Third-Party Research & Development
Technical Discourse

Application of cirQED™ RA for FFT Analysis
Part I – Identifying Real And Aliased FFT Components

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BRIEF

cirQED™ Rotation Analyzer is a PC-based instrument installed and run as a COM Add-in under Microsoft® Excel, which simplifies data acquisition and processing and extends the functionality of the instrument. This intimate relationship permits cirQED™ software to directly access a number of powerful Microsoft Excel Functions, including those built-in and the data analysis tools, i.e., the workfunctions available in the Analysis ToolPak Add-in. cirQED™ software provides the data and parameters for each analysis, the Excel tools employed use the appropriate statistical or engineering macro functions, and cirQED™ software formats and displays the results in tables and charts. This paper is part I of a two part series and discusses applications of cirQED™ Rotation Analyzer in carrying out FFT spectral analysis on digitized sample sets of the analog output from a rotary sensor, taken over fixed time intervals. Results are discussed where (1) the sample collection rate is adequate for analyzing the signal output of a sinusoidal sensor turning at a constant angular speed and (2) the sample collection rate is inadequate. PART II will discuss FFT analysis of more complex sensor output signals, Window Functions that aim to reduce leakage in FFT spectra, and techniques for analyzing the performance of rotary devices "indirectly" by coupling them to a sine wave sensor.

EQUIPMENT

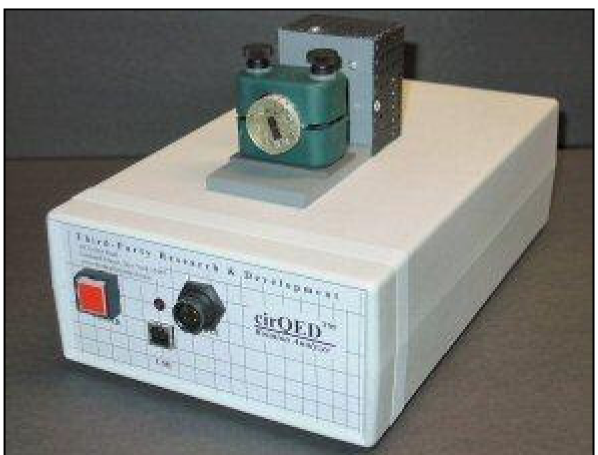


Figure 1. cirQED™ RA 2.0

The instrument used to collect sensor output data is shown in figure 1. An external DC motor with gearbox (not shown) was coupled to a rotary sensor which was in turn attached electrically by cable to the cirQED™ Rotation Analyzer. The speed of the DC motor used varied directly with applied voltage and was nominally 8500 RPM at 6 volts. The gearbox reduced the motor speed by a factor of three and increased the torque applied to the sensor by the same factor. A SinCos HallPot® Resolver, manufactured by Elweco, Inc. of Painesville, OH, was the rotary sensor used for the study and is also shown in Figure 1. This sensor is a dual output type and provides two excellent continuous sine waves (inphase and quadrature components) for each revolution of the shaft. Only the in-phase analog signals were acquired, digitized, and analyzed by FFT during this study. The AutoFFT feature of cirQED™ RA was used to generate the FFT Spectra shown. cirQED™ RA does 12-bit Analog to Digital conversions on all acquired data. Collected digitized sensor output data is automatically stored by cirQED™ RA in columns on an Excel worksheet labeled RawData. Charts and data processed by custom in-program macros are stored on separate worksheets. FFT data and charts are stored and shown on an Excel worksheet labeled FFT. All of these worksheets are part of a unique workbook that is created by simply selecting CREATE DATA WORKBOOK from the cirQED dropdown menu, located on the main toolbar in Excel.

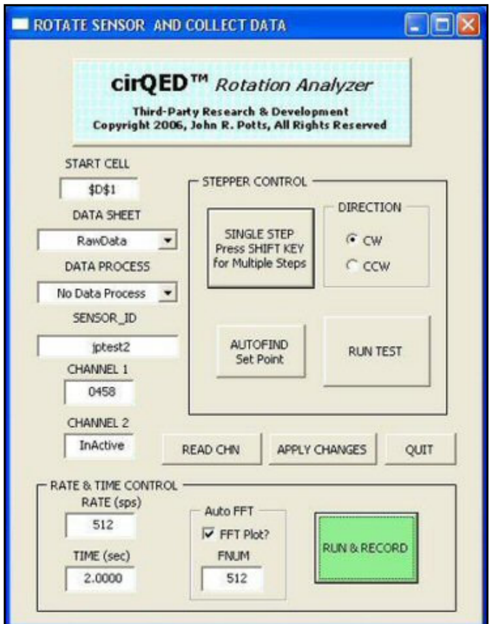


Figure 2 cirQED™ RA Controls

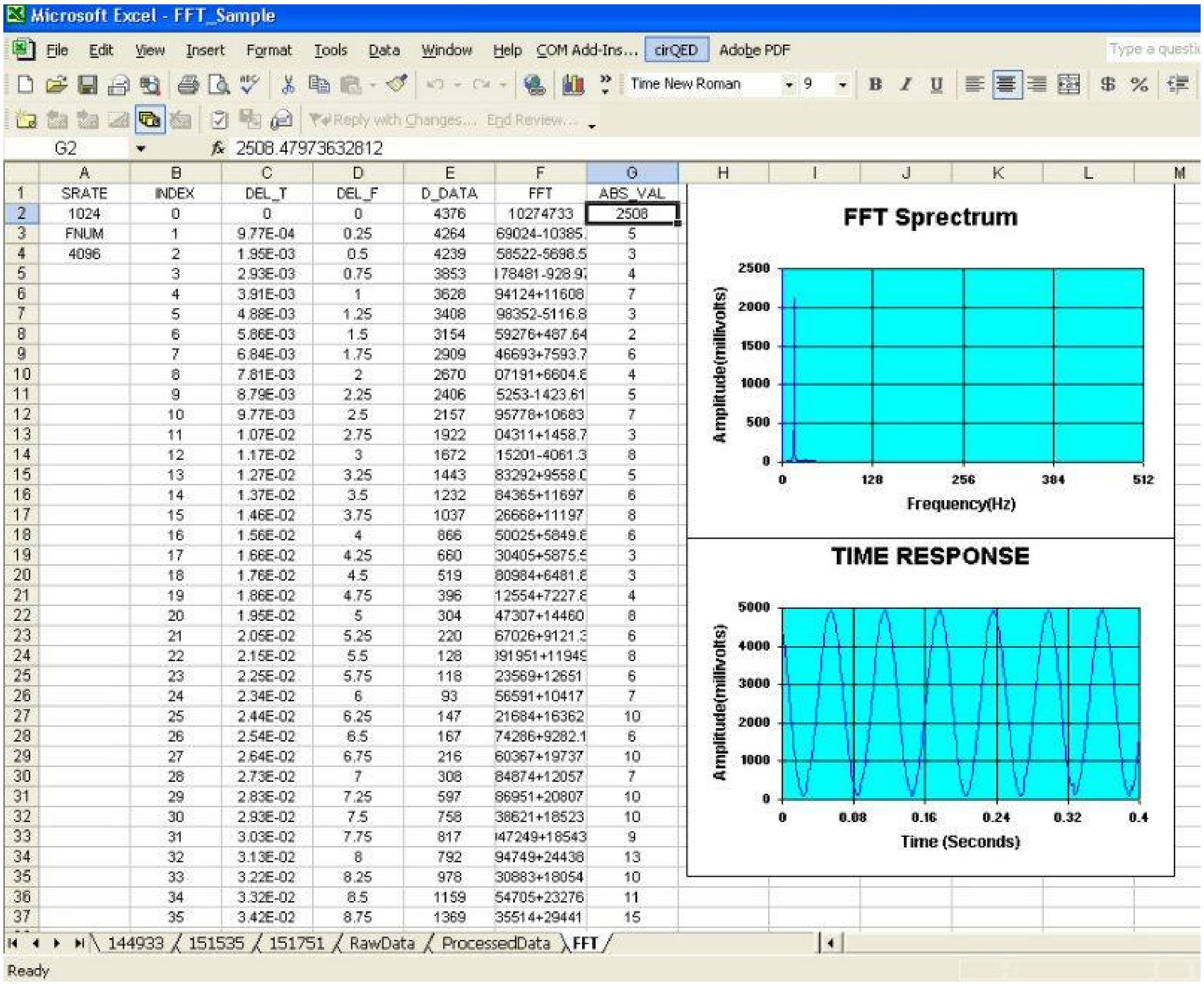
The data acquisition rate and total collection time were set in the RATE & TIME CONTROL section of the cirQED™ Rotate Sensor and Collect Data Window, as shown in figure 2. Sensor data was read into Channel 1. Channel 2 was not used (set INACTIVE).

The rate and the total collection time were set prior to making a data run. Automated FFT Analysis and charting was included in data processing for each run by placing a check in the AutoFFT box. The total number of data points processed for the FFT Analysis shown in this paper, FNUM, ranged from 64 to 4096 for the studies carried out. cirQED™ RA uses Microsoft Excel's FFT Function, which requires that FNUM is selected as a binary number in the series 2, 4, 8, 16, 32…4096. cirQED™ program issues a warning if the number entered for FNUM is not a member of the series or is smaller than the product of the RATE and TIME. The data reported in this paper was acquired at rates varying from 20 dps to 1024 dps.

FFT SPREADSHEET LAYOUT

Figure3 shows the basic layout of the FFT results spreadsheet. Column A shows the rate at which data was actually collected by cirQED™ RA and the total number of samples processed in the FFT analysis. Column B cells contain sample index numbers (counter values) that run from 0 to one less than FNUM. Column C cells contain the individual times in seconds at which each particular sample was acquired. They are calculated as the product of the time increment between samples and the sample index number. The time increment is constant for each reading and is calculated as either 1/ SRATE or (Time To Collect FNUM Samples)/FNUM. Column D cells contain the spectral frequencies, which are calculated as the product of the sample index and 1/(Time To Collect FNUM Samples). Longer sampling times translate to increased frequency resolution for FFT Spectra. Column E cells contain the discrete sensor output readings taken by cirQED™ RA at various times. The actual number of data points in this column could exceed FNUM because the product of total collection time and sampling rate can equal or exceed the value of FNUM. However, only FNUM discrete data points are processed in FFT and any others are simply ignored. Column F cells contain the FFT values, which are complex numbers written as strings in rectangular format RE+IMi . Finally, Column G cells contain the values of the magnitude, i.e., the absolute value, for each Fourier Transform component in column F calculated with the Excel IMABS function. The FFT chart is a plot of the magnitudes in Column G versus the frequencies in Column D. The TIME chart is a plot of the values for discrete data in Column E versus corresponding collection times in Column C.

RESULTS FOR FFT ANALYSIS WITH DATA SETS COLLECTED AT ADEQUATE SAMPLING RATE



	A	B	C	D	E	F	G
1	SRATE	INDEX	DEL_T	DEL_F	D_DATA	FFT	ABS_VAL
2	1024	0	0	0	4376	10274733	2508
3	FNUM	1	9.77E-04	0.25	4264	69024-10385.	5
4	4096	2	1.95E-03	0.5	4239	58522-5698.5	3
5		3	2.93E-03	0.75	3853	178481-928.9	4
6		4	3.91E-03	1	3628	94124+11608	7
7		5	4.88E-03	1.25	3408	98352-5116.8	3
8		6	5.86E-03	1.5	3154	59276+487.64	2
9		7	6.84E-03	1.75	2909	46693+7593.7	6
10		8	7.81E-03	2	2670	07191+6604.6	4
11		9	8.79E-03	2.25	2406	5253-1423.61	5
12		10	9.77E-03	2.5	2157	95778+10683	7
13		11	1.07E-02	2.75	1922	04311+1458.7	3
14		12	1.17E-02	3	1672	15201-4061.3	8
15		13	1.27E-02	3.25	1443	83292+9558.0	5
16		14	1.37E-02	3.5	1232	84365+11697	6
17		15	1.46E-02	3.75	1037	26668+11197	8
18		16	1.56E-02	4	866	50025+5849.6	6
19		17	1.66E-02	4.25	660	30405+5875.5	3
20		18	1.76E-02	4.5	519	80984+6481.6	3
21		19	1.86E-02	4.75	396	12554+7227.6	4
22		20	1.95E-02	5	304	47307+14460	8
23		21	2.05E-02	5.25	220	67026+9121.3	6
24		22	2.15E-02	5.5	128	391951+11949	8
25		23	2.25E-02	5.75	118	23569+12651	6
26		24	2.34E-02	6	93	56591+10417	7
27		25	2.44E-02	6.25	147	21684+16362	10
28		26	2.54E-02	6.5	167	74286+9282.1	6
29		27	2.64E-02	6.75	216	60367+19737	10
30		28	2.73E-02	7	308	84874+12057	7
31		29	2.83E-02	7.25	597	86951+20807	10
32		30	2.93E-02	7.5	758	38621+18523	10
33		31	3.03E-02	7.75	817	47249+18543	9
34		32	3.13E-02	8	792	94749+24438	13
35		33	3.22E-02	8.25	978	30883+18054	10
36		34	3.32E-02	8.5	1159	54705+23276	11
37		35	3.42E-02	8.75	1369	35514+29441	15

Figure 3. cirQED™ FFT SpreadSheet Layout

Analog data froma Sin Cos HallPot(R) Resolver, which was rotated at 18.22 rps (1093 rpm) using the equipment described above, was acquired on Channel 1 by the cirQED™ Rotation Analyzer, converted to 12 bit digital analogs at 1024 samples/second for a total time of 4.000 seconds. The raw data was stored directly into an Excel spreadsheet column, and then processed automatically (AutoFFT) to produce the FFT spectrum shown in the figureabove. The FFT spectrum showed a single sharp peak at 18.25 rps, in close agreement with the speed at which the sensor shaft was actually rotated. The results are what is expected for a pure sine wave.

FFT ANALYSIS FOR DATA SETS WITH INADEQUATE SAMPLE COLLECTION RATES

This effect of sampling rate on FFT Spectra was investigated with analog data from the Sin Cos HallPot(R) Resolver rotated at 18.22 rps (1093 rpm), using the equipment described. The sampling rate was varied and FFT Spectra examined. The Sampling Rate, Total Time, and FNUM are under user control and the lower these values are set, the faster the results are generated, so there is some justification for setting the sampling rate as low as possible. However, the Nyquist Criterion states that reliable information can be obtained at half the Sampling Rate and generally cirQED™ FFT software charts the FFT Spectrum from 0 to half

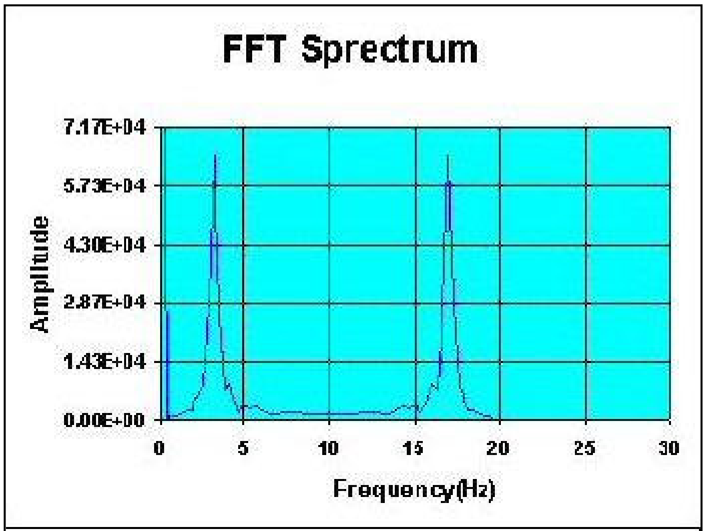


Figure 4 FFT Spectrum at SRATE=20 dps

the Sampling Frequency. At a Sampling Rate of 20 sps (20 Hz), a single peak at 3 Hz appears in the FFT spectrum, if the maximum frequency is set at 10 Hz, as shown in Figure 4. When the maximum on the frequency scale for the chart was increased, as shown in figure 4, another peak at about 17 Hz was seen. To test if the frequency components are real, one has to sample the sensor output at a higher sampling rate. At a Sampling Rate of 30 sps, the peak at 3 Hz no longer appears, however, peaks at about 12 Hz and 18 Hz are observed, as shown in Figure 5. It is clear that a sampling rate of 20 sps was inadequate and resulted in an aliasing error. The aliased frequency of 3 Hz observed in the FFT spectrum at 20 sps is not real and can be predicted as the difference between the sampling frequency (20 Hz) and the component observed at 17 hz. The new peak at 12 Hz is likely also an aliased frequency (not real) and can be tested by increasing the Sampling Rate again, as shown in Figure 6. At a Sampling Rate of 128 sps, the peak at 12 Hz is not seen, however, the peak at 18 Hz and another peak at 110 Hz appear.

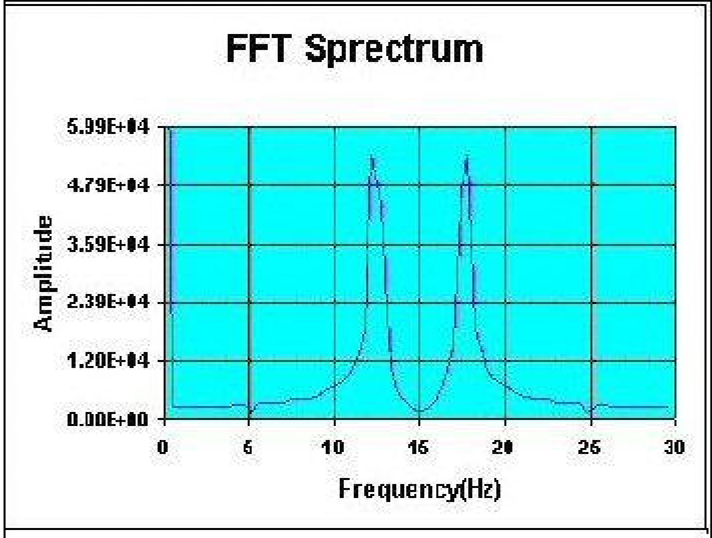


Figure 5 FFT Spectrum at SRATE=30 dps

One can conclude that the component at about 18 Hz is real and surmise that the component at 110 Hz is an aliased frequency, since it is predicted as the difference between the Sampling Rate and the 18 Hz component. Sampling at higher rates produced similar looking FFT Spectra. For example, at 256 sps peaks at 18 Hz and 238 Hz were found. The peak at 18 Hz is again confirmed to be a real component, however, the peak at 238 Hz is predicted to be an aliased frequency (the difference between 256 and 18). Reading for 4 seconds improved the frequency resolution and gave the value of 18.25 Hz for the FFT Spectral component.

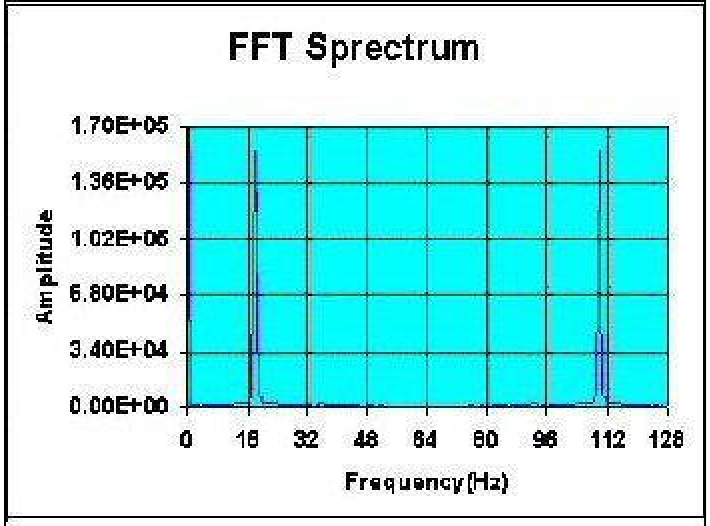


Figure 6 FFT Spectrum at SRATE=128 dps

Sampling in violation of the Nyquist criterion can result in FFT spectra with even more complicated phenomena, whereby alias frequency components appear below half the sampling frequency due to real components that exist at frequencies above the sampling frequency. Antialiasing filters are often used to avoid this, however, are not needed if the frequency bandwidth of the sensor signal being measured is less than half the sampling frequency.