PERFORMANCE OF COTS I/O MODULES IN AN ACCELERATOR CONTROL SYSTEM*

S. M. Hartman†, FEL Laboratory, Duke University, Durham, North Carolina 27708-0319, USA

Abstract

We analyze some recent experiences with commercial off the shelf (COTS) I/O hardware modules, comparing manufacturer specifications with our in-house measurements. Discrepancies between quoted specifications and measured performance under accelerator laboratory conditions have been observed. In some cases, design or manufacturing faults have been found which could have impact on the overall performance of the accelerator.

INTRODUCTION

A modern accelerator control system relies heavily on COTS hardware modules for the bulk of input/output (I/O) needs. The costs of developing and manufacturing custom boards is typically prohibitive. Moreover, COTS modules provide published performance specifications, interchangeability, and manufacturer support which are not typically available for in-house built hardware. The published performance specifications are critical in matching the appropriate commercial module to the requirements of the task.

At the Duke Free Electron Laser Laboratory (DFELL), we do not have the resources to test and certify the performance of each channel of each piece of I/O hardware we purchase. Typically, basic functionality is confirmed over the course of software driver support development. A limited number of measurements are made for noise characteristics and short term stability and repeatability. However, we have developed a comprehensive magnet power supply testing and monitoring program. These test measure the power supply's performance *in situ* using the same physical setup for both I/O and load as during machine operations. This testing and monitoring program has uncovered issues with power supply performance, but has also uncovered a number of issues with the control system I/O hardware.

I/O HARDWARE PERFORMANCE MEASUREMENTS

Our standard analog power supply testing program includes a measurement of the power supply's short term stability, reproducibility, and linearity [1]. The two main parts of the test consists of an interleaved series of extended stability runs at a few settings covering the power supply's typical operation range, and a series of slow step-functions used to ramp the power supply through its entire output range. The series of stepping ramp functions are used to measure reproducibility and also, by comparing measured performance to a linear fitting of the data, the power supply's linearity. The digital to analog converter (DAC) channel which will be used during operations is used to control the power supply. Current readbacks are monitored using the analog to digital converter (ADC) channel which will be used to monitor the power supply during operations using the power supply's internal readback circuitry. In addition, a Danfysik DC current transformer (DCCT) is connected in series with the magnet. The DCCT, monitored by a precision digital voltmeter, provides the DFELL's reference for current measurement. If the overall system of power supply, DAC and ADC are all within performance requirements, the DCCT readbacks are used to calibrate the control and readback channels, and the system is ready for use. However, any problems uncovered require additional focused testing to isolate the subsystem causing the error. For the I/O hardware, this typically entails a customized test setup for thoroughly measuring the performance of that module.

Missing Bit

In testing a series of newly installed power supplies (controlled by a newly acquired DAC module) for storage ring quadrupole magnets, the data showed non-linearity greater then expected. The problem was quickly isolated to the DAC module controlling the power supply and not the power supply itself. Additional tests were performed to measure the performance of the DAC module as compared to the published specification of $\pm\ 0.003\%$ of full-scale range differential non-linearity. Direct measurements indicated an obvious fault in the module as shown in Table 1.

Table 1: DAC Module Differential Non-linearity. Expected Difference to a One LSB Change is Approximately $30.5\ \mu V$

DAC Code	Measured Voltage	Difference Voltage
0x9ffb	2.49784	
0x9ffc	2.49847	0.00063
0x9ffd	2.49847	0.00000
0x9ffe	2.49908	0.00061
0x9fff	2.49908	0.00000
0xa000	2.50062	0.00154
0xa001	2.50063	0.00001

After consultation with engineering staff from the module's manufacturer, it was concluded that two faults were at play, here. First of all, several of the DAC chips used on this module were themselves slightly out of specification in terms of differential non-linearity. Of the number of module we had in house, further testing showed a few per-

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† hartman@fel.duke.edu

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cent of the channels exhibit a non-linearity crossing points such as that shown at the step to 0xa000 in the table. The manufacturer agreed to replace the defective chips for the worst performing channels. The majority of the channels, however, were within specification on this point. The more interesting issue, however, was the zero step response to a change in the least significant bit (LSB) as shown by the step from 0x9ffc to 0x9ffd, for instance. Further testing showed channel seven, and only channel seven, of all the modules in-house demonstrated this behavior. The first power supply tested using this module happened to be using channel seven. The manufacturer's engineer was also able to duplicate this behavior on modules they had available. Further research by the manufacturer determined that this problem was the result of a missing trace on the printed circuit board which had been used for this module since the beginning of production a number of years ago. This missing trace meant that the LSB of one DAC channel could not be addressed, effectively making the 16-bit DAC only 15-bits resolution. The manufacturer was able to add a jumper to the board to connect the missing pin. We were also provided with instruction for fixing additional boards ourselves. Future boards sold by the manufacturer should have this fix in place.

Transient Sign Error

The testing of another power supply indicated acceptable performance in all respects. However, when we attempted to calibrate the power supply's internal readback circuit as measured by the ADC module to the DCCT readings as measured by the precision digital voltmeter, we had a poor fit for the data. Reviewing the data revealed problems in the transients during the slow step-ramp portion of the power supply testing. Since the current as measured by the DCCT did not indicate this problem and no problem appeared to exist in the power supply's readback circuitry, separate testing of the ADC was undertaken to isolate the problem. Since this ADC is primarily used for slow measurements, a test was set up consisting of a function generator producing a sine wave at approximately 0.6 mHz. As can be seen in Figure 1, the ADC module occasionally produced a misread when the input voltage was increasing in the range of four to six volts. The error did not occur on the down ramps, nor was it measured every cycle (though some cycles recorded multiple errors). Further study indicated that the misread is a sign error of the value as returned by the ADC module. The manufacturer is currently still investigating this issue. Since this error does not directly impact accelerator performance, the modules are still in use. The limitations of the readback are kept in mind, particularly with regards to our operational power supply performance monitoring program [2].

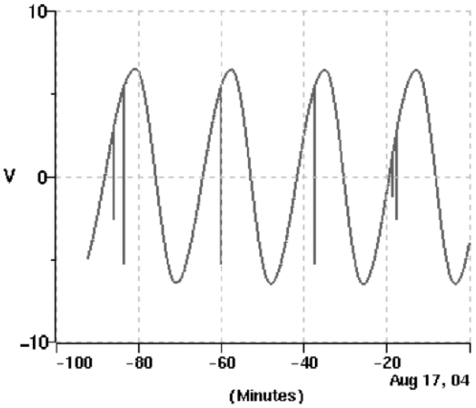

Figure 1: An ADC module recording a waveform generator produced sine wave showing a transient sign error during increasing voltage input. Data were recorded at 1 Hz.

Solder Joint

Another power supply, used for an electromagnetic FEL wiggler, had been returned to service after an extensive overhaul including completely reworked control circuitry [3]. Complete testing of the power supply and a new high accuracy, 18-bit DAC module indicated performance was well within our specifications. However, after several weeks of operation, we experienced a few incidents of beam loss which were traced to problems with this power supply. The power supply would appear to lose regulation and drift from its setpoint. After a period of several seconds to a few minutes, the power supply would return to proper regulation. Given the extensive modifications to the power supply, initial investigation was focused there to find the source of the fault. However, the fault could not be reproduced. Some modifications were made including addressing an impedance mismatch between the power supply's control input and the DAC module's output. Measurements indicated that the DAC module produced a significant high frequency component when driving a high impedence load as was provided by the power supply's control circuit. This noise, at 800 KHz, was unlikely to impact power supply performance, but was addressed to avoid any potential issues. Eventually, the fault occurred while measurement equipment and personnel were in place. The DAC module's output consists of a 4-wire connection with a pair of sense wires to compensate for voltage drop across the output cable. A bad solder joint was found on the connection for one of the sense wires. As the resistance of the connection changed, the DAC module's output tried to compensate, with the result looking like the power supply was out of regulation. Once found, the repair was straightforward. Review of the other channel on this module and on a second module did not reveal any additional bad solder joints. Further modifications to address the high frequency noise of the module when driving a very high impedance device are being investigated.

CONCLUSION

Design or manufacturing problems with commercial I/O modules, while not common, do occur. These problems may not be apparent without some sort of testing program. For instance, the DAC module with the missing trace for accessing the LSB of one channel has been manufactured that way for a number of years and has been in use as a part of the control system for a number of accelerator laboratories. The impact of these faults on the accelerator's operation may not be readily apparent or necessarily easy to trace.

Our experiences with several manufacturers after discovering such problems has been favorable. They have typically been quick in helping to isolate the problem and providing a solution or necessary support. The greatest difficulty has been in the effort required to isolate and test individual modules to localize the fault and on potential impact to machine operations.

REFERENCES

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