STUDIES OF BEAM LOSSES FROM FAILURES OF SPS BEAM DUMP KICKERS

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Abstract

The SPS beam dump extraction process was studied in detail to investigate the possibility of operation with reduced kicker voltage and to fully understand the trajectories and loss patterns of miss-kicked beam. This paper briefly describes the SPS beam dump process, and presents the tracking studies carried out for failure cases. The simulation results are compared to the results of measurements made with low intensity beam.

THE SPS BEAM DUMP SYSTEM

The SPS beam dump system consists of the fast kicker magnets MKDV and MKDH and the internal dump blocks TIDH and TIDV. The system is installed in SPS long straight section 1 (LSS1). A schematic layout of the system is shown in Fig. 1. In the vertical plane 2 MKDV magnets provide a deflection with a rise time of about 1μs, Fig. 2. The 3 MKDH magnets provide a horizontal sweep with a rise time of about one full SPS turn (23 μs), Fig 3. The combination of horizontal and vertical deflection sweeps the beam across the front face of the TIDV core, distributing the high beam energy over a large volume of the absorber block (example in Fig.4) to reduce the stress due to the temperature rise. The kinetic energy of a 400 GeV beam of 3×10^{13} protons is about 640 kJ, sufficient to melt 0.7 kg of steel [1].

For beam energies of up to 37 GeV the beam is dumped on the TIDH block; for energies above 105 GeV the beam is deposited on the TIDV. The TIDV consist of a graphite absorber core inside a copper yoke, surrounded by a cast iron shielding block. The quadrupoles QDA117, QFA118 and QDA119 are transversely displaced to realise a closed orbit bump of about 7 mm in both planes. Dumped beams receive an additional kick from QFA118 which allowed the TIDV block to be installed closer to the design orbit.

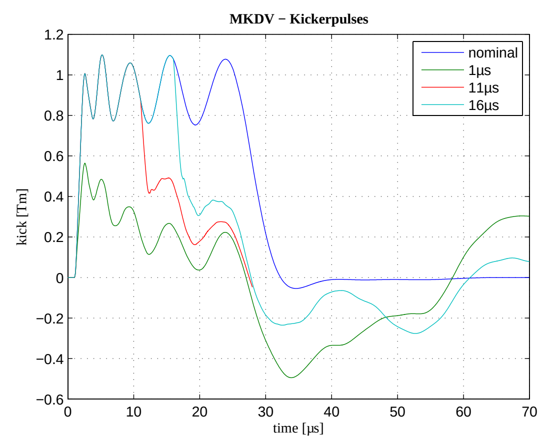

Figure 2: Simulated MKDV kicker pulses, 47 kV, nominal case (blue) and with sparks after 1, 11 and 16 μs.

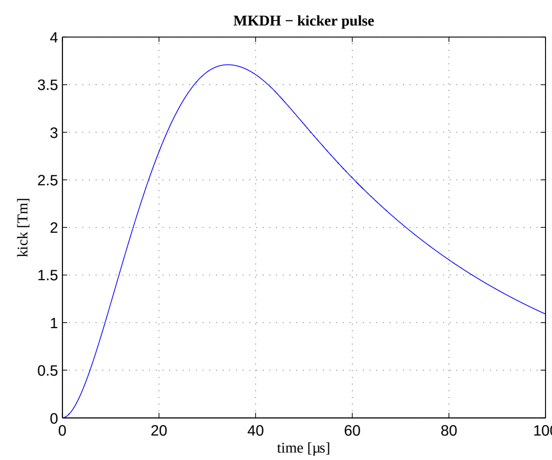

Figure 3: Simulated MKDH kicker pulse, 9 kV.

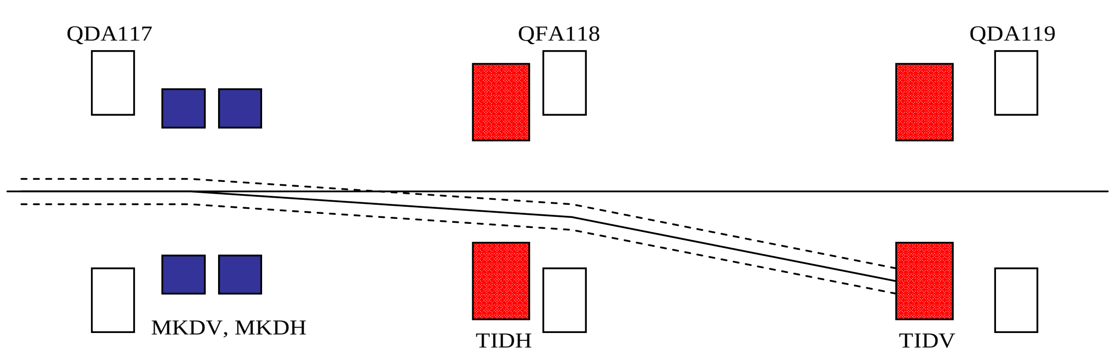

Figure 1: Schematic layout (side view) of the SPS beam dump system, showing the vertical and horizontal kicker systems (MKDV, MKDH) and the two beam dump blocks TIDH and TIDH.

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Failure Cases

During 2006 SPS operation high voltage breakdowns in one of the MKDV magnets were observed. To fulfil the specifications for operation above the original 300 GeV design energy, a third common Pulse Forming Network (PFN) was added to the two original PFNs. This implies that failures occurring in one magnet automatically have an impact on the field in the other magnet. The whole system has been simulated in Pspice. Simulations for different failure cases (sparks after 1 μs, 11 μs and 16 μs) have been made and are included in Fig.1.

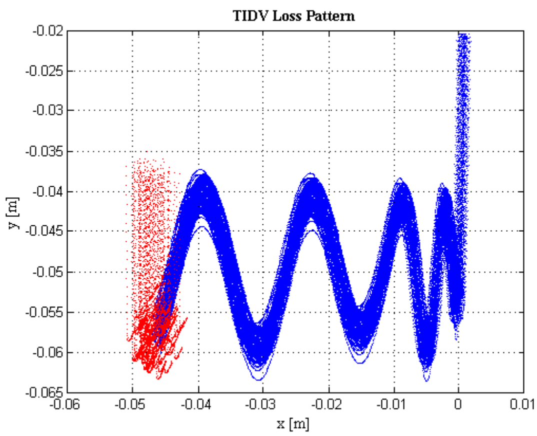

Figure 4: TIDV loss pattern, asynchronous beam dump (400 GeV, nominal pulse), blue: 1st turn, red: 2nd turn.

Two main failure cases have been analysed. The first less problematic is an asynchronous beam dump, where the beam dump kickers are not fired in the abort gap as foreseen. The kicker rise time and field shape are nominal for this case. The second and more critical case is that sparks or short-circuits occur during a normal (or asynchronous) beam dump. In both cases not all particles are directly sent to the TIDV as foreseen. Particles are instead swept through the aperture during the kicker rise time for the asynchronous case, and are also swept with varying deflections in the short-circuit failure cases.

TRACKING STUDIES

In order to quantify where and how such particles are lost around the accelerator, Mad-X tracking studies have been performed.

Methodology

A Mad-X tracking job using standard Mad-X functions was developed to fulfil the special requirements due to the fact that the particles which are not dumped within the first turn receive another, different, kick on subsequent turns. The job is designed for the whole time range over which the MKDV pulse is fluctuating. The job itself is divided into three sections. The first one consists of setting up nominal SPS conditions to create the orbit bump in LSS1 and to rematch several accelerator parameters. In the second part a Gaussian distribution in phase space is created and the calculation for the different kick values is done. The third part contains the tracking modules and contains loops which allow loading of different initial particle positions and a simulation from zero to 23.0543 μs (one SPS turn time) at intervals of 25 ns (corresponding to the LHC bunch spacing). As long as the particle is not lost in the accelerator it is restarted in a cascade of tracking routines with the appropriately modified kicker strength (which is a function of the turn and bunch numbers) until it is lost or it has survived several thousand turns. At this stage no optical, orbit or alignment errors were included in the simulation.

Beams & Aperture Model

The standard SPS aperture model was improved to obtain a better understanding of losses in the region of the TIDV and to make it possible to track particles under such unusual conditions. Therefore especially the apertures of the TIDV and TIDH including their SEM grids had to be defined in a more accurate way. Due to the use of the whole aperture model the CPU time rose above 14000 seconds for 180.000 initial particles. For all cases a fixed target beam with a normalised emittance of ε_{xn}=12.0 π.mm.mrad and ε_{yn}=7.0 π.mm.mrad has been used. The time spacing for all calculations was 25 ns.

SIMULATION RESULTS

Post Processing

The Mad-X output files with the position data of the lost particles for each turn were sorted and filtered, for > 180.000 lines of data for each case to get the loss pattern around the SPS. This was done using MATLAB.

Asynchronous dump (sweep) cases

In Fig. 5 loss patterns for asynchronous dumps (sweeps) under nominal conditions are shown.

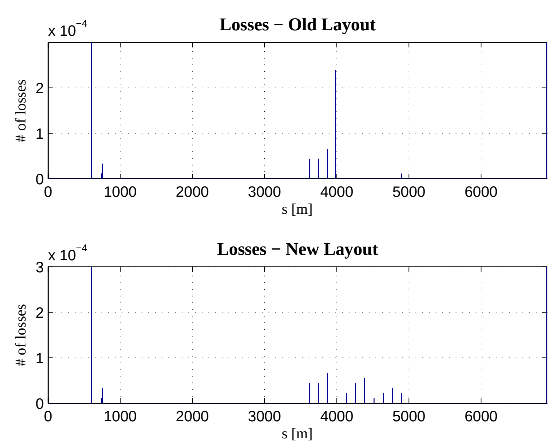

Figure 5: Loss pattern for 400 GeV sweep, old bumper layout (top) compared to the new 2007 layout (bottom).

The upper plot shows a peak in LSS4 at the MPLH 41672 (s=3986.48). This element is a bumper magnet used for beam extraction, with a small horizontal aperture. Abnormal irradiation has been measured here in the past during SPS operation. To overcome this limitation the layout in this region and in the other extraction channel in SPS LSS6 was modified at the start of 2007, with the magnet moved to a position with a lower beta function. The lower part of Fig. 5 shows the loss pattern of the simulation with this new layout. One can see dramatically reduced losses at the MPLH position. Some losses are now recorded on elements (main bending magnets) which were previously in the "shadow" of the MPLH magnet. The peak in LSS1 at s=602 m indicates the losses on the dump block.

Kicker failure (spark) cases

Fig. 6 shows the loss patterns for dumps with MKDV short-circuits after 11µs for 30 GeV (top) and 400 GeV (bottom).

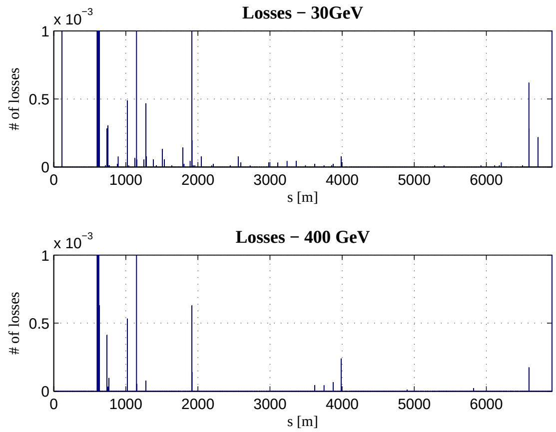

Figure 6: Losses for 30 and 400 GeV; sparks after 11 µs.

The 30 GeV simulation in the "forbidden" dump region was included because of a faulty dump which occurred in 2006 and which was suspected to have irradiated the MPLH magnet. Note the different vertical scale compared to Fig. 6, with losses a factor of 10 higher around the SPS. Fig. 7 shows the TIDV loss pattern of a 400 GeV dump with a short circuit after 1µs.

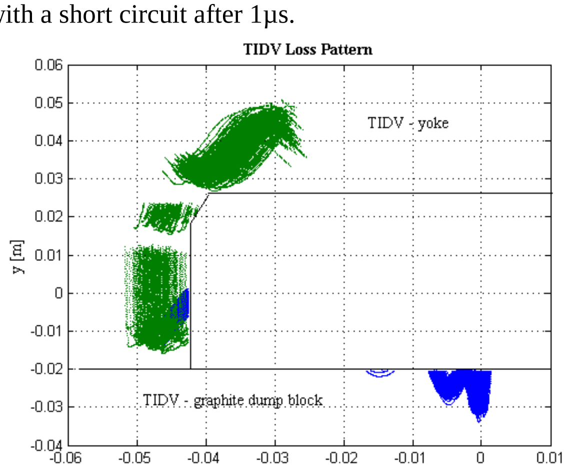

Figure 7: TIDV loss pattern, 400 GeV, short-circuit after 1 µs, blue: losses 1st turn, green: losses 2nd turn.

One can see that most of the beam makes a second turn in the SPS. Interestingly, due to the higher MKDH field in turn 2 and the break-down of the MKDV field, these particles do not hit the graphite block as intended: instead they are deposited on to the TIDV yoke. With high intensity LHC beam this could possibly damage the TIDV; more studies are required to check if the energy deposition would be sufficient to damage the yoke.

MEASUREMENTS

Fig.8 shows a plot (preliminary results) of the beam loss monitor readings during a deliberately provoked asynchronous dump. The relatively low peak in the TIDV region appears because the BLM is installed on the following quadrupole and not directly on the dump block. High losses are seen in SPS point 2 at s≈1600 m, while there are no losses in point 4 as expected. The measured loss pattern does not fully correspondent to that obtained by simulations and looks qualitatively more similar to that obtained with an MKDV spark, which could indicate an effect from the orbit, dump or aperture misalignment.

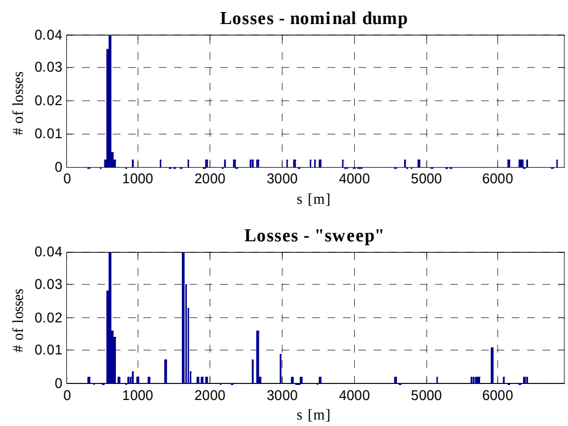

Figure 8: BLM readings during nominal dump and sweep with a 400 GeV fixed target low intensity beam.

CONCLUSIONS

Mad-X tracking and PSpice are being used to model failures of the SPS beam dump. Loss patterns for asynchronous and spark failures were broadly confirmed by measurement. The studies show that during MKDV failures particles do not survive more than two turns due to the MKDH field. In the case of sparks the TIDV yoke is hit, not the graphite core. This might be a problem and requires further investigation. Irradiation and losses at the aperture limiting MPLH bumpers were confirmed for the previous layout: losses with the modified bumper position were shown to be negligible, in agreement with measurement. An extension to include orbit and alignment errors is possible and may be required to explain all the observations. The technique can be applied to other fast failures in the SPS and LHC.

The input from E.Vossenberg and J.Wenninger was essential for this study and is gratefully acknowledged.

REFERENCES

[1] P. Faugeras et al., CERN LAB II/BT/Int./72-5, Geneva, Oct. 1972.