Super-cycles for LHC Commissioning and Operation

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Abstract

During the various phases of LHC commissioning and operation, both PS and SPS will have to continue to supply beam to many other users (North Hall, CNGS, East Hall, AD, nTOF, ISOLDE,…). In addition, the many different beams required for LHC and the stringent requirements placed on the injectors by the LHC mean that the PS/SPS super-cycles will have to undergo many rapid and reliable changes per day. A possible mechanism for controlling these super-cycles is outlined

1 INTRODUCTION

The LHC will need a variety of beams for the commissioning and initial operation phases, ranging from single pilot pulses to 3 or 4 batch filling pulses. See table 1. In addition the injectors will also have to supply beam to other users. See Table 2. This variety will mean that the injector chain (PSB, PS and SPS) will have to operate with a number of different super-cycles. In order to satisfy the requirements of the LHC and the other users the injector chain will have to be capable of switching rapidly and reliably between these different super-cycles.

Table 1: Some possible LHC beams

Cycle	Total Length (secs)
Pilot 1 bunch	2.4
Single batch - 48 bunches	2.4
Single batch - 72 bunches	3.6
Triple batch – 216 bunches	10.8
Quadruple batch – 288 bunches	14.4
Exotic bunch spacings	2.4-3.6

Table 2: Other Users for the Injectors

SPS	All LHC beams
	CNGS, Fixed target & MD beams
PS	All SPS & LHC beams
	East Hall, AD, nTOF & MD beams
PSB	All PS beams
	ISOLDE & MD beams

It has been proposed [1] to extend the current PS/PSB beam and cycle manager to handle the SPS cycle changes. This paper presents an "operations" view of how the new cycle manager should work. I would like to thank the various SL and PS timing and operations experts, who have helped me understand the problem and in particular Julian Lewis (PS/CO) for his valiant efforts in trying to explain the various solutions to me.

2 HOW DO WE CONTROL THE PSB & PS SUPER-CYCLES AT THE MOMENT?

2.1 What is a super-cycle?

The PS Complex "super-cycle" is made up of a number of individual cycles, each of which has to be a multiple of 1.2 seconds in length. These cycles are executed sequentially in a pre-set order. There is no restriction on the length of the super-cycle. The pre-set order is determined by the operator, who uses a graphical editor, called the PLS Editor (Programmed Line Sequencer) to build the super-cycle he/she requires. There are some restrictions on the order of cycles etc, due to certain magnetic considerations in the cycling of various elements in the machine and in the transfer lines. If any of these restrictions are violated by a super-cycle then the editor indicates this to the operator when he/she tries to load the new super-cycle into the machine hardware and the MTG (Main Timing Generator). The PSB & PS super-cycles are controlled from the same editor. Figure 1 shows a typical PSB & PS super-cycle

2.2 Changing or modifying super-cycles

There are currently three ways of changing or modifying the PS Complex super-cycle:-

1. PLS Editor: The Operator can reload a new super-cycle for the PSB & PS using the PLS editor. This is a slow process (around 60 seconds) as the PLS Editor reloads all the machine hardware & MTG with the complete settings for the new super-cycle, even if the change from the previous super-cycle is only minor.
2. Spare Cycles: Each cycle has a spare cycle that is programmed and loaded into the hardware at the same time as the normal cycle. This spare cycle will be executed automatically if the normal cycle cannot be executed. This change from normal to spare cycle is fast and is triggered either by the user beam request for a particular beam, or by some other external condition that forbids the correct execution of the normal cycle. This is a fast change, as the spare cycle is already present in the MTG and can be executed at very short notice (1 - 2 seconds). For cycles in which the beam is

transferred from the PSB to the PS, the two machines are "coupled" together. In this case a change from "normal" to "spare" will obviously affect the cycles of both machines

3. MTG levels: The MTG contains two possible super-cycles, these are known as level 1 & level 2. These are completely independent and each has it's own spare cycle etc. The MTG can switch between these two cycles in a few seconds.

For LHC operation the SPS will need to develop a similar flexibility. Therefore it is proposed to extend a similar MTG based timing system to control the SPS super-cycle [1]

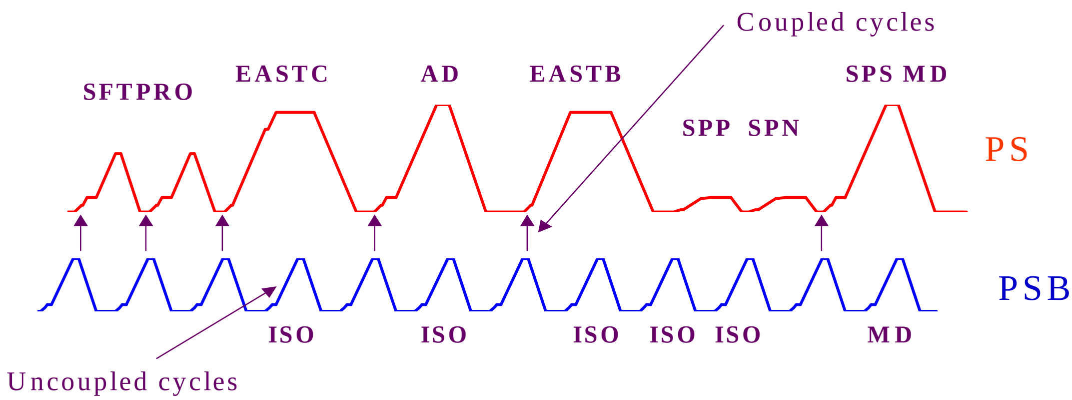

Figure 1: A typical PS Complex super-cycle

3 WHAT ABOUT THE SPS

3.1 Extension of the MTG to the SPS

Since the SPS will need several different super-cycles, it is proposed to extend the current PS cycle timing system to include the SPS. However the SPS will have to switch quickly between these super-cycles. This can be achieved by allowing a number (16) different MTG levels for the SPS super-cycle. In this way, there would be 16 different SPS super-cycles permanently resident in the MTG hardware and the SPS could switch rapidly between them. An editor, very similar to the current PLS Editor, would allow operators to edit and reload these 16 cycles in the 16 SPS MTG levels. Each of these SPS super-cycles would have to be accompanied by the corresponding PSB & PS super-cycles. Two examples of possible SPS super-cycles are shown in Figures 2 & 3. These would be loaded in the MTG as different levels along with the corresponding PS and PSB super-cycles.

Switching between the different SPS MTG levels would be driven by an SPS cycle or "beam request". The different beams in this cycle would then be either injected into the SPS or vetoed, depending on the SPS user requests.

Obviously, by fixing the SPS cycle we must also fix the parts of the PS and PSB cycles that produce the SPS beams. These are the so-called "coupled cycles" and they cannot be modified without affecting the beam for the SPS. The rest of the PS cycle will be "uncoupled" from the SPS and we will have to retain enough flexibility in the new PLS Editor to allow the PS to modify and reload these uncoupled cycles as required, without affecting the SPS beams.

This can be achieved by retaining the current 2 PS MTG levels on top of the 16 SPS MTG levels. I.e. For each of the 16 SPS cycles stored in the MTG, there will be two possible variants in which the PS can edit the uncoupled cycles, without affecting the SPS beams. This is shown in figure 4.

In addition the current notion of spare cycles for both PS and SPS would be maintained as this is very useful for automatically reallocating PS beams to other users.

3.2 How would it work in practice

Suppose that the SPS is running for Fixed Target physics and the CNGS beam. A possible super-cycle is shown in Figure 2. Here there are three beams that can be sent to the SPS. Once this cycle has been requested, each of these beams can be either injected or vetoed by the SPS. However the SPS will not replace one beam with another if the first beam is vetoed. For this particular SPS cycle there will be two possible PS/PSB cycles, which must supply the same beams to the SPS. If the LHC requests a fill then the SPS would request the LHC filling cycle, shown in Figure 3. The PS & PSB would automatically follow suit, but would still have the possibility to supply beam to other users on the "uncoupled cycles".

If the SPS requests the LHC filling cycle, but only wants a single LHC batch then the remaining three batches would be vetoed allowing the PS to automatically switch to the users programmed as "spare". This is shown in Figure 4.

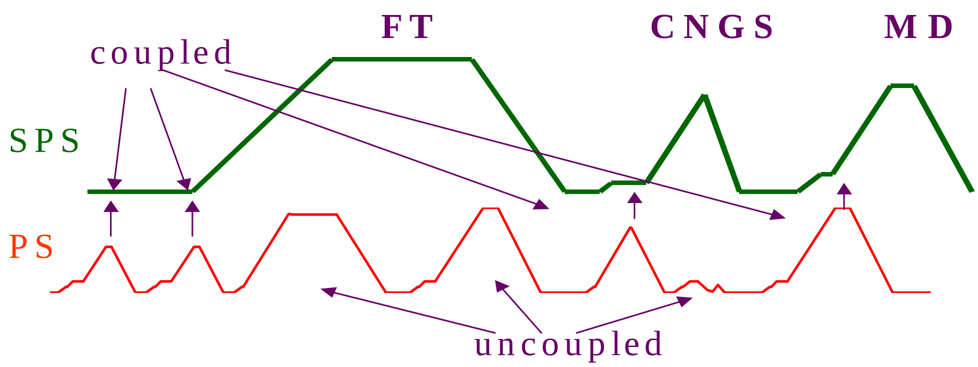

Figure 2: A possible PS/SPS super-cycle for CNGS and FT operation

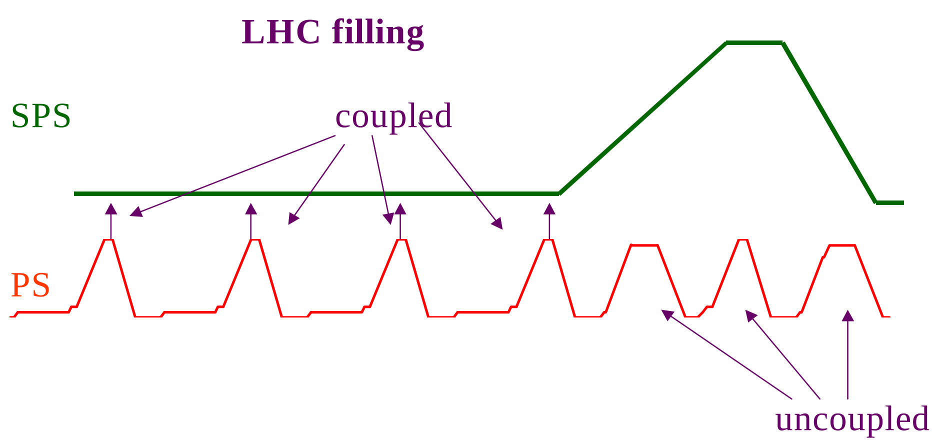

Figure 3: A Possible PS/SPS super-cycle for LHC filling

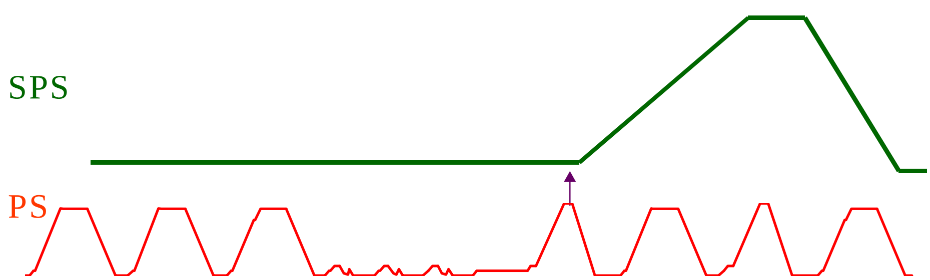

Figure 4: LHC Filling cycle with only one LHC batch sent to SPS

4 DO WE NEED IT DYNAMICALLY VARIABLE CYCLE LENGTH?

Different super-cycles, as loaded in the MTG, will often have different lengths, but each cycle until now has always had a fixed length. For LHC operation is there anything to be gained from allowing the super-cycle length to change dynamically as different beams are requested?

4.1 Standard LHC filling schemes

The latest LHC filling scheme [2] has the PS supplying both 3 and 4 batch transfers to the SPS for LHC. The transfers will be interleaved in the form.334 334 334 333. Each 72 bunch batch takes 3.6 seconds to produce in the PS. A standard four batch transfer to LHC takes 21.6 seconds and a three batch transfer takes 18.0 seconds. Therefore if we assume that we use the same super-cycle for all 12 transfers to an LHC ring, it will take 4.3 minutes to fill one LHC ring. If we use 18.0 second cycles for the three batch transfer we could save around 30 seconds per ring.

However, this will present an added difficulty. What happens if a batch is not correctly injected into the SPS? If we use a standard 21.6 second magnetic cycle, we can simply dump the whole SPS fill and start again on the next 21.6 second cycle. With a variable length super-cycle repeating the fill will be more complicated if the filling sequence (334 334 334 333) has already been predefined.

4.2 What happens if a batch is badly injected into the SPS?

There is a more serious constraint on the injectors than the 18.0 & 21.6 second filling cycles. The LHC cannot tolerate missing or low intensity bunches. Therefore if there is any problem in the injector chain, the beam will have to be dumped in the SPS, before transfer to the LHC, and that particular part of the fill repeated. Here there are two possibilities.

- Dump the entire SPS beam and start again on the next 21.6 second cycle.
- Selectively dump the “bad” batch in the SPS and repeat that particular injection. This will mean that the super-cycle will have to get automatically longer by 3.6 seconds for every “bad” batch.

The advantage of the first option is that it is simpler and the SPS maintains the same magnetic cycle throughout the fill. However, if there are several bad batches during the fill, then the filling time will increase by 21.6 seconds for each “bad” batch.

The second option reduces this lost time to only 3.6 seconds, but introduces the complication of never knowing how long any super-cycle will be. It is also introduces many more complications into an already very complex cycle timing system. Therefore it would seem preferable to me to retain a standard (21.6 second) magnetic cycle for normal LHC filling, and to control the number of batches injected into the LHC on each cycle by a simple SPS request for 1, 2, 3 or 4 LHC batches from the PS.

5 CONCLUSIONS

By extending the current PS MTG cycle control system, it is possible to imagine a combined cycle control package for all the LHC injectors. This package will have to be robust, simply to use but at the same time flexible enough to meet the demands that will be placed upon it.

However, whilst it is very important that we are sure that the system will do what we want, we should resist the temptation to make a cycle timing system so sophisticated that it will do anything we can imagine and as a result will be far too complicated to do what we really need.

REFERENCES

[1] J. Lewis, J-C Bau, M. Jonker, “The Central Beam and Cycle Management of the CERN Accelerator Complex”, ICALEPS 1999, Trieste ,ITALY.

[2] LHC parameters and Layout Committee, “Minutes of the 59th Meeting” April 2000.