MONITORING BEAM QUALITY AT HERA

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Abstract

At Hera (a lepton proton collider), the amount of the data taken by the experiments is determined by two factors: the operational efficiency of the accelerator and the beam induced background rates of the experiments. As both Hera and the booster, used for injection (Petra), are slow cycling machines, about 17% of the scheduled operation time of the machines are spent filling both beams and bringing them to collision energies. The time required for this procedure depends very much on the reliability of the hardware, the degree of automatisation of the procedure and last but not least, on the skills of the operators. Another 26% of scheduled operation time is lost due to hardware failures. Weak components and reasons for failure are trying to be identified. During the remaining 57% of scheduled operation time beams are colliding and the experiments are taking data. The quality of the data depends on the beam quality; for example on the beam emitance, the amount of unbunched (coasting) beam, the amount of parasitic bunches, beam lifetime and so on. All these parameters are not only monitored by the Hera control room, but also shared with the experiments through a site wide data exchange system.

1. HERA

HERA, the 'Hadronen Elektronen Ring Anlage', is an electron proton collider for high-energy physics. Two rings are placed in one tunnel of 6.3 km circumference. The superconducting proton ring has an injection energy of 40 GeV and a flat top energy of 920 GeV. Typically 100 mA are stored in 180 bunches. In the electron ring, (12 – 27.5 GeV) typically 50 mA of either electrons or positrons are stored in 189 bunches with a characteristic spin polarisation of 60%.

In the four straight sections of the HERA ring four experiments make use of the HERA beams: Both H1 and ZEUS use colliding beams used to probe the structure of the proton. Hermes uses the polarised electron beam and a polarised gas target to investigate the proton spin. HERA-B uses a thin wire target in the halo of the proton beam to look for c-p violation.

2. WHAT IS 'BEAM QUALITY' AT HERA?

For the HERA experiments the figure of merit is the integrated luminosity on tape. The integrated luminosity is determined by parameters like the operational efficiency of HERA, the beam currents and beam sizes. The luminosity on tape depends also on the amount of background and on the detector efficiency.

3. OPERATIONAL EFFICIENCY

The average operational efficiency of HERA in the year 2000 was 57%. Here operational efficiency is defined as 'time during which luminosity is delivered, divided by total scheduled operation time'. The number is low compared to other machines, but this is mainly due to the fact that both HERA and its pre-accelerator PETRA are slow cycling machines. Figure 1 shows a plot from the HERA archive. The parameters displayed here are proton energy (black), proton current (red), electron energy (blue), electron current (green) and integrated luminosity (black). On the horizontal axis time is displayed in hours.

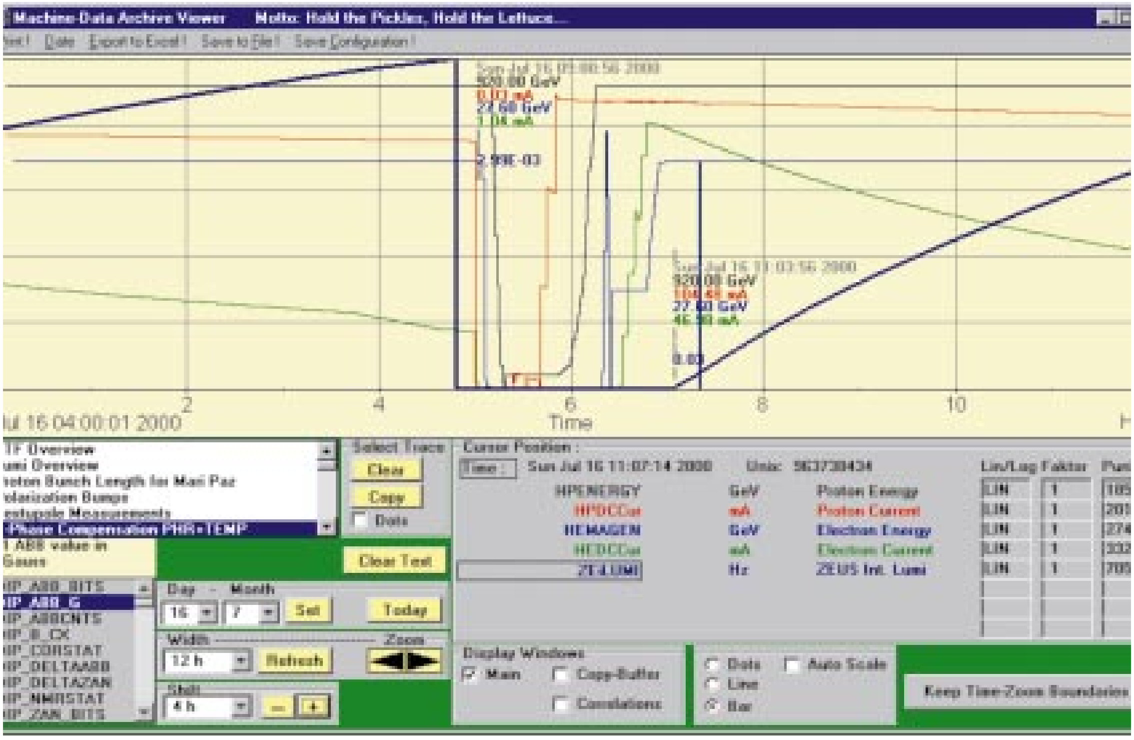

Fig. 1: Data from the HERA archive, showing a refill of the machine from beam dump to luminosity in 2 hours.

In figure 1 it can be seen that it takes about two hours to dump the beam, cycle the proton magnets, fill the proton machine, ramp the protons to full energy, cycle the electron magnets, fill the electron machine, ramp the electrons to full energy and bring both beams to collision.

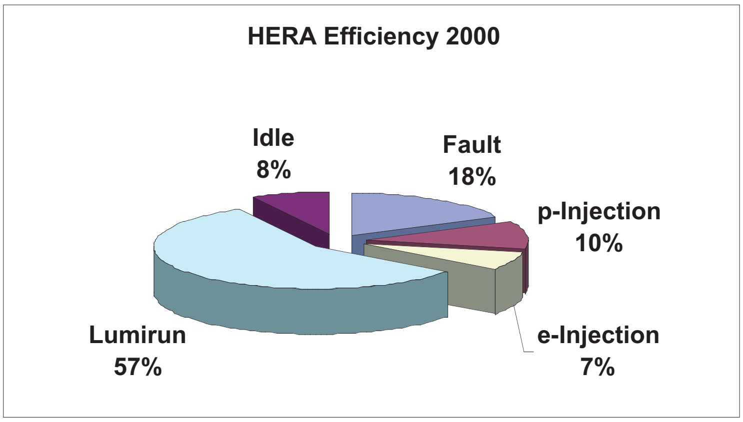

Fig. 2: Operational efficiency of HERA in the year 2000

Figure 2 shows how the scheduled operation time for HERA was used in the year 2000. Apart from the time it takes to inject both beams and bring them to collision (17%) there are two categories of downtime: 'Fault' (18%) means a broken component in HERA, 'Idle' (8%) means that HERA has to wait for either a pre-accelerator or one of the experiments to become ready. During the remaining 57% of the operation time HERA did deliver luminosity.

These data for these statistics are taken from an electronic logbook, which is written by the run co-ordinator. This logbook also contains the cause of each fault and allows one to produce statistics about the reliability of all technical components of HERA. These data are for internal use only and are not made public.

4. BEAM CURRENTS

While the electron current in HERA is mainly determined by the available rf power, the proton current in HERA depends on the beam current and transfer efficiencies of all the pre-accelerators. Protons can only be accumulated in the synchrotron for a limited number of turns after passing a stripping foil in the transfer line from the H-linac. From here on the final beam current in Hera depends on the loss rates in the synchrotron, in the transfer line to PETRA, in PETRA, in the transfer line to HERA and last but not least on the loss rate during the energy ramp in HERA.

5. BEAM SIZE AND COUPLING

A synchrotron radiation monitor measures the beam size of the electron beam in HERA. Synchrotron radiation from a bending dipole is focussed on a CCD camera. A frame grabber is used to display the beam spot and to calculate the beam size. The electron spot size in the interaction regions can also be determined by the photon detectors of the luminosity monitors. These spot sizes are also displayed in the HERA control room.

The pictures of the electron spot size can be used to determine the coupling of the transverse betatron oscillations. If the beam ellipse is not flat, the coupling has to be corrected. This helps both for luminosity and for spin polarisation.

The proton beam size is measured either by wire scanners or by rest gas ionisation monitors. The wire scanners move a thin wire through the beam and measure the amount of scattered particles with respect to the wire position by means of photomultipliers, which are located downstream from the wire scanners. This method is quite accurate, but creates a lot of background and would therefore trip the high voltage of the central detectors of H1 and ZEUS, if used during a luminosity run. The second method, using a rest gas ionisation monitor to determine the proton beam size, can be used all the time, but is not as accurate as the wire scanners. The rest gas monitor is located in a warm straight section of the proton ring. Here the residual gas pressure is sufficiently high so that enough residual gas molecules can be ionised by the proton beam. The electrons liberated through this process are accelerated by an electric field perpendicular to the proton beam. Through a multicannel plate the electrons create an image of the beam on a video camera.

The coupling of the transverse betatron oscillations of the proton beam can be monitored on the betatron tune spectra. If the coupling is well compensated, the tune spectrum shows one single peak for each plane. If the coupling is not well compensated, the horizontal peak appears on the vertical spectrum and vice versa.

6. BACKGROUNDS

The data taking efficiency of the experiments is mainly determined by the dead time caused by beam induced background. The most important background trigger rates from the experiments are displayed online in the HERA control room.

Proton induced background can be caused by bad betatron tunes, coupling or chromaticity (all visible on the tune spectrum), bad collimator positions (collimator loss rates), huge beam emitance (wire scanner or rest gas monitor), particles in the wrong rf bucket (fast current monitors), particles outside the rf buckets (beam current monitors: $I_{DC} - I_{Bunch}$), bad orbit (beam position monitors) and many other reasons.

Electron related background can be caused by a bad orbit (visible through the beam position monitors), misteared synchrotron radiation (collimator positions), off energy particles (collimator positions) and many other reasons.

7. LUMINOSITY

The best parameter to measure beam quality is luminosity. Luminosity is displayed online by the experiments Zeus and H1. Luminosity and specific luminosity are displayed on a five minutes scale (update 1 second) to see effects of manipulations, and on a one hour scale to see slow drifts. At the beginning of a luminosity run the luminosity has to be checked every five minutes (changes due to temperature drifts), later every fifteen to twenty minutes. There is no 'luminosity auto pilot'.

8. ELECTRON/POSITRON SPIN POLARISATION

A good parameter to measure electron beam quality is spin polarisation. Polarisation is displayed online by the experiment Hermes. Polarisation is displayed every minute (to see effects of manipulations) and with a five minute average (for fine tuning). Good polarisation requires (among other parameters) a flat vertical orbit (rms ~ 1mm) and a flat beam (small coupling of betatron tunes).

9. CONTACT WITH THE CUSTOMERS

The status of HERA is published on the WWW and on TV screens all over the DESY site. Figure 3 shows one day of HERA operation.

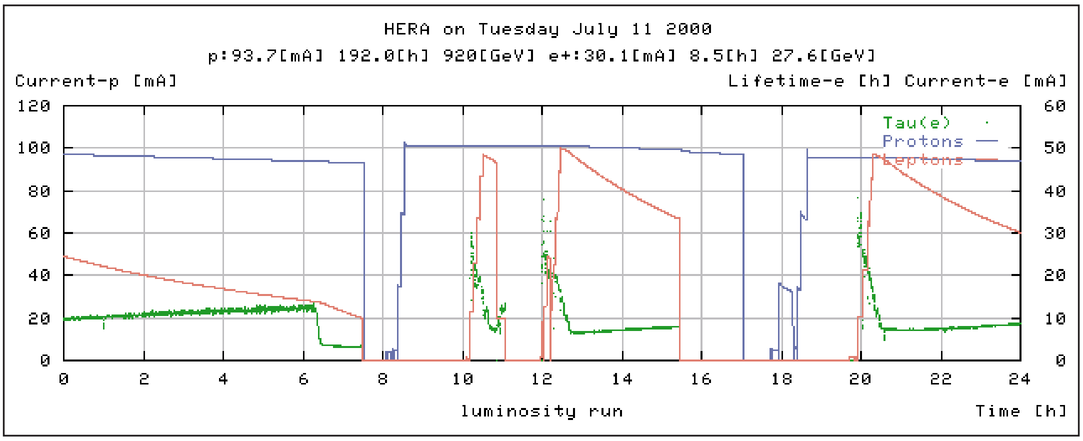

Fig. 3: The status of HERA as it is displayed on the WWW and on TV screens all over DESY.

The HERA experiments do have online access to selected displays of the HERA control system (like collimator positions,…). This requires a Windows-NT PC.

There is a site wide data exchange system (Machine Experiments Data Exchange NETMEX) between machine and experiments, providing online machine data (beam currents, energies,…) and experiment data (luminosity, background,…). The system is platform independent.

The direct telephone contact between the HERA operators and the experiments is supposed to go through the co-ordinating experiment (which changes weekly between the experiments). This was introduced to minimise the number of telephone calls after a beam loss.

10. ACKNOWLEDGEMENTS

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