HIGHLIGHT OF OECD/NEA WORKSHOP ON "UTILISATION AND RELIABILITY OF HIGH POWER PROTON ACCELERATOR"

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Abstract

The first OECD/NEA Workshop on "Utilisation and Reliability of High Power Proton Accelerator" was held at Mito, Ibaraki, in Japan on October 13 -15, 1998. The participants were 92 persons, including 32 persons from the outside of Japan. There were two keynote talks and eleven invited talks from the high power proton accelerator (HPPA) projects. Twenty three technical papers were presented about the areas related to reliability of HPPA, new accelerators, effects of beam trips, and interface technologies. Technical discussion sessions were also arranged for accelerator and accelerator driven system (ADS), in parallel. In the last panel session, the commentators from both fields commented on technical problems.

Scope of the workshop

R&D activities and construction plans related to high power proton accelerators (HPPAs) are being considered in various countries to promote basic and applied sciences, including accelerator-driven nuclear energy system (ADS), using neutrons, protons and other secondary particles. Taking into account the fact that proton beams from existing HPPA trip (suddenly stop) very frequently, it is indispensable to understand the effects (e.g. thermal shocks) of such beam trips on different sub-systems, especially fission sub-systems. Additional R&D will be needed to accomplish a highly reliable HPPA and sub-systems resistant to thermal shocks.

The scope of the workshop comprises:

- The experiences and prospects of HPPA utilisation.
- Reliability of existing HPPAs, especially focused on beam trips and power fluctuations.
- Effects of resulting thermal shocks in fission sub-systems.
- Required accelerator reliability in various applications.
- R&D of sub-systems resistant to such shocks.
- Accelerator types suitable for ADS, interface technology between proton beam and sub-systems.
- Control system and safety concept for ADS and problems relevant to utilisation (multi-purpose vs. dedicated systems, etc.).

The purpose of the workshop is to exploit more efficient utilisation of HPPAs in various fields and to ensure the future possibility of ADS.

Major Presentations

Applications of High Power Proton Accelerators (HPPA)

Five presentations were given to the projects developing spallation neutron sources with HPPA, and six presentations to the accelerator driven system (ADS) with HPPA.

The SNS project in USA was approved, which aims at 1 MW pulsed spallation neutron source for neutron scattering and will be upgraded to 4 MW. The ESS project for 5 MW spallation neutron source in Europe has started an optional study of a superconducting proton linac, in addition to the reference normal conducting one. There are two projects in Japan and it was reported that both projects will join**:** the JAERI Neutron Science Project for neutron science and for transmutation of long-lived nuclear wastes with 1.5 GeV-5.3 mA superconducting linac, and the JHF project promoted by High Energy Accelerator Research Organisation (KEK) which includes two ring synchrotrons of 3 GeV-200 mA and 50 GeV and four research facilities, i.e., for high energy nuclear physics, neutron scattering, muon science and RI beam nuclear physics. The KOMAC project in Korea is a multipurpose accelerator complex aims at constructing a 1 GeV-20 mA HPPA in conjunction with ADS project of HYPER.

Many countries have ADS oriented projects. The Chinese project of a 150 MeV-3 mA HPPA is injecting a beam to 3.5 MWt LWR with criticality of 0.94-0.98. Russian activities of ADS development includes critical experiment with photo neutrons from a Pb or Pb-Bi target. The Czech program is for LLFP and TRU transmutation with mixture of target/MA and Flibe cooled graphite/LLFP blankets driven by a 35 MeV deuteron external neutron source. In France, there are GEDEON activities of development for nuclear waste transmutation. Those include spallation target experiments at SATURN and reactor experiments at MASURCA with a 14 MeV source, material research of structure and Pb , Pb-Bi target and 10 MeV-100 mA accelerator developments. Italy has TRASCO program by ENEA and INFN, and the industrial program by Ansaldo Corp. The TRASCO is developing a 1 GeV-30 mA accelerator, subcritical system like Energy Amplifier with nine sub-programs. The industrial program is focusing on a demonstration proto-type of an 80 MWt, a Pb-Bi target and subcriticality of 0.95. In USA, the ATW is conducting three blocks of developments: accelerator in APT (1 GeV-140 mA), pyrochemical processes and a subcritical burner (2000 MWt/Pb-Bi).

Table 1 **HPPA projects presented at the workshop**

Project	Country	Specification	Utilisation
SNS	USA	1 GeV, 1 mA , 1 MW(4 MW)	Neutron Scattering
ESS	EU	1.333 GeV, 3.75 mA, 5 MW	Neutron Scattering
JAERI-NSP	Japan	1.5 GeV, 5.33 mA 8 MW	Neutron Scattering, ADS
KEK-JHF	Japan	3 GeV-200 mA, 50 GeV-10 mA	Neutron Scattering, Muon, Kaon
KOMAC	Korea	1 GeV, 20 mA	RI production, Therapy, ADS
RCNPS	China	150 MeV, 3 mA	RI production, Therapy, ADS
TRASCO	Italy	1 GeV, 30 mA	ADS
GEDEON	France	not yet specified	ADS
ATW	USA	1 GeV, 140 mA (APT)	ADS
?	Russia	target & subsystem only	ADS
?	Czech	35 MeV deuteron	ADS

Reliability of HPPAs

The reliability of the accelerator was investigated by using a statistical code, based on the data from LANSCE, ISIS, PSI and TJNAF facilities. The accelerator down time predicted from MTBF (mean time between failure) and MTTR (mean time to repair) taken from those were agreed well with observations. The results of analysis of beam trip and down time of LANSCE during 1996 to 1997 showed that the most frequent trip is at H^+ injector with 77% but its down time is shorter than one minute. The next component with frequent trips is at RF systems. In Moscow Meson (500 MeV, 20 mA peak current, 50 Hz and 90 ms duration), it was shown that the average beam current loss is less than 0.2 % but localised along the linac. It was pointed out from the PSI cyclotron experience that the major cause of beam trips are due to micro-sparks of the RF systems. The shutdown time by the most frequent sparks is less than 200 ms and the beam is automatically restarted.

The concept adopted in the SNQ project in 1980s showed that the accelerator consists of independent single cavities so as to compensate one cavity by the others if a fault in a cavity occurs. The multiplexing of accelerators and ADS systems largely increase the reliability. A method to improve the reliability of an accelerator based on experiences of IPNS and APS at ANL is to operate the accelerator adequately below the upper limit of its ratings, i.e., with an enough margin. From experiences of LEP at CERN for cavities, couplers and RF systems, it was pointed out that the life of 34 crystrons are expected to be more than 10,000 hours and the reliability of superconducting electron linac is well established.

New Accelerators

A H_2^+ cyclotron concept was proposed to reduce the space charge effect and to eliminate deflection by a stripping foil. A separated orbit cyclotron with superconducting magnets and cavities was also proposed with the results of the test device TRITRON, in which three cascade rings can accelerate the beam up to 1 GeV. A FFAG (fixed field alternating gradient) accelerator was proposed to improve power efficiency of accelerator for ADS, because of the context of progress in cavity and magnet technologies.

Beam Trips/Fluctuations: Effect on ADS and ADS Resistance

From a preliminary analysis on a modest design concept of ADS, it was shown that thermo-mechanical effect on ADS components is the most important problem of the trip, but the effects on fuel pellets, fuel pins and beam window would be negligible. It was also shown from the results of temperature transient test for making structural design guide in FBR, that in repetition of temperature variation between 250°C and 600°C, the test piece was damaged by thermal fatigue for short period of cycles and by creep fatigue for long period of cycles.

From the analysis of the components with temperature variation during the trip based on the EFR concept, it was pointed out that above core structure (ACS) and intermediate heat exchanger (IHX) were important components for such analysis.

Interface Technology

In the IFMIF analysis, a decay constant of Li temperature is a few minutes for the two kinds of trips of two deuteron beam injections with 40 MeV-250 mA: two beams of 10 MW and one beam of 5 MW.

In transient thermal stress analysis in the window of mercury target made of SS316 steel, bombarded by pulsed-protons at a beam power of 5 MW with 50 Hz, it was shown that an asymptotic temperature at the beam window was quickly achieved within a couple of seconds, although the temperature fluctuates at 50 Hz.

A temperature decay constant in the lead incore and the cladding for a lead rod target is estimated to be 5-10 s for unscheduled beam trip or loss of coolant. Maximum stress was 90 MPa in the cladding through normal operation and beam trip transient.

In the lead-bismuth spallation target at a proton beams of 600 MeV-6 mA, the thermal stresses decoupled by the fluid dynamic transient showed the Mises stress (conserved quantity related to yield function) of 175 MPa and a fatigue damage induced by cyclic beam trip longer than 4-5 s leads to predict the allowable number of interruptions to failure.

Discussions

Parallel Discussion/Accelerator

The items discussed here were:

1. Origin of beam trips and fluctuations
2. Possible improvements for HPPA
3. Achievable reliability in future and necessary R&D
4. Linear vs. Ring accelerators as HPPA systems.

And the major conclusions are the followings:

1. For Beam trips, three types were categorised as: 1) short (< 1 min.), 2) medium (1 min. - 1 h), 3) long (>1 h). The most frequent trip is type (1). Most of (1) and (2) are caused by sparks in HV/RF systems. The down time of micro-spark is typically 100 ms, according to PSI data, and its recovery time is 600 ms. The frequency of trips depends on machine.
2. For possible improvements, to reduce sparks (then to reduce damage), it is considered to design carefully the devices and controls, to build and maintain as clean room, to keep good conditioning. The micro-sparks are not avoidable. It is important to note that accelerators are normally tuned to get maximum and "possibly more" performances, and this is the main reason of trips and faults.
3. To get reliability, overdesign is necessary, i.e., the same concept applied to the HV/RF systems should also be applied the other components besides those. The reliable accelerator is possible, but the meaning of "reliability" should be agreed. The participants agreed with: 1) MTBF (mean time between failures) can be reduced to about 100 hrs, and 2) MTTR (mean time to repair) depends on spares and redundancy, i.e., cost.
4. It is important to rely as much as possible on proven accelerators and to select considering specific application. For CW machines, "dream" cyclotron (1 GeV, 10 mA) was discussed and general opinions were collected. "Halo" aspect, as most important technical issue, was stressed. The compactness, modulability, flexibility and so on were also discussed as well as achievable power.

Parallel Discussion/ ADS and Sub-Systems

The discussion were summarised in the following categories:

(A) Definition and separation of problems

- System Test Facility (STF) vs. Transmutation Plant (TP).
- Driven Facility (DF) vs. Spallation Target (ST).
- Nature of trips.

(B) Issues not definitely resolved

(C) Issues not discussed but that need to be considered.

And the major conclusions are the followings.

(A) STF is defined as a demonstrator of combination of a subcritical facility with an accelerator. Only one reliable accelerator will be utilised in this case. The facility should have the maximised flexibility. TP is defined as the facility routinely carrying out actinide transmutation. The multiplexing of ADSs and HPPAs is conceivable, it is optimised for cost and reliability. In discussion, separated coolant loops are assumed for DF and TP. DF consists of above core structure (ACS), intermediate heat exchanger (IHX), primary coolant piping(PCP), fuel core (FC), etc. TP has a beam window and a liquid or solid spallation target. Trips are separated into two time ranges: 1) shorter than a system characteristic time t (40-60 sec or less) and 2) much longer than t. In the case of 1), self-recovering (automated) is considered and effect mainly takes place in ACS or PCP. In the case of 2), special restart protocol is necessary.

(B) Effect of pulse operation of accelerator and possible restriction to pulse structure were not clearly discussed. These questions are related to economy, possibility of multiplexing and beam control.

(C) The necessity of control rod in ADS needs to be discussed, relating to compensation of burn up and a safety device. Controllability of beam power and power surge are also to be discussed. Specific questions, partial Loss of Beam (LOB) for multiplexing, direct/indirect feedback of electricity to the system, and construction philosophy, were also left without any discussion.

Summary

The conclusions and recommendations from the workshop are summarised as follows:

[1] Required accelerator reliability

[2] Siginificant reduction of beam trips is inevitable for ADS application. (two order of magnitude) Regulatory requirement is to be considered. It may be comparable to “Critical Reactor”. If once unscheduled stops happen, a long period will be needed to restart. Specially at the beginning of commissioning it should be very stable to get reliance on the technology. Power control must be studied.

[3] Achievable accelerator reliability

[4] MTBF (mean time between failures) can be reduced to about 100 hrs (85 trips/y) using recent technology.

[5] R&D needs in HPPA

[6] MTBF has not been important issue for current use of existing HPPAs. Severe requirement from ADS is completely new for the accelerator community. Beam trip that will cause the ADS restart would be less than once a year.

[7] R&D needs in ADS

[8] A reference subcritical system should be developed for benchmark analysis to get common understanding of possible problems. A way how to control ADS power level must be studied. Whether k_{eff} has to be stable or changeable should be discussed. R&D on structural materials for frequent thermal shock is required.

[9] Linear vs. Circular Accelerators

[10] It depends on current, power, energy. A linac is for tens mA and GeV, a linac or a cyclotron is for 10 mA and a cyclotron is for less than 10 mA. Beam shape and "Halo" are also to be considered. At the same time, a good core with stable k_{eff} is necessary.

[11] Multiplexing vs. Single Accelerator

[12] It is to be considered from the cost, the reliability and the number of components. The STF may be one accelerator and TP has options. The key question is economy and reliability in the commercial operation, including repairing and maintenance.

[13] Dedicated or Multi-purpose Facility

[14] A multi-purpose facility, such as JAERI-NSP and JHF, aims at multi-disciplinary or cross-disciplinary. Secondary particles such as neutrons and also muons are the purpose of HPPA utilisation. Many dedicated facilities are not allowed especially for small countries. But ADS is not in this domain. It is important to make a dedicated facility to demonstrate ADS as a promising system to a society.

[15] Future Collaboration

[16] International collaboration is fruitful to contest the ideas and to reduce the R&D cost. Large number of R&D could be shared. The frame work of OECD/NEA is also useful.

[17] Next OECD/NEA workshop will be held on November 1999 at Cadarache in France.