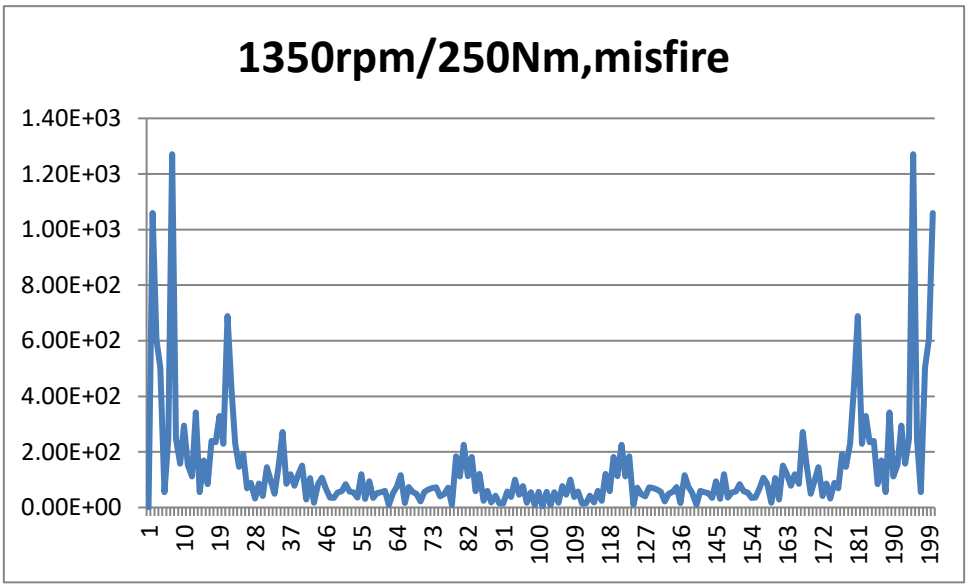

Figure SI3-12. 1350 rpm/250 Nm, misfire.

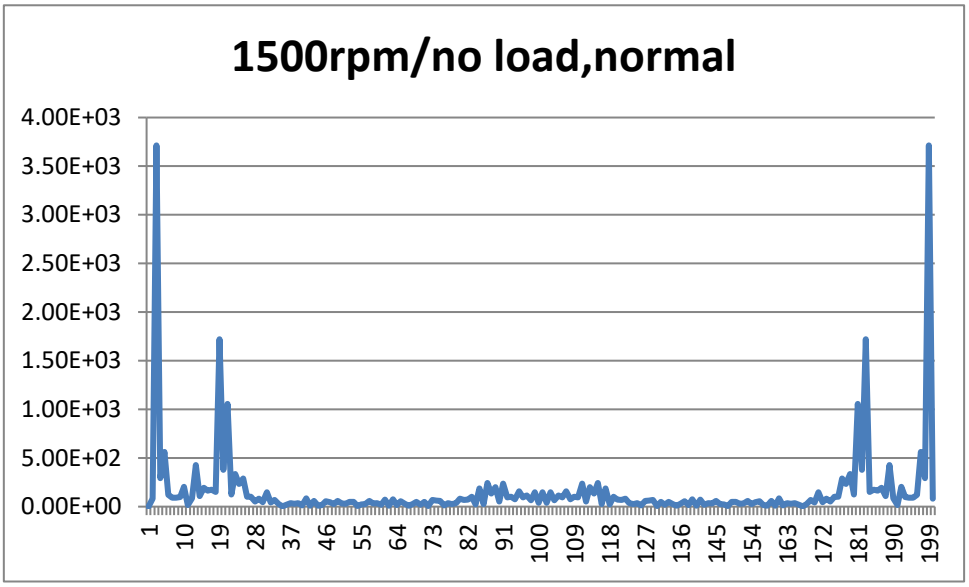

Figure SI3-13. 1500 rpm/No load, normal.

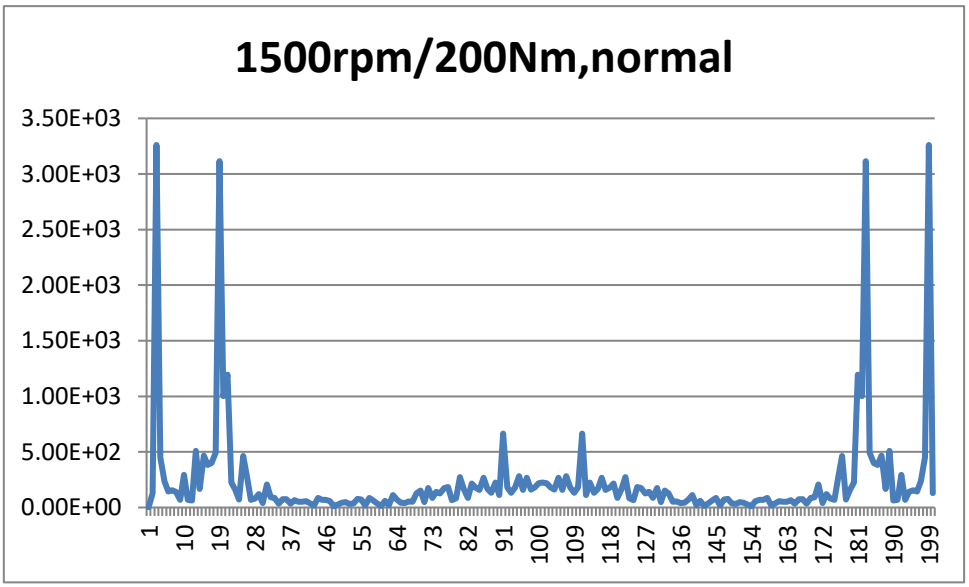

Figure SI3-14. 1500 rpm/200 Nm, normal.

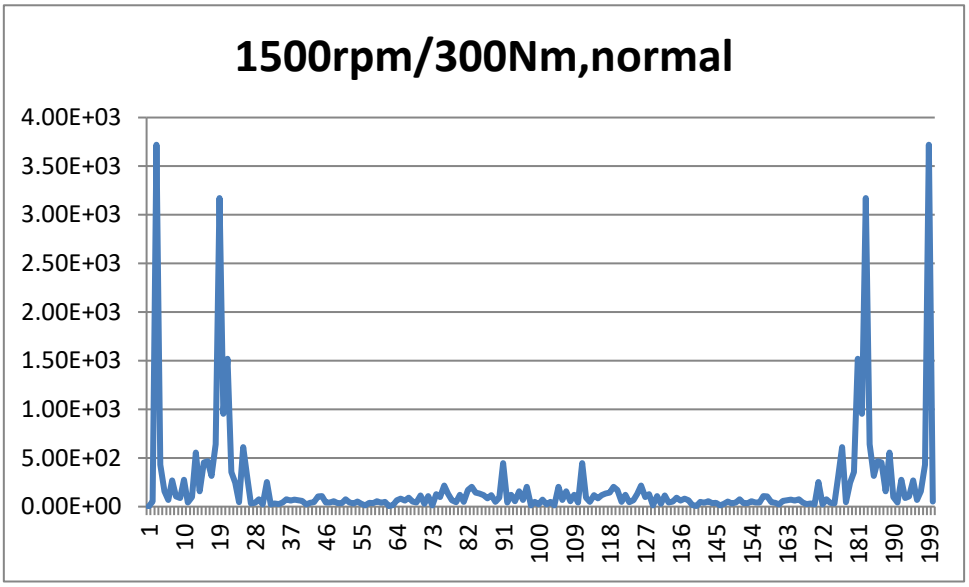

Figure SI3-15. 1500 rpm/300 Nm, normal.

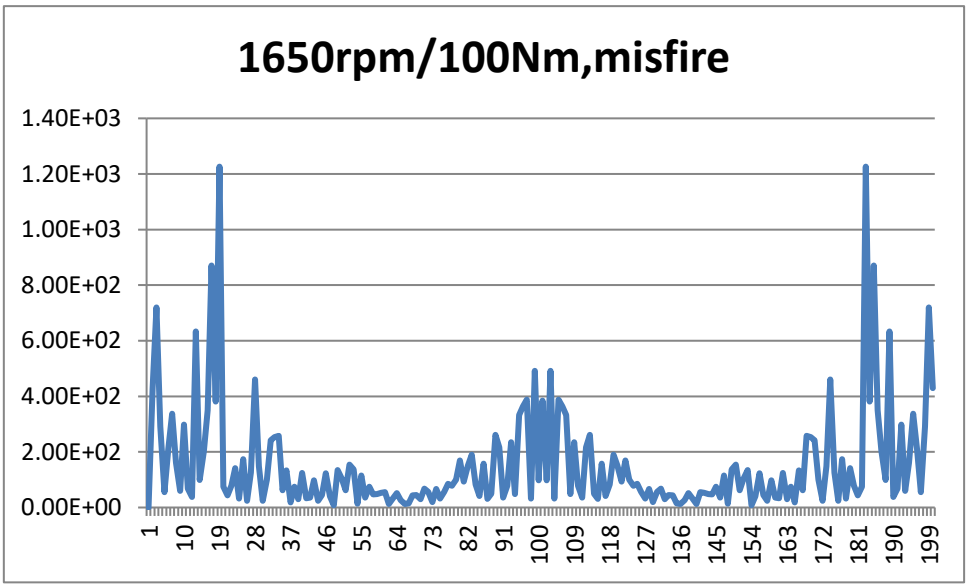

Figure SI3-16. 1650 rpm/100 Nm, misfire.

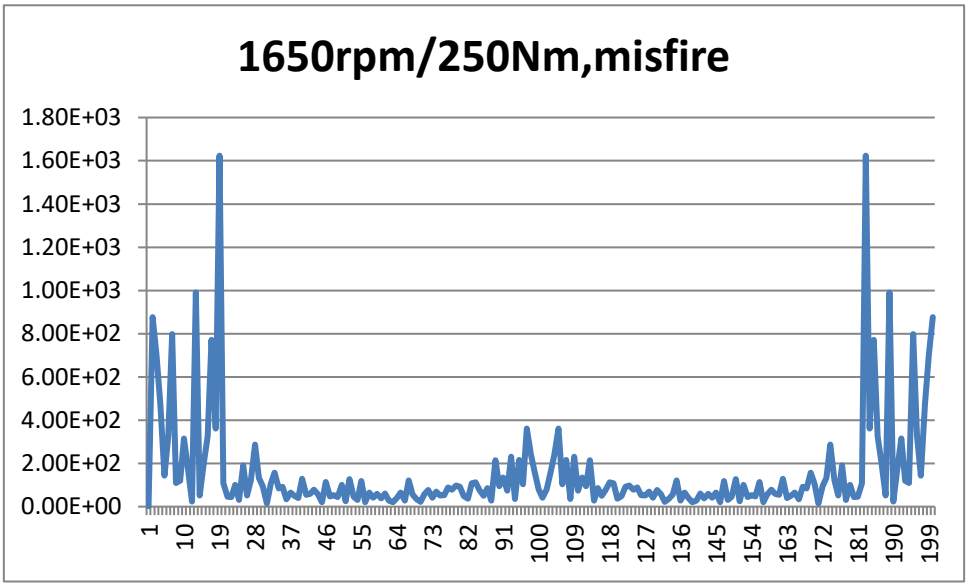

Figure SI3-17. 1650 rpm/250 Nm, misfire.

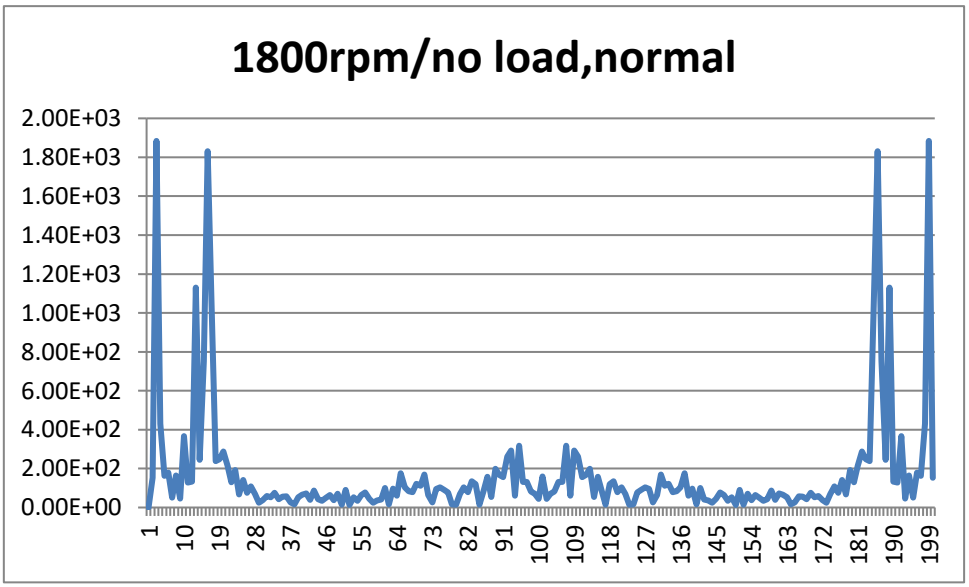

Figure SI3-18. 1800 rpm/No load, normal.

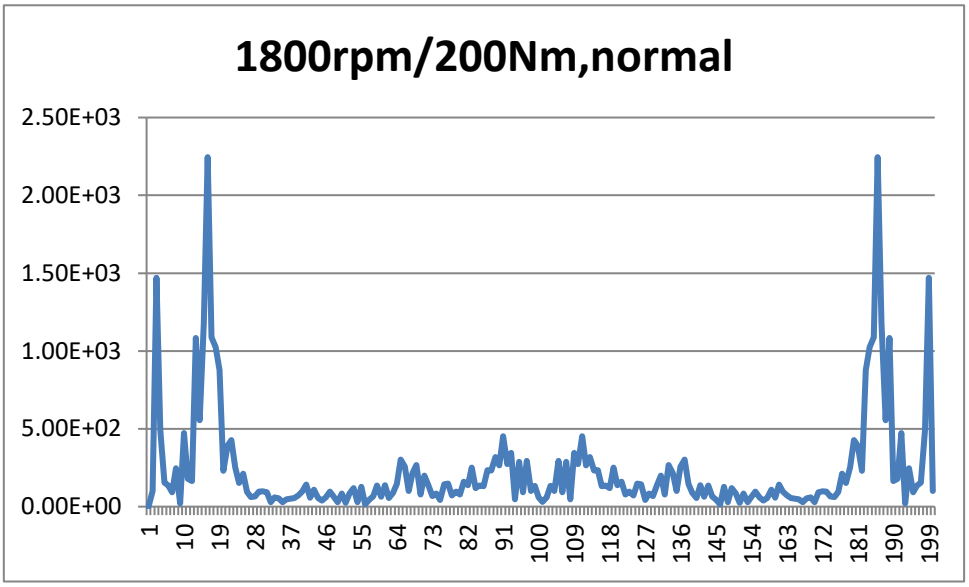

Figure SI3-19. 1800 rpm/200 Nm, normal.

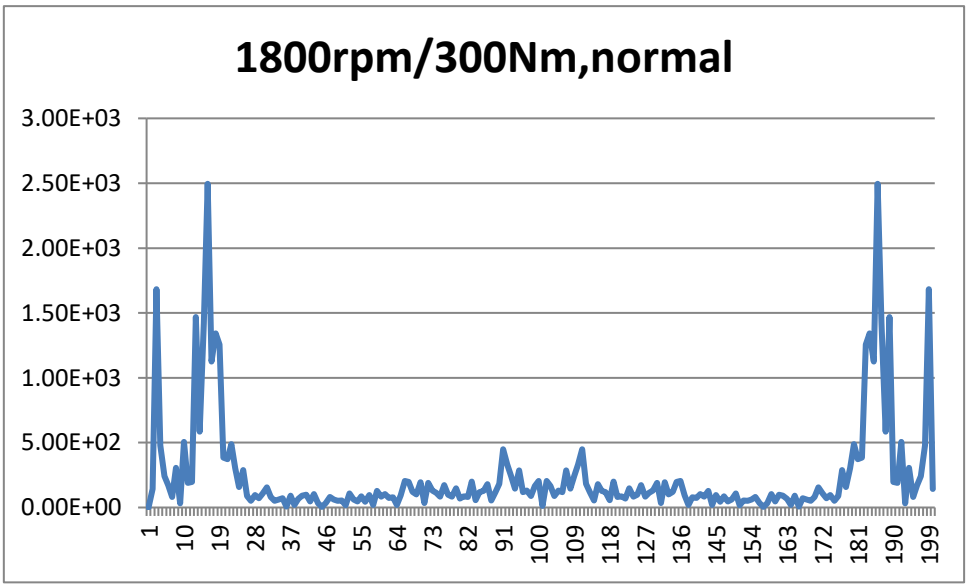

Figure SI3-20. 1800 rpm/300 Nm, normal.

§2 Tables

Table SI1. DFTs of six cylinders at their respective harmonics for case 1 under healthy condition.

n	$n\lambda_f$	$A_{\lambda f}$ of cylinder					
		1	5	3	6	2	4
1	3	2.73E-12	1.02E-12	3.41E-12	4.09E-12	1.15E-11	5.00E-12
2	6	3.41E+04	3.09E+04	3.16E+04	3.88E+04	3.73E+04	3.64E+04
3	9	2.44E+04	2.32E+04	1.50E+04	3.04E+04	6.01E+03	1.25E+04
4	12	7.04E+03	7.37E+03	5.80E+03	1.39E+04	6.58E+03	1.00E+04
5	15	1.52E+04	1.06E+04	1.11E+04	7.78E+03	1.07E+04	2.09E+04
6	18	1.70E+04	8.70E+03	5.71E+03	1.19E+04	1.83E+04	1.34E+04
7	21	3.27E+04	1.55E+04	9.27E+03	2.20E+04	2.33E+04	1.41E+04
8	24	7.84E+03	1.43E+03	1.07E+04	2.23E+03	8.91E+03	6.34E+03
9	27	7.67E+03	8.45E+03	3.37E+03	4.86E+03	1.05E+03	1.17E+04
10	30	5.32E+03	2.81E+03	9.97E+02	3.79E+03	7.40E+03	6.11E+03
11	33	4.73E+03	4.03E+03	4.04E+03	5.96E+03	5.32E+03	6.46E+03
12	36	1.67E+03	3.16E+03	1.15E+03	2.12E+03	5.55E+03	1.56E+03
13	39	2.34E+03	1.32E+03	1.06E+03	2.88E+03	4.57E+03	2.92E+03
14	42	6.98E+02	1.64E+03	3.21E+03	3.06E+03	2.84E+03	1.19E+03
15	45	1.01E+03	2.38E+02	3.57E+03	2.08E+03	3.02E+03	1.14E+03
16	48	1.53E+03	1.03E+03	1.18E+03	1.31E+03	8.11E+02	1.24E+03
17	51	3.16E+02	2.96E+02	1.05E+03	5.25E+02	7.34E+02	2.52E+02
18	54	3.13E+02	2.70E+02	8.59E+02	7.14E+02	6.92E+02	3.09E+02
19	57	1.51E+02	2.74E+02	5.93E+02	6.45E+02	5.23E+02	3.00E+02
20	60	2.10E+02	3.11E+02	1.04E+03	5.34E+02	2.55E+02	3.45E+02
21	63	3.61E+02	2.91E+02	7.26E+02	5.53E+02	3.59E+02	1.79E+02
22	66	1.27E+02	2.80E+02	6.64E+02	4.32E+02	2.76E+02	1.44E+02
23	69	4.55E+01	1.19E+02	6.35E+02	4.79E+02	8.36E+01	3.28E+02
24	72	3.01E+02	1.91E+02	6.23E+02	5.67E+02	3.74E+02	2.35E+02
25	75	1.61E+02	1.93E+02	7.21E+02	4.17E+02	1.51E+02	2.04E+02
26	78	6.78E+01	2.39E+02	6.07E+02	3.86E+02	8.77E+01	2.44E+02
27	81	2.33E+02	9.96E+01	4.97E+02	5.06E+02	2.48E+02	2.25E+02
28	84	7.43E+01	8.26E+01	6.09E+02	3.22E+02	2.66E+02	2.59E+02
29	87	1.60E+02	1.01E+02	4.60E+02	3.19E+02	8.22E+01	1.67E+02
30	90	1.90E+02	6.90E+01	6.37E+02	4.17E+02	1.36E+02	3.15E+02
31	93	2.27E+02	9.85E+01	7.35E+02	3.59E+02	1.51E+02	3.05E+02
32	96	1.11E+02	7.47E+01	3.04E+02	5.54E+02	1.31E+02	1.13E+02
33	99	8.31E+01	1.14E+02	7.85E+02	3.27E+02	2.56E+02	5.11E+02
34	102	3.63E+02	3.55E+02	9.36E+02	4.89E+02	3.13E+02	7.25E+02
35	105	1.66E+02	1.14E+02	5.74E+02	5.65E+02	1.45E+02	2.33E+02
36	108	4.57E+02	1.40E+02	6.40E+02	1.12E+02	4.22E+02	7.48E+02
37	111	2.24E+02	8.42E+01	9.79E+02	9.22E+02	8.73E+02	8.93E+02

38	114	8.16E+02	3.72E+02	3.10E+02	5.17E+02	5.66E+02	8.87E+02
39	117	8.96E+02	2.15E+02	1.45E+03	6.95E+02	8.15E+02	9.39E+02
40	120	8.84E+02	6.15E+02	5.79E+02	1.44E+03	8.25E+02	9.56E+02
41	123	4.24E+02	6.09E+02	1.38E+03	3.45E+02	1.31E+03	6.65E+02
42	126	1.92E+02	6.63E+02	1.07E+03	2.25E+02	5.44E+02	6.91E+02
43	129	1.30E+03	3.39E+02	6.27E+02	1.92E+03	7.65E+02	1.13E+03
44	132	1.91E+03	9.88E+02	1.54E+03	1.57E+02	9.99E+02	1.08E+03
45	135	1.03E+03	6.63E+02	6.63E+02	9.87E+02	8.57E+02	1.77E+03
46	138	9.84E+02	6.22E+02	7.98E+02	6.59E+02	1.36E+03	1.54E+03
47	141	9.87E+02	1.18E+02	1.04E+03	3.02E+02	2.16E+03	1.25E+03
48	144	7.69E+02	9.63E+02	1.65E+03	1.15E+03	6.05E+02	1.17E+03
49	147	1.04E+03	6.59E+02	2.06E+03	1.36E+03	9.93E+02	9.83E+02
50	150	1.06E+03	1.69E+03	4.14E+01	2.44E+02	7.75E+02	9.88E+02

Table SI2. DFTs of six cylinders at their respective harmonics for case 1with cylinder 1 misfiring. The characteristic harmonics and characteristic DFTs are marked in red.

n	$n\lambda_f$	$A_{\lambda f}$ of cylinder					
		1	5	3	6	2	4
1	3	6.99E-12	7.96E-13	3.52E-12	7.39E-12	3.01E-12	4.77E-12
2	6	3.31E+04	2.72E+04	2.47E+04	3.17E+04	2.78E+04	2.94E+04
3	9	2.59E+04	1.01E+04	1.53E+04	1.58E+04	1.85E+04	6.61E+03
4	12	1.85E+04	9.49E+03	2.96E+03	1.03E+04	1.13E+04	6.72E+03
5	15	2.79E+04	5.40E+03	2.36E+04	6.55E+03	6.91E+03	1.16E+04
6	18	1.15E+04	2.98E+03	1.54E+04	1.48E+04	1.36E+04	9.60E+03
7	21	1.50E+04	1.88E+04	2.93E+03	1.57E+04	2.51E+04	8.03E+03
8	24	3.80E+03	2.57E+03	1.02E+04	3.34E+03	4.40E+03	6.29E+03
9	27	4.69E+03	6.19E+03	1.02E+04	2.99E+03	5.14E+03	8.31E+03
10	30	4.61E+03	5.27E+03	4.28E+03	3.15E+03	5.11E+03	5.26E+03
11	33	2.71E+03	4.17E+03	4.18E+03	4.96E+03	7.57E+02	5.97E+03
12	36	2.07E+03	3.25E+03	1.55E+03	3.59E+03	1.11E+03	1.55E+03
13	39	3.04E+03	9.43E+02	1.44E+03	1.70E+03	1.76E+03	8.67E+02
14	42	1.06E+03	2.11E+03	7.73E+02	2.37E+03	1.72E+03	4.55E+02
15	45	1.19E+03	1.91E+03	2.16E+03	2.04E+03	1.84E+03	2.70E+03
16	48	1.22E+03	1.04E+03	1.01E+03	1.05E+03	4.18E+02	3.31E+02
17	51	7.87E+02	7.28E+02	9.68E+02	4.33E+02	4.97E+02	6.54E+02
18	54	9.62E+02	7.69E+02	7.63E+02	3.22E+02	1.14E+02	7.50E+02
19	57	8.25E+02	5.77E+02	4.40E+02	2.71E+02	2.96E+02	5.60E+02
20	60	7.19E+02	5.50E+02	1.90E+02	2.99E+02	2.67E+02	6.46E+02
21	63	7.09E+02	5.06E+02	3.61E+02	1.71E+02	3.24E+02	5.36E+02
22	66	6.34E+02	5.18E+02	4.05E+02	3.38E+02	3.22E+02	4.70E+02
23	69	5.74E+02	4.83E+02	2.67E+02	1.92E+02	9.70E+01	4.41E+02
24	72	5.71E+02	4.14E+02	2.14E+02	1.42E+02	2.63E+02	4.63E+02
25	75	5.31E+02	3.85E+02	4.05E+02	3.09E+02	2.33E+02	4.35E+02
26	78	4.93E+02	3.76E+02	4.10E+02	1.66E+02	1.93E+02	4.41E+02
27	81	5.15E+02	4.03E+02	1.94E+02	1.95E+02	1.95E+02	3.82E+02
28	84	4.13E+02	3.78E+02	3.04E+02	2.72E+02	1.92E+02	4.32E+02
29	87	4.57E+02	3.61E+02	2.48E+02	1.63E+02	2.21E+02	4.70E+02
30	90	4.58E+02	3.93E+02	1.96E+02	2.35E+02	1.89E+02	3.33E+02
31	93	3.50E+02	2.68E+02	2.59E+02	1.84E+02	2.31E+02	3.88E+02
32	96	3.09E+02	3.29E+02	2.60E+02	1.21E+02	2.18E+02	4.51E+02
33	99	4.11E+02	3.88E+02	3.52E+02	2.78E+02	2.57E+02	6.13E+02
34	102	5.44E+02	5.60E+02	4.33E+02	2.91E+02	4.22E+02	6.51E+02
35	105	2.17E+02	2.41E+02	2.97E+02	4.06E+02	2.60E+02	3.99E+02
36	108	3.44E+02	3.19E+02	6.62E+02	1.39E+02	1.65E+02	2.30E+02
37	111	1.26E+02	1.75E+02	3.87E+02	5.31E+02	3.25E+02	1.60E+02
38	114	2.49E+02	3.00E+02	3.26E+02	5.56E+02	4.19E+02	8.63E+02

39	117	1.60E+02	4.15E+02	2.63E+02	6.44E+02	5.10E+02	1.39E+03
40	120	2.60E+02	9.22E+02	1.40E+03	1.17E+02	8.13E+02	9.21E+02
41	123	1.33E+02	2.62E+02	1.40E+03	7.40E+02	9.92E+01	8.50E+02
42	126	4.41E+02	9.50E+02	1.60E+03	2.58E+02	1.05E+03	9.29E+02
43	129	2.06E+02	8.96E+02	8.53E+02	1.14E+03	2.43E+02	1.66E+03
44	132	1.55E+02	1.05E+03	7.70E+02	8.67E+02	2.88E+02	1.23E+03
45	135	4.76E+02	1.45E+03	1.52E+03	8.34E+02	8.75E+02	1.63E+03
46	138	5.95E+02	7.44E+02	1.42E+03	2.34E+02	4.00E+02	1.40E+03
47	141	6.89E+02	6.66E+02	1.37E+03	1.45E+03	5.99E+01	1.25E+03
48	144	2.70E+02	9.18E+02	2.48E+03	8.19E+02	6.04E+02	1.01E+03
49	147	2.69E+02	1.13E+03	1.31E+03	1.53E+03	8.00E+02	8.14E+02
50	150	6.59E+02	1.41E+03	1.45E+03	1.51E+03	4.87E+02	1.75E+03

Table SI3. Ratios of $A_{\lambda f}$s with cylinder 1 misfiring to that under healthy condition for case 1.

n	$n\lambda_f$	R_A of cylinder					
		1	5	3	6	2	4
1	3	2.563	0.778	1.033	1.806	0.262	0.955
2	6	0.970	0.879	0.781	0.816	0.745	0.807
3	9	1.061	0.435	1.020	0.518	3.071	0.529
4	12	2.628	1.287	0.509	0.737	1.716	0.671
5	15	1.830	0.510	2.118	0.842	0.648	0.553
6	18	0.676	0.343	2.701	1.250	0.743	0.717
7	21	0.459	1.214	0.816	0.715	1.074	0.572
8	24	0.485	1.805	0.954	1.500	0.494	0.992
9	27	0.612	0.732	3.041	0.614	4.881	0.712
10	30	0.866	1.875	4.291	0.832	0.691	0.862
11	33	0.574	1.035	1.035	0.832	0.142	0.923
12	36	1.240	1.030	1.357	1.693	0.199	0.994
13	39	1.297	0.712	1.359	0.589	0.384	0.297
14	42	1.520	1.286	0.241	0.775	0.604	0.382
15	45	1.172	8.022	0.606	0.983	0.609	2.380
16	48	0.794	1.009	0.855	0.807	0.516	0.266
17	51	2.492	2.457	0.926	0.824	0.677	2.594
18	54	3.075	2.848	0.889	0.450	0.165	2.428
19	57	5.464	2.108	0.742	0.420	0.567	1.869
20	60	3.419	1.771	0.182	0.559	1.050	1.874
21	63	1.964	1.736	0.497	0.309	0.902	2.997
22	66	4.999	1.846	0.611	0.784	1.165	3.261
23	69	12.611	4.057	0.420	0.400	1.160	1.346
24	72	1.900	2.163	0.343	0.251	0.703	1.970
25	75	3.292	1.996	0.561	0.740	1.546	2.131
26	78	7.276	1.574	0.675	0.429	2.207	1.806
27	81	2.216	4.052	0.391	0.384	0.788	1.696
28	84	5.563	4.574	0.500	0.844	0.724	1.667
29	87	2.848	3.578	0.540	0.510	2.689	2.825
30	90	2.417	5.700	0.308	0.565	1.392	1.056
31	93	1.541	2.722	0.352	0.512	1.525	1.272
32	96	2.775	4.400	0.857	0.218	1.667	3.986
33	99	4.949	3.392	0.448	0.850	1.001	1.199
34	102	1.500	1.577	0.463	0.595	1.348	0.898
35	105	1.310	2.112	0.518	0.718	1.800	1.710
36	108	0.752	2.284	1.036	1.248	0.391	0.307
37	111	0.565	2.084	0.396	0.576	0.372	0.179
38	114	0.305	0.805	1.053	1.075	0.740	0.974
39	117	0.178	1.932	0.182	0.926	0.625	1.484

40	120	0.294	1.499	2.417	0.081	0.986	0.963
41	123	0.315	0.430	1.011	2.144	0.076	1.277
42	126	2.303	1.433	1.491	1.146	1.926	1.345
43	129	0.158	2.641	1.361	0.594	0.317	1.470
44	132	0.081	1.067	0.499	5.519	0.288	1.144
45	135	0.460	2.187	2.289	0.845	1.021	0.917
46	138	0.605	1.195	1.774	0.356	0.295	0.906
47	141	0.698	5.639	1.316	4.810	0.028	1.002
48	144	0.351	0.953	1.507	0.711	0.999	0.864
49	147	0.257	1.714	0.634	1.124	0.806	0.828
50	150	0.620	0.837	34.963	6.171	0.628	1.770