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REPLACING THE ENGINE IN YOUR CAR WHILE YOU ARE STILL DRIVING IT – PART II*

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Abstract

Two years ago, at the 2015 ICALEPCS conference in Melbourne Australia, we presented a paper entitled "Replacing The Engine In Your Car While You Are Still Driving It" [1]. In that paper we described the mid-point of a very ambitious, multi-year, upgrade project involving the complete replacement of the low-level RF system, the timing system, the industrial I/O system, the beam-synchronized data acquisition system, the fast-protect reporting system, and much of the diagnostic equipment. That paper focused mostly on the timing system upgrade and presented several observations and recommendations from the perspective of the timing system and its interactions with the other systems. In this paper, now nearly three quarters of the way through our upgrade schedule, we will report on additional observations, challenges, recommendations, and lessons learned from some of the other involved systems.

INTRODUCTION

To briefly re-cap the previous paper, we compared the installation/operations schedule to driving through mountainous terrain on a road with many peaks and valleys. When you start down a valley, you shut down your engine, replace as much of it as you can, then try to get it running again before you have to start up the next peak. At the bottom of each valley there is a relatively flat stretch of road representing the "start-up period" – during which you mostly coast while you discover how your changes affected the machine's operation (for good or for ill).

The installation and operation schedule is shown below in Figure 1. The green blocks represent the operating periods, the red blocks represent the installation and maintenance periods, and the yellow blocks represent the start-up periods. The durations of the operation, maintenance, and start-up periods vary as the project progresses. The first three years of the schedule call for longer operational periods (seven to nine months), shorter upgrade periods (four months), and shorter start-up periods (one month). The middle three years – during which the most complex upgrades take place – have longer maintenance periods (four to five months), longer start-up periods (three months), and shorter operational periods (three to four months). During the last three years, things theoretically get easier and we go back to longer operations, shorter maintenance, and shorter start-up periods. This is the point where we are currently at in the schedule.

Figure 1: Installation and operation schedule.

OBSERVATIONS AND RECOMMENDATIONS

In the previous paper, we presented three observations and two recommendations. The observations were:

1. You can't replace the whole system at once.
2. Some compatibility must be maintained between the old and new systems.
3. You will be surprised.

The two recommendations were:

1. Always have a way to fall back
2. Have sympathy for the operations staff.

This paper amplifies on the three observations and includes one new recommendation.

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THE RICE SYSTEM

The previous paper focused mainly on the timing system replacement. In this paper we will focus on what is possibly the most entrenched and hardest to replace component in our accelerator – the "Remote Information and Control Equipment" (RICE) system [2].

The RICE system was designed and built in 1969 to handle all of the industrial I/O, beam synchronous I/O, and fast machine protection reporting. It consisted of a single "RICE Interface Unit" (RIU) that could communicate in parallel. with up to 128 remote RICE stations see Figure 2). This topology allowed a single read request to return up to 128 channels of data, which is how we acquired our beam synchronous data. It is also how we obtain the data required to analyse a machine protection fault.

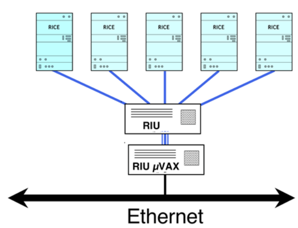

Figure 2: RICE topology.

As time progressed however, RICE also became our biggest bottleneck. The system is limited to only one synchronous read operation per machine cycle. For our machine, this means that the maximum rate for all beam synchronous data requests is 120 Hz. (our maximum repetition rate). The rate is less if the accelerator is running at low repetition rates. Which it does during tune-up periods (4 Hz.). Which is also when we have the highest demand for beam synchronous data.

Observation 1:
You Can't Replace the Whole System at Once

The RICE replacement task was subdivided into three independent projects – Industrial I/O, Beam Synchronous I/O, and Fast Protect reporting. Even with this subdivision it was not possible to complete any of these projects in a single installation and maintenance period. This meant that we would have to operate the accelerator using both the old (RICE) system and the new system.

This is not much of a problem for the new industrial I/O system since it can operate independently of the RICE industrial I/O function. However, a beam synchronous read or a fast protect read must contain data from both the old (RICE) and the new systems – which brings us to our second observation.

Observation 2:
Some Compatibility Must Be Maintained Between the Old and New Systems

As of this writing (September 2017), the fast protect project is about halfway completed and the beam synchronous project is just getting started. Both projects require that their data sets contain data from both the new and old systems, and that all the data be acquired at the same time within the same beam pulse.

Like many other facilities, we employ a correlator to assemble the data based on timestamps. To make life easier (or sometimes even possible) for the correlator, each machine cycle is given a timestamp and all the data taken during that machine cycle is given the timestamp for that machine cycle. The machine cycle timestamp is broadcast through the timing system. The correlator can then use exact matches to assemble its data set.

Beam synchronous data is acquired as vectors, so "time-in-cycle" requirements can be met by selecting the appropriate vector element. Fast protect data is stable throughout the duration of the machine cycle, so it does not require any finer grained timestamping. What is a problem, however, is that all the RICE data comes through a MicroVAX 4 computer which does not have access to the timing system event link and cannot apply the cycle timestamp to its data.

To solve this problem, we must recall that the RIU can take synchronous data from up to 128 remote stations. At present, only 66 stations are in use. So we mounted an EPICS IOC with a timing event receiver and a binary output card next to the RIU. The IOC reads the cycle timestamp and extracts 36 bits from the middle (24 from the seconds field and 12 from the nanoseconds field). It then writes these bits into the RIU data buffers for three of the unused RICE stations (12 bits each). The result is that

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every RICE dataset now contains the middle 36 bits of the cycle timestamp, which is enough precision to guarantee an "exact" match within a range of 194 days.

Observation 3:
You Will be Surprised

And sometimes it will be a pleasant surprise! The industrial I/O replacement project is now in its third year. We have been replacing the RICE industrial I/O functions with National Instruments Compact RIO crates running EPICS [3]. The first year, we succeeded in replacing the industrial I/O function of 4 RICE stations. The second year we succeeded in replacing the industrial I/O function of 7 RICE stations. Recall, however, that we have a total of 66 RICE stations to replace. At this rate we were on schedule to finish the industrial I/O replacement project somewhere in the year 2023! During the 2017 outage, however, we replaced the industrial I/O function on 33 RICE stations. So how did that happen?

The first thing that was different about 2017 is that we had more manpower. Most of the operations staff, freed from their regular duties of operating an accelerator, were recruited to help with the industrial I/O project. Most of these operators were not particularly trained as electricians or engineers. However, when we compared error rates, the rates of the untrained workers were comparable to the rates of the trained workers.

The second thing that was different was repetitiveness. The 33 stations were all part of the main LINAC and each station pretty much had the same signals going into the same locations. This made the planning and execution much easier.

But the thing that made the most difference, and is the subject of our next recommendation, was:

Recommendation 1:
Do as Much as You Can Before the Maintenance Period Starts

After those first two years, we began to realize that a lot of the work involved with replacing an industrial I/O system could be performed while the accelerator was still running. So during the 2016 run cycle, the project engineer took the following actions for each of the RICE stations scheduled to be replaced:

- Inventoried the existing wiring at each station.
- Cross checked the existing wiring with the control system list of known channels to determine which wires were still needed and which wires were not.
- Removed all unneeded wires
- Removed all trunk cables that no longer contained any needed wires.
- Labelled all the remaining wires with regard to whether they belonged to the industrial I/O system or one of the other systems.
- Installed the terminal blocks that will interface to the new cRIO systems.
- Built the cRIO systems, configured their software, installed them in the racks, and connected them to their terminal blocks.

Once all this was accomplished, almost the only thing left to do during the maintenance period was to move wires from the old system to the new one and do the testing.

Observation 4:
You Will Continue to be Surprised

As mentioned above, the RICE system has been our biggest bottleneck for many years. A pretty obvious way to help alleviate that bottleneck would be the removal of over 4,500 I/O channels from RICE – which is exactly what we did during the 2017 outage.

But it didn't. In fact, during the 2017 startup period the bottleneck got worse! At this point we don't really know why. There is some speculation that systems physicists and engineers, giddy at the prospect of a more responsive RICE system, may have been adding more beam synchronous data requests to the logging facilities. As of this writing, however, we have no definitive answer.

CONCLUSION

We hope these observations have been useful – especially if you are contemplating a similarly ambitious upgrade project. If you are, however, you might want to check back with us at the 2019 ICALEPCS. There are sure to be a

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number of other challenges in store for us!

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