RELIABILITY STUDY OF THE AIRIX ACCELERATOR OVER A FUNCTIONING PERIOD OF TEN YEARS (2000-2010)

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Abstract

AIRIX is a high current (20 MeV, 2 kA) electron linear induction accelerator used as a 60 ns single shot X-ray source for hydrodynamic experiments. As single shot experiments are performed, the best performances and a high reliability level must be met for each experiment. A high availability is also a key issue for the successful development of hydrotest projects.

The AIRIX accelerator has been running for hydroshot experiments since 2000 and several thousand electron and X-ray beams have been produced. This paper outlines the reliability results of the AIRIX accelerator over a functioning period of ten years. Failure rates for each main subsystems are shown: injector, accelerating cells, high voltage generators, vacuum equipment, measurement chains and drift tube. We also give an overview of the most probable faults, with the associated occurrence rates which can alter the AIRIX X-ray source, assessed over this ten-year period.

EXPLOITATION: FACTS AND KEY FIGURES

The AIRIX accelerator has been successfully operated since its commissioning in 1999 [1] and the following key figures can sum up its exploitation over the 2000-2010 ten year period:

- 20,200 electron flashes were produced over the functioning period.
- 5,700 electron flashes were produced with the injector alone. They are mainly performed after changing the injector vacuum insulator panel, for preventive or corrective maintenance, and/or the cathode. After such operations, flashes are needed for the conditioning of these parts and for beam parameter determination [2].
- 14,500 electron beams were accelerated up to 20MeV.
- 3,700 of the 14,500 e-beams were converted into X-ray flashes for hydroshot preparation and the experiments themselves.
- 10,800 of the 14,500 e-beams were sent to the beam stop. These ones are mainly used to achieve the beam centering procedure [2].
- The cumulated accelerator operation time is about 10,000 hours.
- There is one shift per day, 140-150 days per year; the remaining time is devoted to maintenance
- More than 25 million parameters are stored in and available from a database.
- About 4,000 preventive maintenance operations per year are carried out.
- The mean preventive operation time is around 2,000 hours per year.
- Corrective maintenance operations have decreased since 2,000 from more than 600 per year to less than 200 per year.
- Mean corrective operation time is about 3,000 hours per year.

FAILURES - MAINTENANCE

Survey Methodology

Each failure occurring on the AIRIX accelerator is recorded and saved in a database. This has been done since half-year 2001. In order to have an ergonomic list of indicators the accelerator is divided into 6 sub-systems: injector, accelerator, drift tube, measuring systems and diagnostics, vacuum equipment, high voltage generators. Each sub-system is itself divided into equipment then into components, etc. For instance, the drift tube is divided in the following subsystems: guiding equipment, process control and wire lines, power supply and command, X converter, mechanical parts, supporting equipment, anti-debris system, and cooling system.

Failures - Corrective Maintenance

Figure 1 shows the number of corrective operations per year for the whole AIRIX machine (2001 is incomplete because the database was started after mid-year).

After an initial increase of the corrective operations mainly due to debugging and correction of the machine teething problems, a regular decrease from 2004 until now may be noticed.

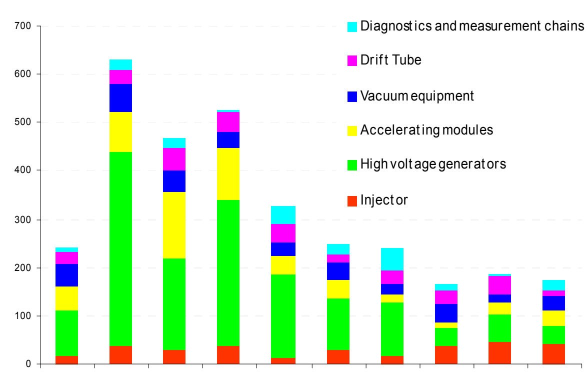

Figure 1: Number of corrective operations per year for the whole AIRIX machine. 2001 is incomplete; the database was started after mid-year.

The number of corrective operations has markedly decreased since 2004 which has allowed the facility to reach a plateau below 200 operations per year. The subsystem where the improvement is most noticeable is the high voltage generator subsystem. The failure number has been divided by about 10 in 8 years, as shown on figures 1 and 2.

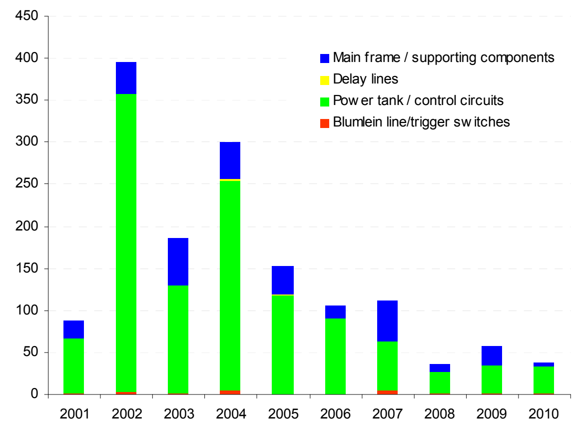

Figure 2: Number of corrective operations per year for the high voltage generator subsystem.

The corrective operation time per year for the whole AIRIX machine reached its peak in 2004 at around 7,500 hours as shown on figure 3. It was mainly due to problems with the vacuum insulator panel and half of the corrective maintenance time was devoted to this part that year.

Many corrective maintenance were spent on the drift tube, especially in 2008 and 2009 (see figures 3 and 4). They were mostly devoted to the anti-debris spinning wheel system. This piece of equipment was completely refurbished and improved by the beginning of 2010 and its reliability has been markedly improved as shown on figure 4 (orange bars). The drift tube pumping system was also improved in 2009 which enabled around 10 minutes between two X-flashes to be saved.

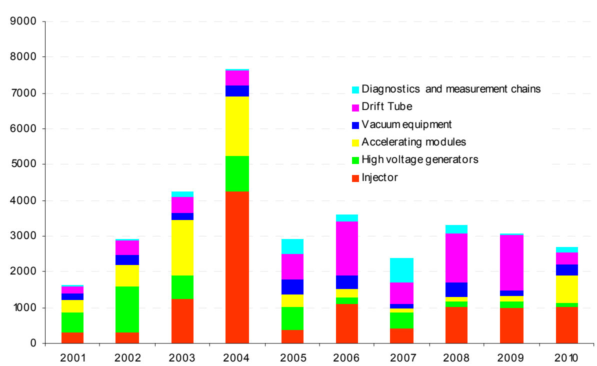

Figure 3: Corrective operation time per year for the whole AIRIX machine. 2001 is incomplete; the database was started after mid-year.

On the whole, the constant technical improvements carried out on the AIRIX accelerator since its commissioning have enabled the failure numbers after the initial debugging period to be divided by 3. The average corrective operation number has stabilized below 200 per year and the corresponding hour number below 3000 per year (see figures 1 and 3).

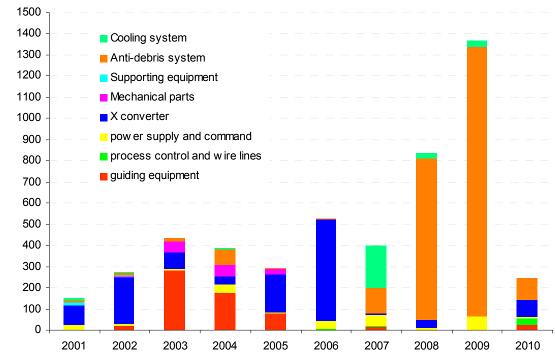

Figure 4: Corrective operation time per year for the drif tube subsystem. 2001 is incomplete; the database was started after mid-year.

Preventive Maintenance

The preventive maintenance plan has been continuously modified and optimized over the past ten years. However, it has been kept roughly constant between 3,000 and 4,000 operations per year (see figure 5) and around 2,000 hours per year (cf. figure 6). Obviously, the amount of operations varies from year to year for some preventive actions only occur every 2 or 3 years.

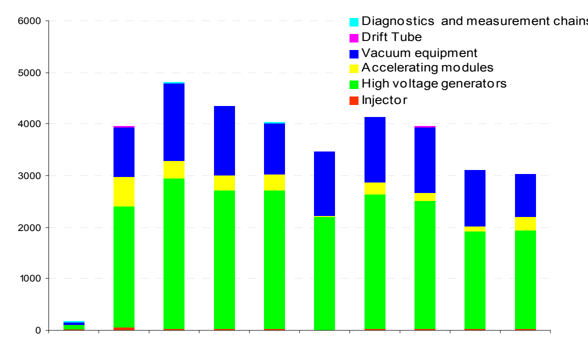

Figure 5: Preventive operations per year for the whole AIRIX machine. 2001 is incomplete; the database was started after mid-year after the annual five week maintenance period.

Preventive operations take place on average four afternoons and one complete day per week. Once a year, usually in summer, there is a five-week maintenance period when long interventions are run including: dismounting, cleaning-up, inspection, replacement of wearing parts, prime power tank inspection, transmission line inspection and cleaning up, mechanical alignment, insulating oil cleaning and insulator vacuum panel removal for maintenance.

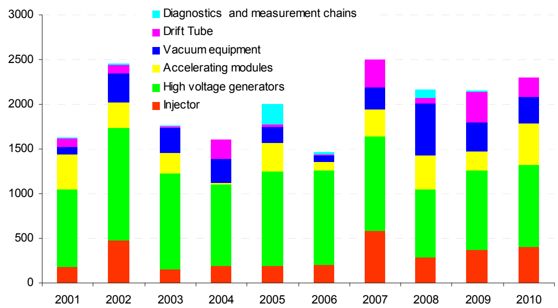

Figure 6: Preventive operation time per year for the whole AIRIX machine.

Thanks to both preventive maintenance plan optimization and continuous technical improvements made since the beginning of the accelerator exploitation the failure rate has been reduced by a factor of 3. In addition, the maintenance cost and the accelerator availability have been optimized. For example, the production cost per X-ray flash, taking into account maintenance costs without CEA labor costs, has been divided by 3.

X-RAY SOURCE RELIABILITY

Survey

As single shot experiments are performed with the AIRIX accelerator, the highest reliability is mandatory. Several hundred electron beams and X flashes are necessary when preparing an experiment to get the required performances with the highest possible reliability.

All the characteristics of electron beams and X-ray flashes made since 2000 have been stored in and are available from a database. In this way, we can study any particular parameter and measure the intrinsic reliability of the X-ray source for hydrodynamic experiments.

The highest occurrence for the known failures that may alter the electron beam and thereby radiographs have been calculated over 20 000 flashes. They are listed by order of gravity in the following paragraphs.

Probability of a Total X-ray Source Loss

This could be due to a voltage break-down in the diode and its likelihood is 0.13%. This is a critical event for no electron beam would be produced and thereby the radiographic diagnostic on a hydroshot would in turn be lost. Fortunately the occurrence of such voltage breakdowns is not purely random. They mainly occur after changing vacuum insulator panels, therefore the probability is upperbound.

Probability of an X-ray Source Quality Loss

This probability is 1.3%. The two main sources of such a degradation are:

- Voltage breakdowns or rampings in an induction cell: this happens in 1.0% of the flashes. In fact, a closer inspection shows that most of the breakdowns occur in the oil insulated impedance matching connections. These breakdowns do not damage the accelerating cells. The voltage breakdown impact on the beam is strongly dependant upon the cell position. The dose loss is about 3 to 4% and the focal spot is enlarged.
- Loss of one high voltage generator. This occurs in 0.25% of the cases. The impact depends upon the generator position. The dose loss is around 7% and the focal spot size is enlarged.

Probability of Barely Noticeable to No X-ray Source Quality Loss

In 1.9% of the cases post-pulse rampings and/or break-downs in the diode are observed. As these phenomena occur after the main pulse, the impact on the electron beam is barely and in most cases not noticeable on the X-ray source. As for voltage break-downs in the diode, they mainly occur after changing the vacuum insulator panel.

On the whole 96.7% of the electron beams are produced as expected with nominal characteristics. This figure has been quite stable since AIRX's commissioning. We can even claim that the probability of nominal X-ray source characteristics is 98.6% since post-pulse breakdowns do not or only scarcely alter the X-ray source.

CONCLUSION

All the figures given in this paper are experimental facts, assessed over an entire ten-year exploitation.

The mean failure rate has been continuously decreasing since 2004, after the teething problem debugging and improvement period.

Maintenance is optimized, and the maintenance policy has enabled the failure rate per year to be divided by 3.

The probability of radiographic diagnostic loss for hydroshot experiments is below 0.2% and so far we have had 100% success for radiographic diagnostics on hydroshots.

AIRIX is a very reliable and available accelerator with stable performances.

REFERENCES

[1] M. Mouillet et al., “First results of the AIRIX induction accelerator”, Proc of XXth LINAC conf., p. 491 (2000).
[2] E. Merle et al, “Transport optimization and characterization of the 2 kA AIRIX electron beam, Proc of XXth LINAC conf., p. 494 (2000).