DIAMOND: TEN YEARS OF OPERATION

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Abstract

Diamond [1] is a 3rd generation 3 GeV light source. It became fully operational for users in 2007 and is presently celebrating 10 years of operation in 2017. It services approximately 6000 users a year, an increasing number who do not need to physically be the Diamond site.

Diamond's storage ring is populated with 29 Permanent Magnet Insertion devices, 2 superconducting wigglers and 7 bending magnet beamlines. Two major lattice updates, the most recent at the end of 2016 have been installed and commissioned. Three new beamlines are under construction not yet commissioned, a number of early beamlines (2007) have been or are currently being replaced or upgraded to keep them scientifically competitive. Diamond beamlines were funded in three tranches to fully populate the facility, the first two were completed as planned, the final phase, phase three - completes in March 2018.

INTRODUCTION

Routine operation of Diamonds storage ring is Top-up mode, 300mA, 900bunches, lifetime ≈12 hours, 0.33% coupling, natural emittance 2.7 nmRad. Other bunch fill patterns or configurations are used to suit specific beamline and user activities - (Hybrid with single bunch, hybrid with multi-bunch, low alpha and 156 bunch) but in total they are less than 10% of the ≈5000 operational hours typical for users each year. Figure 1 shows the complete Diamond facility.

The 'normal' annual run/shutdown pattern is 5 runs, 5 shutdowns, some shutdowns are longer than others (3-4 weeks).

Figure 1: The Diamond facility, Oxfordshire.

All runs contain a 1 day a week (fixed on a Tuesday) machine development day. This is flexibly allocated to small or urgent fault fixes, 4-6-hour machine physics tests, engineering tests, longer range development testing and any operational issues. In particular, it is also used for commissioning new beamlines with first light as beam can be run initially at lower beam current than 300mA.

ACCELERATOR OPERATIONS

Accelerator Operations is a group within the technical division at Diamond. It consists of 8 machine operators who man the control room 24/7, a Technical manager of the storage ring and a Head of the group. Only one operator is required to run and operate the accelerators (Storage ring, Injector and the machine interfaces with beamlines) and man the control room. They are on rotation around three shifts a day, two at weekends. Accelerator operations is supported by technical groups within the technical division of Diamond - Accelerator Physics, Engineering, Diagnostics, Vacuum, Power convertors and magnets, RF and Injector, Controls, Survey and Facilities.

Additionally, on call support is available 24 hours a day during a run and staff are called in, or fix remotely incorrectly functioning items - if a problem occurs requiring a specialist.

Operations has 3 keys aims: Maintaining specified machine beam parameters as designed and optimised in development periods, maintaining reliability over extended periods (uptime) and minimising off periods in user runs (downtime). The latter two are most easily characterised by MTBF (Mean Time Between Failures) and MTTR (Mean Time To Recover)

It is a particular feature of light sources that the loss of electron beam by an unplanned beam trip can have a disproportionate effect on some particular beamlines whose optics have for example large single piece x-ray mirrors as these can take 3 hours or more to thermally stabilise to optimum performance. If the heat load of a 300mA stored beam/ID is removed as in an electron beam trip, recovering the *electron* beam can take only 30 to 45 minutes (MTTR) the remaining time for thermal recovery reduces the beamlines effectiveness. For some beamline users, expensive and complex protein samples can be lost by a beam trip. Beam Trips can therefore be very disruptive to facility operations, and maximising MTBF is essential.

STATISTICS

Collection and analysis of key statistics are important, for routine reports during a run and for driving fault repairs to improve reliability. A fault database is used to record all faults and to process their status with the relevant support group. Every fault (even trivial faults) have an entry in the Fault Database (FDB) and is allocated to the technical support group responsible. The beam trip faults are filtered out and others indicating they may cause a later problem, these are reviewed weekly at an Operations meeting. Here the faults are also classified in the FDB as Better Than Before (BTB) or As Bad as Before (ABAB). The aim is to improve each fault to a better than before status to drive MTBF improvements, however some faults are more intractable, occur very infrequently or need long

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term fixes in multiple locations, these are tracked for the period it takes to improve them - with increases in priority if they are recurring.

The FDB is also used to generate fault satistics on a regular basis in graphical form. These statistics are reviewed at the regular weekly operations meetings and collated and presented in an annual review of the years operations run by the operations group with the technical groups.

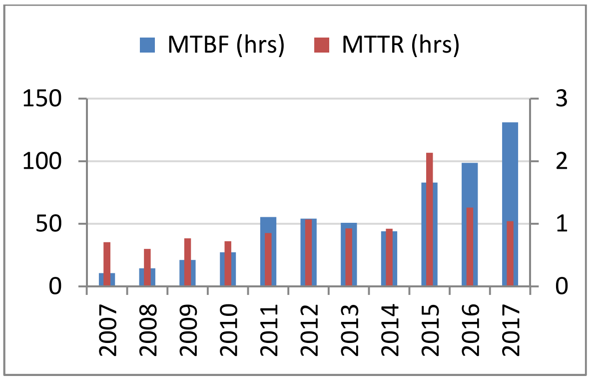

Figure 2: 10 years MTBF and MTTR.

A summary of the 10 year MTBF/MTTR is shown in Fig. 2. Year 2017 is up until end April. It can be seen that MTTR has remined fairly static at 1 hour or less except in 2015 when a cavity failure occurred doubling the MTTR.

Fault Rectification

The FDB also allows tracking of MTBF or trip rate assigned to a technical group. For two thirds of the 10 years of operation the balance of faults were towards the RF systems, although many procedures, interlock limits and interlock management changes were required in other areas to improve them. The balance of RF trips to Non RF trips is plotted in Fig. 3.

A particular fault class called a 'fast vacuum trip' (an RF cavity initiating an arc causing a vacuum burst and stored beam is lost) which occurred frequently has been progressively worked around and by reducing significantly the operating voltages to 1.1MV and 1.4 MV respectively of the two installed s/c cavities, it has now disappeared from the fault statistics. Figure 3 is demonstrating this, although not all the trips in the figure are fast vacuum trips the majority are and the last 3 years show the improvement made from eliminating this type of fault. The RF system overall (the two systems combined) have now reached a collective MTBF of 200 hours for 2016. Figure 4 is showing this (2017 is not a complete year but looks promising at 420 hours.) In the years 2013-15 a cavity had to be replaced each year two due to leaks and one a broken coupler window.

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Similarly, some outstanding MTBF numbers from Power converters – two separate one year periods where there were zero beam trips from over 1500+ power convertors. This does not mean there were zero faults from these units but most are designed with internal contingency and are fault tolerant and rarely appear in the beam trip statistics.

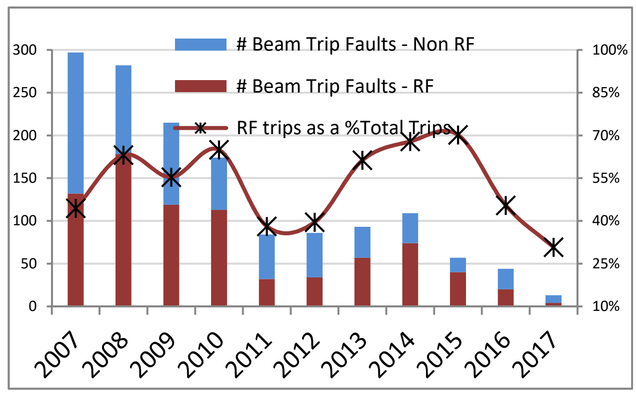

Figure 3: ratio of RF trips to non RF trips by year.

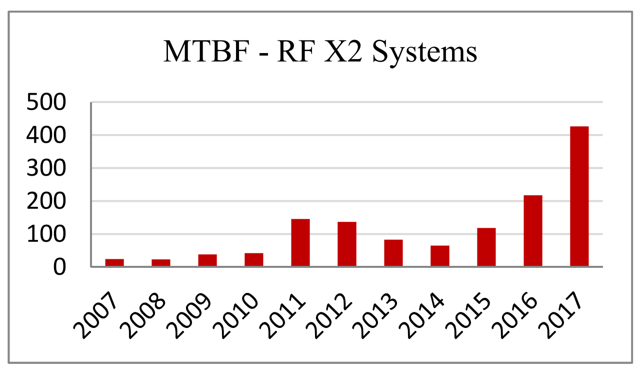

Figure 4: MTBF(hrs) by year for both installed Rf systems cavity and RF amplifiers combined.

Analysis of BTB and ABAB beam trip data can be performed on the data when it is tagged with the correct label.

Table 1 contains totals of beam trips for each of two consecutive years.

For 2016 RF made zero improvement in trip *cause* removal yet had 20 that should have been removed (difficult IOT trip issues) whereas in 2015 22 trips were BTB, these were the 100% elimination of cavity vacuum trips for which an operational solution was eventually found.

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For 2016 Non-RF trips were left with a BTB total of 10 very similar to 2015, giving the implying that underneath within that category they were, (unlike RF) very different types of trip from each other in widely differing locations.

Table 1: Two Consecutive Years ABAB and BTB Data

Year	2016	2016	2015	2015
Area	**RF**	**Non-RF**	**RF**	**Non-RF**
Total #Trips	20	24	44	16
BTB	0	10	22	8
ABAB	20	14	22	8

Overall the technique gives an indication to each technical group that recurrent problems are not being fixed.

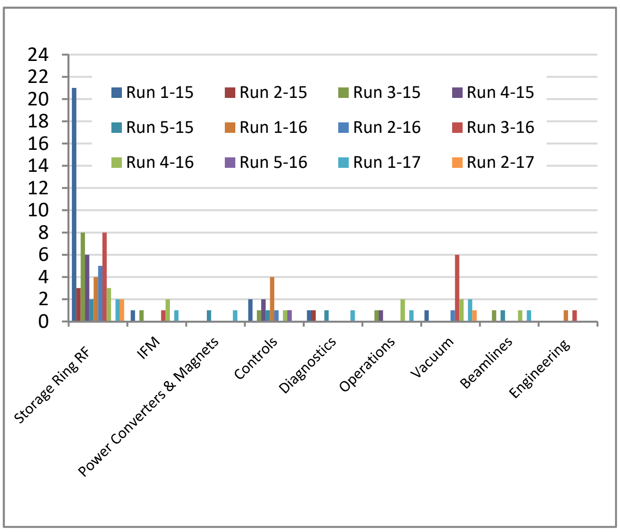

Figure 5: number of beam trips (y axis) against technical system on a run by run basis. For the last 2 years.

The number of subsystems contributing to beam trip statistics are shown in Figure 5 - RF has the majority of trips for most runs but a steep decline after Run 1 2015 shows better than a factor 3 improvement as the previously mentioned techniques to stop the fast cavity trip mechanism were adopted.

Reflecting on reliability/trip count issues over the ten year period it is pretty clear we did not (with four notable exceptions: power convertors , Controls networking, RF cryogenics and PSS) build in reliability and robustness at the level we now have, right from the project start. Nor did we realise the implications for commercial systems we purchased and designed in to other systems (Cavities, IOTs). Any system wide changes, eg for vacuum or machine protection interlocks, took many months to implement as can only be carried out in shutdowns during which major installation works for front ends and beamlines reduced available resources for rectification work in other areas.

MACHINE IMPROVEMENTS AND MODIFICATIONS

Beam current: Operational current for routine operation was set at 300mA from April 2012 onwards.

Top up: had been designed in from the start of Diamond. After the Top up safety case was prepared top up was successfully introduced during September to October 2008. Top-up was a huge step forward in keeping beam current stable and thermal loading constant.

Higher beam current trials to 350mA in user time were stopped in 2012-13 when it was clear cavity trips of the kind mentioned above were occurring more frequently with the higher beam current. There was a clear direction from beamline scientists that reliability (MTBF) was more important than modest increases in beam current.

The DDBA project successfully completed and was rapidly commissioned in late 2016 is so far, the largest machine modification made, replacing 3 lattice girders with two and releasing space for extra IDs to utilise existing beam port apertures in the storage ring ratchet wall. The project had zero effect on reliability post commissioning.

We are looking at support issues for all hardware now that the majority of Diamonds installed systems are 13 years old. An in-depth obsolescence review is in progress however this is giving early signs that there may not be any serious obsolescence issues with equipment specifically but is pointing out that a Fault Scenario analysis across all functioning equipment may be beneficial in identifying more clearly work around plans in the event of serious faults so that potential impact on MTBF and downtime can be assessed.

CONCLUSIONS

Diamond has now been operational for more than 10 years, most recently with 4600 operational hours a year. Achieving above 100 Hours overall MTBF was a major step forward in 2016.

REFERENCES

[1] R. P. Walker, “Diamond Light Source: A 10-year View of the Past and Vision of the Future”, presented at IPAC’17, Copenhagen, Denmark, May 2017, paper WEPAB096, this conference.

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