NEW SPS COOLING SYSTEM: ‘THE DAY AFTER’

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Abstract

During the shutdown from November 2000 until May 2001, major modifications of the cooling system of SPS have been carried out in the frame of the refurbishment and restructuring of the water network on CERN sites (Water Project). Since the new configuration is based on a closed circuit loop, the most important consequence is the increase of the cooling water temperature from 11°C to a reference temperature of 25 °C on the primary circuit. After a brief overview of the performance statistics in 2001 of the new cooling system, a preliminary analysis of the impact of the new temperature working point will be given. Special attention will be focused on those aspects that proved to be critical for reliable equipment operation as well as on the observed consequences on reproducibility of machine parameters and finally the capability of the system for future expansions. Recommendations and possible improvements will also be outlined.

1 INTRODUCTION

The cooling system of the SPS complex at CERN has been completely renewed and modified during the shutdown from November 2000 to May 2001 in the frame of a wider project concerning the entire
water network at CERN [1]. The modifications were necessary in order to match the machine requirements with the new working parameters of the cooling installations.

A brief outline of the new working parameters and the major changes occurred on the installations is given. The preliminary results of the analysis of the data collected during the first year of operation of the new cooling system are presented. Particular attention has been given to operational aspects such as reliability of equipment operation and reproducibility of accelerator performance. Aspects related to the effect of the new working point on equipment lifetime will be not considered as the operation time under the new conditions is too short to draw any conclusion to that respect.

2 NEW COOLING INSTALLATIONS

The major modification applied to the cooling system is the change of the primary cooling loop from an open circuit configuration to a closed circuit one, where the water circulates several times in the cooling loop and the rejected portion is represented only by the blow down of the cooling towers.

This modification implies that the temperature of the water entering the cooling equipment on the primary circuit is the temperature at the exit of the cooling towers (maximum 25°C during summer, fig. 1) and no more by the temperature of the water in the lake 10 °C (almost constant all the year) that was previously supplying the primary circuit.

The set up value of the inlet temperature in the secondary circuit has been fixed to 25 °C. The temperature difference between inlet and outlet has been kept to the original value, i.e. 15 °K, and therefore the other main parameters of the cooling circuit have not been modified: flow rate, pressure difference etc.

![Fig. 1: Temperature variation in the SPS primary cooling circuit in 2001](image)

The increase of the temperature to 25 °C requested the change of all the plate heat exchangers (and therefore, all the connected piping), the upgrade of the cooling towers and the modification of all the control system. For all the equipment that could not guarantee the same performances with an inlet temperature of 25 °C, a local mixed or chilled water circuit has been installed [1].

3 PERFORMANCE STATISTICS

The evolution of the relative contribution of cooling problems to the SPS total downtime as a function of time is presented in Table 1, together with the corresponding number of machine stops.

<table>
<thead>
<tr>
<th>Year</th>
<th>1997</th>
<th>1998</th>
<th>1999</th>
<th>2000</th>
<th>2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downtime [%][2-7]</td>
<td>1.3</td>
<td>1.4</td>
<td>4.8</td>
<td>0.5</td>
<td>4.1</td>
</tr>
</tbody>
</table>
The relative contribution of cooling problems to SPS downtime in 2001 has been higher than the average of the last 5 years but is comparable with the result obtained in 1999. The quoted value (4.1%) does not include downtime due to equipment failures that could be traced back to cooling problems (see section 4.1). Around 40% of the CV downtime is due to some installations that have been modified during the last shutdown. However, none of the stops is directly related to the new working conditions or parameters but to some hardware (pumps, leaks, fouled heat exchangers) or software (control system) teething problems.

The larger number of stops observed in 2001 as compared to the two previous years can be partly explained by the higher number of circuits and by the problems on the new installations. It is however clear that the equipment is more sensitive to any modification of the working condition and that the alarm limit can be reached much faster than before.

4 IMPACT ON ACCELERATOR OPERATION

The evaluation of the impact of the new system on the accelerator operation includes two main aspects: the effect on equipment reliability and the effect on machine reproducibility and performance.

4.1 Impact on reliability

The short-term effect on reliability can be deduced by fault statistics and it is mainly related to some teething problems of the new system and in particular of its control. The criticality of the mixed water systems and the major complexity of the associated cooling circuits have brought to a larger fault rate and in particular have made diagnosis more difficult mainly for the absence of adequate remote alarm reporting. This was the case for the septum magnets in BA2 and BA6 where the status of the chilled water station was not available remotely all through the 2001 run. Cooling problems manifested in the form of a power converter trip as a consequence of the high temperature detected at the magnet. Intervention of the extraction hardware expert, of the demineralised water expert and of the chilled water station expert in sequence was necessary with a consequent long downtime. Improvement in that respect should be pursued and the early detection of warning conditions should be enhanced.

Other problems are related to the different behaviour of the new cooling system and on the need of additional protections against system failures. This was the case for the RF cavities and their loads. In the previous configuration a single demineralised water circuit was feeding the RF cavities and their RF power loads in series. Any failure of the pump of the circuit was stopping the RF amplifiers preventing from overheating of the cavities and of the loads. After the modification several separate circuits have been provided: one for the RF cavities using mixed water and four with demineralised water at 25°C for each RF loads. No RF interlock was foreseen in case of a trip of the chilled water system. The latter event occurred on 12th September 2001 and determined an important temperature increase of the RF windows at the couplers from 19°C to about 40°C. Ageing and the mechanical stress resulting from the temperature increase are very likely responsible for the failure of the two RF windows in RF cavity 3 occurred on 13th September and 27th September.

The separation of the RF cavities and RF load circuits has made the latter more sensitive to mechanical shocks occurring when a water valve closes. In the previous configuration the RF cavities were in series to the RF loads and protected by pressure limiters that acted as shock absorber for both. Two such events (valve closure) produced cracks in cooled ceramic RF windows separating the load from the RF waveguide.

Actions are being taken to avoid similar problems in the future (interlock on the cooling pump for the RF loads in case of problems on the chilled water system, installation of slow closure valves for the RF loads to protect them from mechanical shocks).

Long-term effects on the equipment due to the higher temperature working point (combined with the radioactive environment of the machine) are difficult to measure. Possible ageing effects, e.g. on magnet coils (in particular deterioration of the insulations) should be carefully monitored in the future.
4.2 Impact on reproducibility and performances

Beam Time Users require not only low downtime but also good beam quality in a reproducible way. Minimization of the sources of drift of the machine and equipment operating parameters or ways to counteract their effects with minimum human intervention are therefore necessary.

As an example of loss of reproducibility in the operation of a piece of equipment, the relative adjustment of the temperatures of the 4 RF cavities proved to be more critical than in the past because of the difference in conductance of the corresponding new cooling circuits. Modifications (installation of manual valves to compensate for the difference in conductance among the circuits) are foreseen during the present shutdown.

One of the main concerns related to the operation of the SPS cooling system in closed loop was the deterioration of machine reproducibility resulting from the expected larger excursion in temperature of the machine elements. During the 2001 run no significant loss of machine reproducibility was observed with the exception of the stability of the trajectory of the extracted beam in the TT20 line. Important drifts in the horizontal and vertical beam trajectory were systematically observed after interruptions of SPS operation, even as short as a few tens of minutes. Figure 2 shows the correlation between temperature variations of the water at the exit of the TT20 transfer line cooling circuit and the corrections performed at the first splitter in the line.

The analysis of the beam position data seems to indicate that these drifts could be the consequence of the movement of a coil or of an inter-turn short circuit in a quadrupole of the TT20 line. The water (and therefore coil) temperature fluctuations could be therefore responsible intermittent appearance (or disappearance) of the fault. Investigations are under way to exactly localize and correct the problem in the suspected magnet.

Limitations in the machine working point tunability were observed during machine development sessions performed with the LHC beam. High chromaticities \((\Delta Q/Q)/(\Delta p/p) \sim 1)\) are required in order to fight the transverse instabilities affecting this kind of beam as a consequence of the onset of the beam-induced electron-cloud.
Figure 3: Time evolution of demineralised water temperature at the inlet of the main magnet circuits in BA2 and BA6.

Figure 4: Time evolution of demineralised water temperature at the outlet of the main magnet circuits in BA2 and BA6.

At least in four occasions the sextupole magnet temperature exceeded the interlock threshold in Sextant 6. No similar events have occurred (without human intervention or equipment failure) in other Sextants with the exception of BA2 where during fixed target operation in two occasions (the last on 3rd September 2001) trips of the main power converters due to the main magnet temperature occurred (due to the rapid recovery of the temperature after the trip there was no possibility to individuate the
As one can see in Fig. 3 and 4, the inlet and outlet temperatures, as well as the temperature fluctuations at the inlet of the main magnet circuit (where the machine sextupoles are connected) in BA6 are consistently higher than in the other buildings. Only in BA2 the water outlet temperature is comparable to the BA6 values for the first part of the run. In January 2002 the heat exchangers in BA6 have been internally checked and an important fouling on the primary side has been found: this can partly explain the reduced performances of this circuit compared to similar ones in the other BAs and, in particular, the higher temperature of the outlet water. No clear explanation has been found yet for the BA2 behaviour.

5 COOLING INSTALLATIONS AND CAPABILITIES

The modification of the cooling system has an influence on the performance of the machine in the tolerance and criticality of the cooling parameters and in the risk of breakdowns, due to an increase in the number of installations and circuits.

When the cooling system was in an open loop the inlet temperature was almost constant at 10°C throughout the year since the water was coming directly from the Leman Lake; the system was not subject therefore to the specific atmospheric conditions, nor to the moment in the day (these last parameters influenced the rejected water characteristics but there was not a direct impact on the equipment). In the new configuration, the inlet temperature is determined from a set of cooling towers and therefore it varies along the day and according to the time of the year: a faster control system is therefore required and the tolerance to the temperature variation is more limited. An increased number of machine stops can therefore be expected and has been noted during the last run.

The most sensible limit is represented by the future possible expansions of the cooling system, since the nominal thermal power to dissipate at the present stage (63 MW) is already close to the maximum capacity installed on the cooling towers after their upgrading (65 MW). In the previous configuration the required cooling capacity was 44 MW, allowing a margin of about 30%. At present, a future modification of the machine with a higher thermal charge will require the construction of additional new cooling towers.

<table>
<thead>
<tr>
<th>Year</th>
<th>Water used in the SPS complex [Mm³]</th>
<th>Water consumption on SPS complex [Mm³]</th>
<th>Total Water consumption at CERN [Mm³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>2001</td>
<td>10.2</td>
<td>0.5</td>
<td>6.65</td>
</tr>
<tr>
<td>2000</td>
<td>10.65</td>
<td>10.65</td>
<td>15.10</td>
</tr>
<tr>
<td>1999</td>
<td>10.60</td>
<td>10.60</td>
<td>15.50</td>
</tr>
</tbody>
</table>

Table 2: Water consumption in the past years in the SPS complex and at CERN

The advantages of the new system are:
- complete refurbishment and renewal of old equipment that, in most cases, should have been done due to its old age;
- adaptation to the future requirements needed in the SPS complex in view of the LHC future operation;
- modern and reliable control system.

Finally the water consumption has been reduced by a significant amount, allowing savings for more than 1 MCHF in 2001 (Table 2).

6 CONCLUSIONS

The operation of the new cooling system in 2001 has been satisfactory. Some teething problems mainly related to the remote control and logging of the cooling parameters have been encountered and have been or are being fixed. The most critical elements proved to be the mixed water circuits for the septum magnets and for the RF cavities. Non-optimal integration of the chilled water stations control with the rest of the cooling system and with the equipment protection system has been preventing rapid
diagnosis of cooling problems and it engendered serious breakdowns of the RF system. Solutions in that respect are being put in place jointly by the RF and cooling experts.

No evident loss of reproducibility in machine performance imputable only to the new cooling system has been evidenced for the time being. Performance limitations have been hit during machine developments sessions with LHC beams and have been correlated with a poorer operation of the BA6 cooling system as compared to the other BAs likely related to fouling of the primary circuit in the heat exchangers.

It has been evident that the capability of the new system is reduced for future extensions and that the accelerator is more sensible to any malfunction on the cooling installations, being the critical temperature closer to the working parameters. All these factors have to be compared with the advantages obtained by the new configuration, making the overall evaluation of the change positive.

No conclusion can be drawn for the moment on the possible consequences of the operation at higher temperature on hardware ageing. Only a long-term follow-up on the hardware together with an adequate logging (mandatory) of all the cooling parameters can provide an answer. Follow-up of the performances of the cooling system in the years to come is important in order to confirm these preliminary indications and to provide some more information on hardware reliability and machine reproducibility.

7 ACKNOWLEDGEMENTS

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8 REFERENCES


