DIAMOND LIGHT SOURCE: MOVING FROM COMMISSIONING TO FULL MACHINE OPERATION

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Abstract

Diamond Light Source commenced routine operation in January 2007. Light to beamlines/users was provided for 3000 hours in 2007 increasing to 4000 hours during 2008. During shutdown periods insertion devices, front ends and beamlines have been and are being installed at a rate of approximately four per year. The evolution of the performance of the machine during this period is described and future developments are discussed.

INTRODUCTION

Diamond is a 3 GeV high brilliance 3rd generation light source. The facility has been fully operational providing light to beamlines and users since January 2007. Additions and improvements are being made continuously in the form of new beamlines as the complement is built up to the funded 'Phase II' which represents 22 beamlines operating by 2012. Table 1 shows key machine parameters.

Table 1: Key Diamond Parameters

Parameter	Design Values	Actual Values
Energy	3 GeV	*3 GeV*
Beam Current	300 mA	*300 mA* *200 mA User Mode*
Lifetime	> 10 hours at 300 mA	*> 10 hours at 300 mA* *22 Hrs at 270mA*
Emittance	2.7 nm rad	*2.7 nm rad [1]*
Coupling	1%	*0.15-2%* *1% User Mode*

Considerable improvements in performance have been made since January 2007 including progressive increases in beam current, lifetime, important additions such as fast orbit feedback, transverse multibunch feedback systems and a second RF cavity.

STORAGE RING OPERATION – FIRST 18 MONTHS

Following completion of the machine commissioning program in Dec 2006, June 2008 represents 18 months of machine operation giving a cumulative 700 Amp-hours of stored beam. During 2007 10 user runs of unequal lengths were interspersed with shutdowns. Commencing 2008 the number of runs has been reduced to 9, all of longer duration than 2007 to accommodate increased running hours, again interspersed with shutdown periods of varying lengths to allow IDs, front ends and beamline installation to take place.

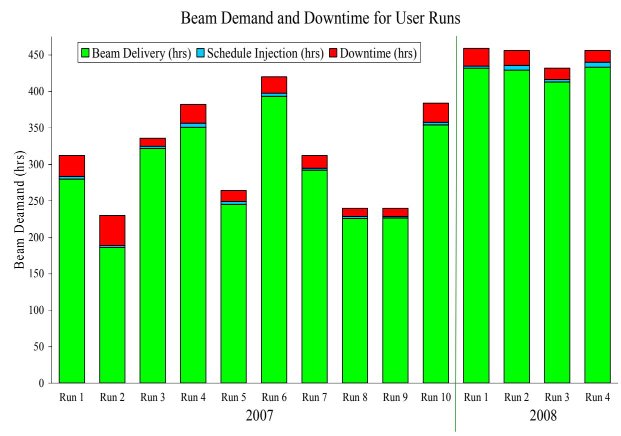

Figure 1: User Mode statistics.

Overall beam uptime during User Mode in 2007 was much as anticipated for the first year of operation - 92.2% beam delivery for 3120 scheduled hours. In 2008, so far we have achieved 94.7% beam delivery for 1824 scheduled hours. Fig. 1 summarises User Mode statistics and the increased run lengths for 2008 can be clearly seen.

Reliability

From the start of machine commissioning a fault data base logging system was set up to track and process machine faults and trips using a fault report. This is used operationally now to log every fault, to email Diamond technical groups that the fault has occurred, and to log the responses/long term resolution to each individual fault. It is also used to track recurrent faults of the same type and of similar type occurring in different locations. The fault report contains pertinent data for the type of fault, for example a beam loss/trip fault or a fault accruing downtime. This data is used to create the operational data on uptime, downtime, scheduled injection time and MTBF and MTTR on the whole accelerator complex (injector booster and storage ring plus critical utilities) and MTBF in key technical areas eg RF system or utilities.

Interruption to beam from beam trips is an important measure of operational performance and is shown in Fig. 2. For 2007 MTBF was variable and declining giving an average for the year of 11.5 hr , however for 2008 a concerted attack on recurrent faults and a re-evaluation of the necessity for the high number of interlocks that dump the electron beam (and their subsequent removal) has led to a steady improvement in MTBF to an average of 15.5 hours in 2008 as well as reductions in MTTR.

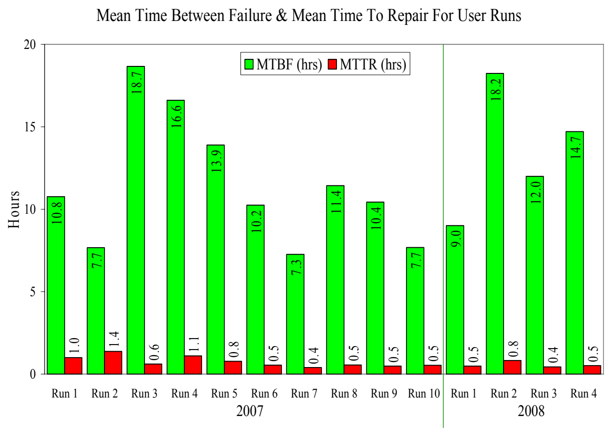

Figure 2: User Mode MTBF and MTTR data.

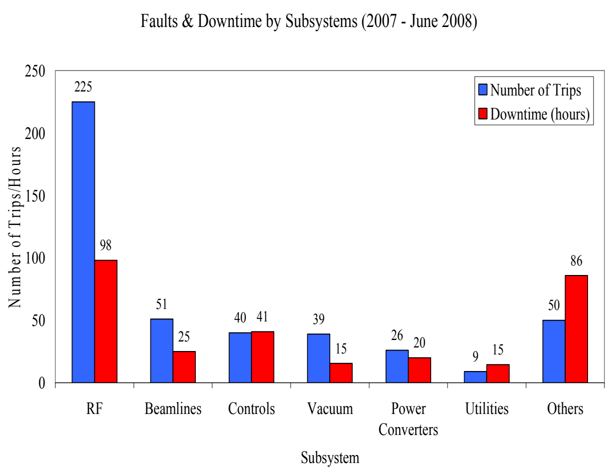

Figure 3: Number of faults and downtime by technical area.

Figure 3 is a simplified summary of beam trips by various subsystems. The statistics are dominated by RF faults and this has led to extra diagnostics [2] (Vacuum and key rf parameters) equipment being added to both cavities to assist in analysing the failure modes. Essentially a fast data acquisition system based on a Libera diagnostic box produces post mortem data at each event enabling a clear distinction between an RF trip and a beam trip by other mechanisms such as machine protection. The majority of beam trips are RF induced trips and also is a substantial contributor to downtime.

INTRODUCTION OF INSERTION DEVICES AND BEAMLINES

As of June 2008 there are 12 beamlines installed of which 11 are commissioned along with their IDs except the 1 bending magnet line, the 12^{th} is being commissioned to first light during June 2008. Some early problems with a 3.5T wiggler have now been rectified. The majority of the in-vacuum undulators are available for small gap running at a minimum of 5 mm with a resultant small lifetime decrease [3].

MACHINE DEVELOPMENT

Beam Stability

From Day One operation a slow orbit feedback system was available to correct the machine orbit. This was replaced completely by a Fast Orbit FeedBack system [4], in July 2007.

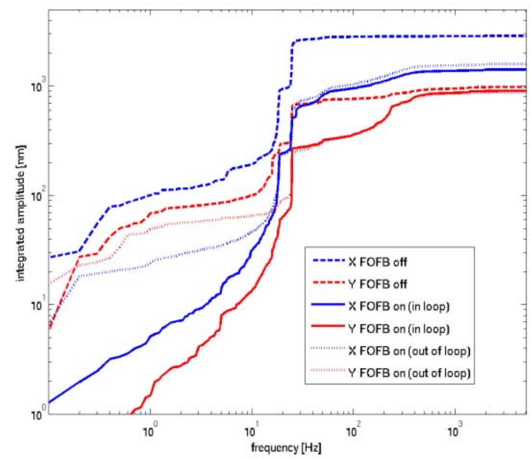

Figure 4: Comparison of integrated amplitude of positional noise for horizontal (X) and vertical (Y) with loop control on and off

FOFB achieves integrated beam stability up to 100 Hz of less than 1% of horizontal, and 2% of vertical (at 1% coupling), beam size and divergence. An additional loop in the FOFB software corrects RF frequency to maintain a constant horizontal circumference and since January this year routine use of the Transverse multibunch feedback system (TMBF) has commenced [5].

Operating Current

Commencing June 2008 beam current provided to beamlines is 200 mA with a lifetime well above 20 hours (1.9 MV rf), which has been an incremental increase from the initial (Jan 2007) 125mA as beamlines have been able to take more current. Additionally during weekly machine development periods 300 mA testing has been pursued, initial testing at 300 mA saw a lifetime in excess of 10 hours with 2 x 1.5MV in the rf cavities. Further work is continuing to investigate issues that arise from a 300 mA stored beam, as the step up in thermal load has necessarily led to careful investigation of the machine thermal environment and investigation of temperature increases in the range 30-80ºC in areas not anticipated to run at these temperatures. These areas were identified by thermal sensors routed back to the control system, local temperature indicators and by use of thermal (infra-red) cameras in key locations. Whilst in general temperature rises to 50^{o}C are not seen as a real problem, the fact that heating typically occurred local to ceramic chambers, BPMs and a number of flanges, a cautious approach has been adopted and additional cooling has been fitted to the locations of most concern which was completed in April 2008. There is clear evidence that the heating effects are electron beam RF induced heating as they are bunch length and charge per bunch dependent.

Injector and Single Bunch

An improvement in the understanding of the injector system performance [6] has been made over much of the first year of operation and more recently as part of top-up requirements. Significant improvements to linac stability were implemented such as modulator cooling stability and locking to the 50 Hz mains, made along with a more in-depth understanding of booster performance and parameters in relation to storage ring injection timing and the storage ring kickers. From June 2007 single bunch in hybrid mode was made available (typically 600 bunches with a higher current single bunch in the centre of the remaining empty 336 bunch slots) for beamline/user specific application trials. The single bunch fill process is extremely versatile and in combination with the master timing system it is possible to 'dial up' any bunch and fill it, or fill up any partially filled bunch as required. Increasingly we are starting to adopt single bunch alone to provide initial storage ring fill to avoid having to switch between two modes of operation of the linac.

Top-up Testing

Diamond was designed from the outset to have the ability to run in top up mode [7] and the many advantages of top-up are now well established on many similar machines. A top-up trials program throughout the last 12 months has led from limited tests on single bunch injection, to single bunch filling and charge levelling across the fill pattern, addition of new interlocks, and analysis and minimisation of the injection transient produced by the storage ring injection kickers when they are fired. A top-up application program controls the process and provides software limits to key parameters such as injection efficiency with a continuous stream of statistics on how top-up is performing. Tests for periods of up to 4 hours (beamline shutters closed) have kept beam stable to within ± 0.1% with injection cycles of 10-20 pulses every 2 minutes. Additional tests involving beamlines investigating beamline/end station performance during simulated injection process (that is kickers firing without bringing in electrons) to study the residual oscillations that cause beam blow up during kicker firing have commenced. Gating is available if necessary from the master timing system for beamlines to gate this out - but the intention is to minimise the oscillation by reduction of the injection transient effect.

NEXT STEPS

Increases in Machine Operational Current

It is anticipated, depending on beamline demand and subject to making progressive incremental tests in radiation safety clearances for beamlines, to establish routine 300mA operation before the end of 2008.

Top-up Introduction

Plans are being made for moving from decay mode operation to top-up operation during User Mode on a phased basis commencing late summer 2008, in order to assess the impact on beamline performance.

Other Developments

During the remainder of 2008 the intention is to perform low-alpha mode studies, stored beam energy measurement by electron spin relaxation and a program to understand and reduce and isolate vibration sources [8,9] in the synchrotron building itself and to further reduce on-girder vibration at around 300 Hz presently outside the Fast Orbit Feedback system capabilities. In addition, new IDs are being added: within the next year a cryo-cooled undulator and a second s/c wiggler. To accommodate a bending magnet infra red beamline, one of the twenty four machine girders is being removed in November 2008 to allow a replacement girder, modified to facilitate the infra-red beam extraction, to be installed.

SUMMARY

Diamond is continuing to improve in performance as a new medium energy 3rd generation light source. Further increase in beam current and the introduction of top-up mode are the next major challenges.

ACKNOWLEDGEMENTS

The author acknowledges the contributions of the entire Diamond project team in progressing through the commissioning program into routine operation. The machine development team have kept up a rapid pace of development, testing and implementing a number of key systems that significantly enhance machine performance.

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