ISBN: 978-3-95450-132-8 doi:10.18429/JACoW-IPAC2014-THPRI041

TWENTY YEARS OF OPERATION OF THE ELETTRA RF SYSTEM

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Abstract

Six thousand hours per year is the typical running scheduled time of the user-dedicated Elettra facility and twenty years is a significant amount of operating hours for the radiofrequency (RF) system. Failure and weak points of the installed equipment is discussed as well as the up-time statistic. The effectiveness of the standard versus the extraordinary maintenance is presented. The gained operational experience has allowed the planning of the priorities to revamp the installed components within a reasonable budget, in compliance with the user operation time schedule and following the technical need to improve the RF system performances.

THE RF SYSTEM

Elettra, the Italian 2.0/2.4 GeV third generation light source, operates for users since 1994 being the first third generation light source for soft x-rays in Europe [1].

Four RF stations at 500 MHz are installed in the 2.0/2.4 GeV 310/160 mA storage ring. Each RF cavity, a normal conducting single cell, is fed by an independent transmitter. Three of them are 60 kW E2V K3672BCD klystron-based transmitters, installed in the early 1990s. The last is a 150 kW transmitter set into operation late 2007 and it is based on the combination of two 80 kW E2V D2130 Inductive Output Tubes (IOTs). The power delivered to the beam is 70 kW at both beam energies. The total accelerating voltage is 1.68 MV that leads to a total cavity' copper losses of about 120 kW.

One 500 MHz RF station is installed in the full energy injector booster that was set into operation beginning of 2008. The booster accelerating resonator is a five cells Petra type cavity fed by a 60 kW klystron based transmitter. It was previously installed in the storage ring and replaced after the new IOT transmitter, even though the booster RF power's demand is less than 20 kW. Each klystron transmitter has 120˙000 heater hours. Both IOTs transmitters have 40˙000 heater hours.

Each RF station is equipped with analogic Low Level RF (LLRF) electronic composed by amplitude, phase and frequency tuning feedback loops. Besides the standard cooling circuits, a dedicated cooling rack keeps stable the reference temperature of each cavity. Several mechanical phase shifters are installed to set the proper phase adjustment among the RF stations.

The 500 MHz machine clock signal of the master oscillator is distributed to the full energy injector, the storage ring RF stations and to other equipment (multibunch transverse feedback, beam lines, diagnostic tools and so on) for the requested synchronization.

Elettra is operating 6000 hours/year, 5000 of which are designated to the beam lines. Several components of the RF stations are the ones installed in 1993, including the booster RF transmitter. The remaining RF component of the booster has been installed late 2007.

THE DOWNTIME

After the completion of the Elettra installation and operation, the machine uptime and reliability issues became a priority. All the data on failures and beam unavailability began to be collected in a reliable and comparable way [2].

The reliability of the Elettra RF system is shown from the down time caused by RF in comparison with the total machine down time, see Fig. 1. Every RF failure is fatal meaning machine downtime for the users.

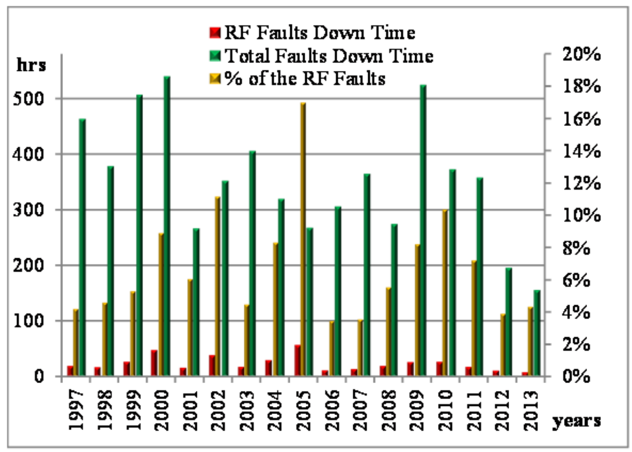

Figure 1: Total and RF down time in hours, vertical axis on the left, and percentage of RF downtime with respect to the total downtime, vertical axis on the right.

The "total faults" means machine downtime due to any failure including power outages. Three operation modes of the storage ring are shown in Fig. 1: energy ramping up to 2007 (since 1999 ramping also to 2.4 GeV), full energy injection since 2008 and top-up since 2010.

These machine ways of operations greatly affected the RF parameters. The energy ramping operation needed a different set of the RF system parameters because of the energy's gap between injection and operation of the storage ring. Moreover the cavities working point had to follow the stored current decay mode. They had to be free from High Order Modes (HOM) in a range of about 2.5 ˚C of the reference temperature and, at the same time, had to give enough longitudinal instability to allow the beam accumulation at the 0.9 GeV. The RF system coped being properly designed to address wide operational needs.

With the top up operation in 2010 the RF system works almost at a unique operating point with minimal dynamic range required from LLRF feedback loops. But, according

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to the data shown in Fig. 1, the RF down time is not significantly decreased. The absence of a significant improvement of the reliability is mainly due to the obsolescence of the RF equipment and to the lack of qualifications of the Thales IOT tubes.

The RF down time statistic includes the RF booster station from 2008 but the impact of its faults is absolutely negligible with respect to the storage ring RF stations. Till now the main failures of the RF booster station were caused by poor shielding of the electronic against radiation and setting up issues at the beginning of the operations. The effect of these failures was a delay in terms of few minutes of the injection. These troubles have been easily fixed once identified.

Therefore the contribution to the RF downtime of Fig. 1 comes entirely from the storage ring RF stations.

The overall RF uptime trend shows a see-saw phenomenon, mainly reflecting severe hardware troubles followed by "lightweight" failures. Various are the sources of the RF faults but no downtime comes from RF vacuum components like cavities, RF picks up or the HOM frequency shift movable plunger, from the low level RF. The klystron based transmitters were widely reliable up to 2010 and the 500 MHz signal distribution up to 2012. Then some ageing troubles came.

THE FAILURE STATISTIC

The RF down time can be certainly split in two categories: short time failures that need just a "software reset" to be restored the RF system and heavy failures that need replacement of hardware components. These last have the most significant impact on the RF reliability.

Lightweight Failure

Irrespective of the Elettra setup or energy of operation, the RF system was and is still afflicted from some short time "free from repair" failures.

Roughly four times per year the circulator arc detector stops the RF operation and causes a beam dump. This trouble is well known in the RF community: coincidence arc detectors are usually implemented to avoid spurious faults. Now this is not a priority issue at Elettra and the recovery time of such failure is around 35 minutes on average.

From 2008 to 2010 the Thales IOTs of the newly installed transmitter had an increasing number of trips during the machine operation boosting the RF downtime [3]. In 2009 and 2010 one trip occurred every fifteen days on average. It was not possible to cure or prevent these trips even if large efforts were undertaken. During user time operation, the Thales IOTs trip was just reset and the IOTs transmitter powered on once again, with the same recovery time of the circulator arc detector fault. Finally a different IOTs model from E2V firm was installed middle 2010. At the beginning of the operation the E2V tube exhibited some trips, five in six months, but now its reliability is significantly improved and the failure rate is three to four trips per years for two IOT tubes. It is appropriate to highlight that the klystron reliability, that is no trip during operation till its end of operation, is still unique and not so far equalled.

Heavy Failure

Heavy failure covers the replacements of hardware components of the RF system when broken/damaged. Restoring and commissioning the system after such failure is a time consuming operation that typically increases the RF failure rate to values larger than 5 % of the total failure.

In 1999, after 34˙500 hours of operation, one input power coupler (IPC) had a water breakthrough under vacuum. Before it could become a leak it was replaced.

In 2002, 2004 and 2005 the sensitivity of the IPC and of the coaxial lines to the High Order Modes power together with some mishandling caused severe failure of those components [4]. That time the RF system had to cope with the beam instabilities [5]. Moreover the Elettra operation at several energies (1.0 GeV for the storage ring FEL, 0.9 GeV for injection, 2.0 and 2.4 GeV for the user operation) required different cavity tuning and increased the human mishandling possibility.

Another cause of long recovery time from failure is the klystron replacement. The average lifetime of a 60 kW klystron is 32000 hours. Due to the expensive cost of this spare part it was decided to keep the klystron in operation up to its fatal break or considerable loss of performance with no prearranged replacement. The money saving was paid off with some unavoidable RF downtime but it should be recalled that, after the fatal klystron trip, it was permitted to operate with three RF stations instead of four during the klystron replacement.

Figure 2: Klystron based transmitter ageing: damaged insulation of the linear HV transformer laminated core and burnt klystron output coaxial line.

The full energy injection and top up operation has greatly helped the RF system, relaxing the requested performances. Nevertheless first evidences of aging troubles arose from the increasing operating hours mainly on the klystron based transmitter. Several failures happened in 2010 and 2011, for example burnt part of a power coaxial output line and of the linear high voltage transformer, shown in Fig. 2. Those have been replaced during user time.

THE MAINTENANCE

The Elettra shut down time, 60 to 65 working days per year, is dedicated to maintenance and new installation according to the following planning:

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- standard periodic tests to be performed at least one once per year and routinely prestart-up check;
- planned servicing to improve the RF performances;
- planned servicing to overcome the production discontinuity;
- dedicated servicing triggered by the failure's incidence.

The overall proper operation of the RF system is verified by standard and periodic checks, like klystron tuning, measurement of the band width and dynamic range of the LLRF loops, interlock check and so on. Even if recurring and boring tasks, these tests are the main key points to keep efficient and reliable any system. Moreover prior any machine start up the RF system check list is completed to monitor the main parameters.

During the years several installations have been done to improve the RF performances. The new hardware replacement had to be carefully planned to meet the time limit fixed by the Elettra calendar.

In 2003, 2009 and 2013 respectively, three among four cavities have been replaced having an improved copper losses capability of 60 kW as shown in Fig. 3.

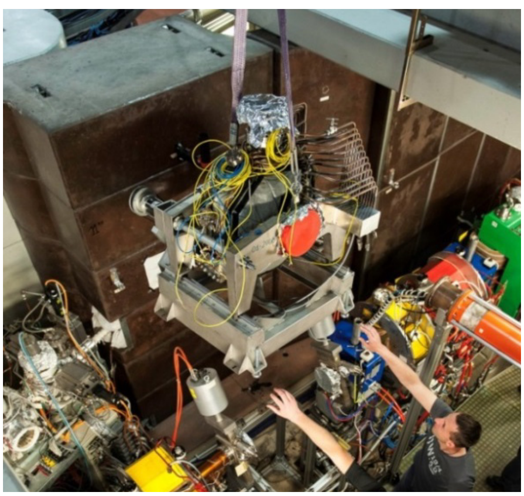

Figure 3: Cavity installation in the Elettra storage ring.

Each cavity replacement time (the new cavity ready for acceleration) is around 15 working time but is should be recalled that the cavity is already conditioned at full RF power in the laboratory.

In 2007 the renewal of the whole RF power part of one RF station was carried out [6]. Together with the new 150 kW transmitter all the power line components having the proper RF power capability were replaced and the RF station lay out was rearranged.

The production discontinuity of components and the availability on the market of 500 MHz electronic with improved performances is another issue for revamp. The LLRF electronic equipment has never failed and some spare electronics ready for swap have been arranged. But the greater performance of the integrated circuits has pushed new development. A more compact frequency tuning loop and a novel RF power monitoring will be installed this year.

A prototype of digital LLRF electronic for RF amplitude and phase regulation has been successfully tested and the evaluation of the complete analogue equipment renew is under assessment stage.

The extraordinary servicing is also triggered by the failure's incidence. A renewal campaign of the aging klystron transmitters was performed from 2010: high voltage capacitors and cables, electronics components if available and HV transformers were replaced to extend their lifetime. This operation has been made possible because of the large spare parts made available at the transmitter's purchasing stage. Todays the replacements are running out and the klystron production has being discontinued. The transmitter failure rate is almost cleared for the next few years, but is is not anymore worth to invest budget and effort in these ageing transmitters.

CONCLUSION

After 20 years of operation the reliability of the Elettra RF system is good, even excellent taking into account the components wearing. A constant maintenance schedule and new installations are of primary importance to achieve this result.

The spare parts availability has proven useful, but after twenty years it is not any more worth to replace obsolete components and it is even not possible to find the same electronic. Development and replacement of new up-to-date electronic is mandatory.

The RF system priority is now the replacement of the klystron based transmitters to meet the high reliability specification of the light source user facility.

ACKNOWLEDGMENT

The authors would like to thank the operator crew for the statistic data collection and their effort for the successfully reliability of the Elettra facility.

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