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PETRA III VACUUM SYSTEM – EXPERIENCE FROM THE FIRST DECADE OF OPERATION

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Abstract

In 2008 the construction of the PETRA III vacuum system started. A year later the first photons were delivered to initial experiments and in 2010 the user operation started. In this paper the operation of the vacuum system will be reviewed. Some of the lessons learned in the initial phase will be presented as well as the main upgrades since then. By now the vacuum system has shown a very high reliability and shows no significant impact on the availability of the machine.

INTRODUCTION

Modern synchrotron light sources are accelerators which are producing photons for users. Several users are performing experiments simultaneously. For efficient experiments unplanned interruptions of the photon delivery have to be reduced to the absolute minimum. Photon beam interruptions can lead e.g. to extended loss of time due to the necessary thermal stabilisation of monochromators. In other terms, the availability of the accelerator is very important. A common metric to account for the availability across different accelerator laboratories has been developed [1]. The availability goal for PETRA III was 97 % in 2017.

Each subsystem of the accelerator has to aim for supporting high availability. In this paper, the first decade of operation of the PETRA III vacuum system is investigated.

OPERATION OF THE PETRA III VACUUM SYSTEM

The vacuum system of the PETRA III accelerator con-sists of several sectors [2-4]. Extensions to establish more experimental stations have been implemented in 2014 [5]. The initial phase of the commissioning has shown the expected performance of the vacuum system in terms of dynamic pressure [6].

With the operation of the vacuum system since 2008, several experiences were made, which have led to minor adaptions of the vacuum system.

In this evaluation, the focus will be on failures or problems related to vacuum systems components. Failures of other components leading to vacuum system problems are not discussed here.

An example of the latter category would be a leak which developed due to a laser whose focus was acci-dentally placed into the window material causing a local overheating followed by a crack.

AVAILABILITY OF PETRA III FOR USER OPERATION

In 2008 only a few vacuum sectors of PETRA III were assembled and pumped down. After completion of the vacuum system in the beginning of 2009 the initial electron beam commissioning took place. Thus, availability in a strict sense was evaluated only when user operation started in 2010.

The development of the accelerator availability from 2010 to 2017 is shown in Fig. 1.

Only then a systematic operation at full beam current with various bunch patterns was implemented. In 2017, PETRA III met the availability goal set to 97 %. For 2018 it is aimed for to improve to 98 %.

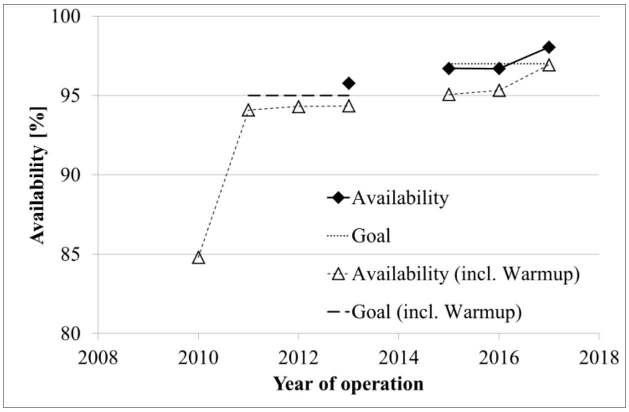

Figure 1: The availability of the PETRA III accelerator. In the initial availability calculation, an hour for the warmup of the photon beam transport components was included (triangles). The diamonds represent an evaluation according to Ref. [1].

INITIAL DESIGN ISSUE: RF FINGERS

In 2010, the beam current was increased over the year. When beam currents near the design level of 100 mA were achieved, it became clear that the design of RF fingers to screen a bellow were not capable of sustaining the electromagnetic fields associated with the higher beam current. In fact, mechanical tolerances including a potential misalignment were not taken into account properly, so that the fingers would have no contact. Subsequently, they bent due to heating and obstructed the circulating beam.

In Fig. 2 it is obvious, that this design problem caused a significant downtime in 2010 and 2011. While the operation was limited to a beam current of 80 mA, an improved design was made, built and installed during regular maintenance slots. Finally, in 2011 all problematic RF fingers were replaced.

INTERRUPTIONS CAUSED BY THE VACUUM SYSTEM

In general, the number of interruptions of user operation due to vacuum system problems is not high. In 2015 there was no single beam abort due to the machine vacuum system of PETRA III. Clearly, this demonstrates that the system can perform extremely reliable.

A deeper investigation of the other years has shown that there was the option to further increase the reliability by optimising the system layout and operating procedures.

In fact, most of the beam aborts were caused by single points of failure in the vacuum interlock. They were identified in most cases:

- False alarms of the vacuum interlock
- Failure of sputter ion pump power supplies
- Shorts in high voltage cables due to radiation
- Leaks due to aging of bellows

In a few cases, valves were shut (and causing a beam dump) for unknown reasons. The most likely explanation for these events is that the power supplies of the sputter ion pumps were causing them by delivering a sudden noisy signal to the valve control logic.

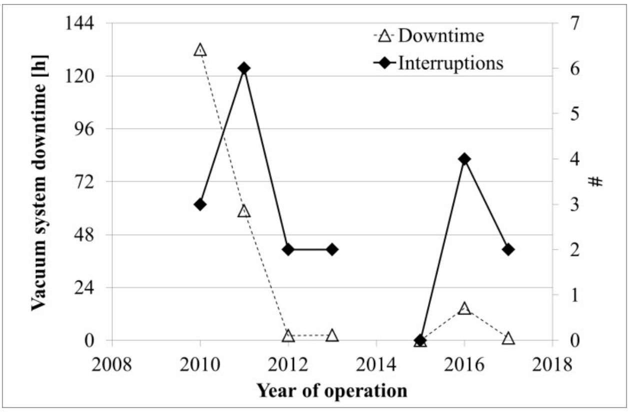

Figure 2: Downtime due to the vacuum system and its components (triangles). In addition, the number of interruptions is shown (diamonds).

INCREASING REDUNDANCY TO IMPROVE AVAILABILITY

The first three causes for beam aborts were due to single points of failure in the vacuum interlock which closed the gate valves of the sector of the accelerator and led to a beam dump. The first problem was the insufficient reliability of an in-house developed sensor which detects whether a system is vented or not. When detected in 2011, the simplest and most cost effective solution to improve was to double the amount of sensors so that only the simultaneous alarm in two sensors would cause a beam abort. Since the implementation of this solution in 2013 no further beam aborts were caused.

The second and third single points of failures are related to the sputter ion pumps. At PETRA III the ion pumps are used as pressure sensors. In the initial layout of the pump control system the average pressure of all pumps in the system was calculated. When a threshold – typically 10^{-7} mbar - was passed due to a pressure increase, the gate valves were closed to protect other sectors from pressure rises. The averaging of the pump pressures was taken from the HERA vacuum interlock. The downside of this approach is that a single power supply can fail and send out a false signal indicating a very high pressure. Only when the number of pumps is very large these individual failures will not cause a problem.

The similar problem occurs when a short develops due to the failure of insulation after exposure to radiation. Specifically, in the damping wiggler section of PETRA III a lot of x-ray radiation is generated and some of that escapes the beam tube and causes radiation damage.

Both failure modes can be addressed by modifying the condition to close a gate valve and profiting of the redundancy in the vacuum system, with about 15 pumps in the larger sectors of the accelerator. Since 2017, the valves will be closed when any two of the pumps of the sector surpass the threshold. Thus individual failures of components will not cause gate valves to shut, while maintaining an effective interlock to contain potential vacuum problems to single sectors in the vacuum system. It has to be seen on how this measure will affect the number of interruptions.

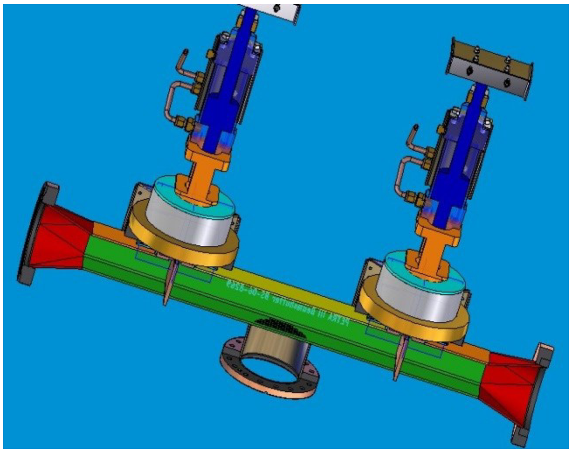

Figure 3: Beamstop for PETRA III.

AGING OF COMPONENTS AND PREVENTIVE MAINTENANCE

The problem of the radiation damage of cables has been addressed also on the layout and routing of the cabling of the pumps. The cables which are used have a length of up to 200 m. To simplify the exchange of cables it has been split. The short part which is located in the radiation environment can be exchanged preventively. The necessary additional interconnect plugs of the cables are believed to be less of a problem.

In 2016, the two beam stops (Fig. 3) in PETRA III developed leaks nearly simultaneously. Within two month a relatively large leak (10^{-6} mbar l/s) in the same type of bellow opened. Investigations have shown that about 1000 movements have been done. The bellows now have been replaced and will be exchanged preventively until a more reliable solution is found.

OTHER VACUUM SYSTEM RELATED ISSUES

In addition to the points mentioned above, a problem with the beam collimators occurred which did not impede accelerator operation. The initial design of the spring ensuring contact between housing and collimator block allowed the spring to dislodge. This led to wear on the blocks and housing so that the collimator got stuck. An improved design has been made and installed. This does not show any wear.

Finally, the temperature measurement system of PETRA III which monitors the vacuum system amongst others has shown about 3 beam aborts per year of operation. These are due to aging caused by excessive radiation. As it is indispensable to monitor certain locations in the accelerator to ensure safe operation, discussions are ongoing to implement redundancy in this system, too.

CONCLUSION

The PETRA III accelerator vacuum system works very reliable. After the resolution of an initial design problem the downtime is about 2 hours per year.

A premature aging of a set of bellows at beam stop has caused a longer downtime in 2016.

To reduce the number of beam aborts due to the vacuum technical interlock additional redundancy has been implemented in hardware and control logic.

Additional measures to enable preventive maintenance on high voltage cabling in a high radiation area have been implemented.

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