# AUTOMATION AND STABILISATION OF HERA OPERATION

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*Abstract*

The control system for the HERA lepton-proton collider is based on several hundred networked computers, mostly serving as front ends or operator consoles. The HERA collider was upgraded in 2002 and, as it is pushed closer to its limits, operation has become more complicated, and requires more precise control of the orbits and other beam properties. Stable operation now depends much more than previously on automation provided by the control system. This has been accomplished partly by adding functionality to the sequencer, and partly by adding a group of ‘middle-layer’ computers which work together with the sequencer to provide services such as orbit stabilization in coordination with changing optics and machine states. We describe the structure of the system and our operating experience.

## INTRODUCTION

The Hera lepton-proton collider consists of two 6 km circumference rings; 920 GeV protons collide with 27.5 GeV leptons. The two experimental detectors H1 and Zeus occupy the low beta insertions at the interaction regions (IRs). A third detector, Hermes, studies collisions between the lepton beam and a polarised gas jet target.

Hera has operated with a mini-beta configuration since 2002, for which iron quadrupoles were installed on bridges between tunnel and experimental detectors. The final focussing and the ep beam combination and separation are provided by iron-free superconducting magnets mounted within the tracking detectors and their solenoids. Both beams are influenced by these magnets and this requires complex steering mechanisms.

Bringing the protons from injection (40 GeV) to luminosity (920 GeV) requires a factor 23 of energy increase. With the stored proton beam at 920 GeV the leptons must be injected, stored and ramped to 27.5 GeV with the beams well separated at the IRs until the final transition to luminosity optics.

Hera operation has never been fully automated. The limited repeatability of the energy ramping and luminosity and background conditions has required operator supervision and frequent intervention, for example with orbit bumps, orbit corrections and tune adjustments. After the upgrade, the load on the operators was no longer sustainable, and the extensive tuning required detracted from run to run repeatability. It was therefore essential to include additional procedures in the system automation, the most important of which has been the ‘orbit stabilization’ for the lepton machine.

The Hera automation is coordinated by a Sequencer which runs on a console PC, and communicates via an RPC mechanism with front end servers controlling hardware and ‘middle layer’ servers which provide integrated control of subsystems and other system services. Part of the improved system automation has come from increasing this middle layer functionality.

The Sequencer is also responsible for managing the states of the two rings and of the machine as a whole. The coupling of the two rings via the common IR magnets results in relatively complicated state definitions and transitions, which must be taken into account when loading files with stored settings for magnets and other devices.

This report describes the structure and functionality of the special features which have to been added to cope with the operation of the post-upgrade Hera, and in addition some of the middle layer functionality which has been essential to improve automation of Hera operation.

## AUTOMATION WITH THE HELP OF THE SEQUENCER

The Sequencer must be capable of storing the settings of all machine elements (including more than 1200 magnet currents) in a file and then on demand restoring the machine to this state. Moving the machine from one operational state to another is not a static procedure in which values are simply written to the components, rather, a complex time sequence which takes into account the interdependence of the lepton and proton rings.

### *States and Substates of the Machine*

The states of Hera are installed via so-called File Sequences (‘Filefolgen’). A File Sequence consists of a list of operations to be carried out with appropriate commands to the sequencer. The files include the settings for the components, references to auxiliary files, and descriptions of the instructions to be carried out by other tasks. Thus, the command list in the File Sequence is the procedure which takes the machine from one state to another. There are five such File Sequences.

Because installing an operational state in Hera includes many single steps, the File Sequence consists primarily of references to these steps and to the substates.

For normal operation about 20 substates have been defined for Hera. The installation of these substates uses the ‘Symbolic Files’. These files, like the File Sequence, include lists of operations to be performed and commands to the sequencer with corresponding file references.

For the installation of a state the operator can choose from pre-defined groups of magnets and has the choice of several different rates and modes for the clocking of the magnet current changes. Default values suitable for normal operation are stored together with the files and are modified only for special operation modes and machine studies.

### *Commands to Remote Servers*

The transition between operational states in Hera requires the setting of values in a wide variety of machine components. The corresponding commands are sent from the sequencer via an RPC mechanism to the front end computers (FECs) or middle-layer servers responsible for the equipment. Most of these commands are handled synchronously, in that the sequencer receives an immediate reply as to the success of the operation, but others involve actions which take several minutes to complete, so that the sequencer must inquire later in the sequence about the state of the underlying system. Table I gives an overview of the participating servers.

Table 1: Server operations managed by Sequencer

| Server | Operations | Server | Operations |
|---|---|---|---|
| FEC | Reset Hera-e RF Frequency Offset at start of magnet cycle procedure | FEC | Set up the Hera-e/p Kicker & Septa for injection |
| FEC | Prepare Hera-e RF System for energy setup | FEC | Set up Hera-p Injection correction for injection |
| FEC | Set Hera Data TV messages | FEC | Set up Hera-p Dipol correction for injection |
| FEC | Setup and perform magnet energy ramp and file transfer operations | FEC | Set longitudinal profile monitor mode |
| FEC | Set Hera-e/p Status info for changes of the machine state | FEC | Load and activate Hera-e/p correction tables for energy setup |
| FEC | Allocate signals for machine setup on the Hera Scopes | FEC | Set Hera-e tune Controller mode |
| FEC | Move Hera-e Collimators during energy ramp and luminosity setup | FEC | Switch off Hera West transmitter for controlled access to the tunnel |
| FEC | Move Hera-p Collimators during energy ramp and luminosity setup | Middle layer | Provide reference orbits for Hera-e reference orbit server |
| FEC | Start Hera-e/p RF synchronisation at Hera-p energy setup before Hera-e injection | Middle layer | Provide reference orbits for Hera-p reference orbit server |
| FEC | Ramp Hera-p RF Frequency together with the Hera-p magnets during energy ramp from 40 to 677GeV | Middle layer | Start and stop correction task on the Hera-e/p Orbit Stabilizer. Change the correction modes. |
| FEC | Perform Hera-p 52MHz RF Correction | FEC | Read orbits for orbit reference files from Hera-e BPM server |
| FEC | Close vacuum valves for controlled access to the tunnel | FEC | Read orbits for orbit reference files from Hera-p BPM server. Set BPM alarm thresholds. |
| FEC | Set Hera-p Sextuple Correction mode | Consol Appl. | Prepare lepton and proton beam lines for injection |
| | | Consol Appl. | Store and retrieve machine state files on file server |

### *System Supervision and Tolerances*

The free choice of the operator for the clocking rate would in some situations permit driving magnet currents above their maximum permitted rate of change. Therefore the sequencer calculates the ramp rate for each magnet, and if necessary slows the clocking rate to match.

After every state transition the sequencer generates a comparison between the actual machine settings and those stored in the file, and shows a list of devices for which the deviations exceed defined limits. The limits can be device specific, to take into account for example the operator tuning on non-linearities during the energy ramps.

A similar feature has been implemented to permit testing the validity of target files before the transfer by comparing the magnet settings to those of standard reference files for the target state. Here also device specific limits are possible, as is completely excluding particular magnets; this is necessary since, for example, the system should not be triggered by deviations resulting from normal orbit corrections.

The orbit feedback now contributes significantly to system stability, meaning that each stored file must include a corresponding valid beam orbit, which is not always the case. If the sequencer sees that such a file should be restored to the machine, it uses the orbit from a previous file corresponding to the same state.

## STABILIZATION OF HERA OPERATION

The most important contribution to stabilizing Hera operation has been the orbit feedback system for the leptons.[2] Figure 1 gives an overview of the system and the participating processes and servers The Sequencer sends the target orbit for a state change to the reference orbit server and initialises the orbit stabilizing procedure. Communications between the servers are via RPC.

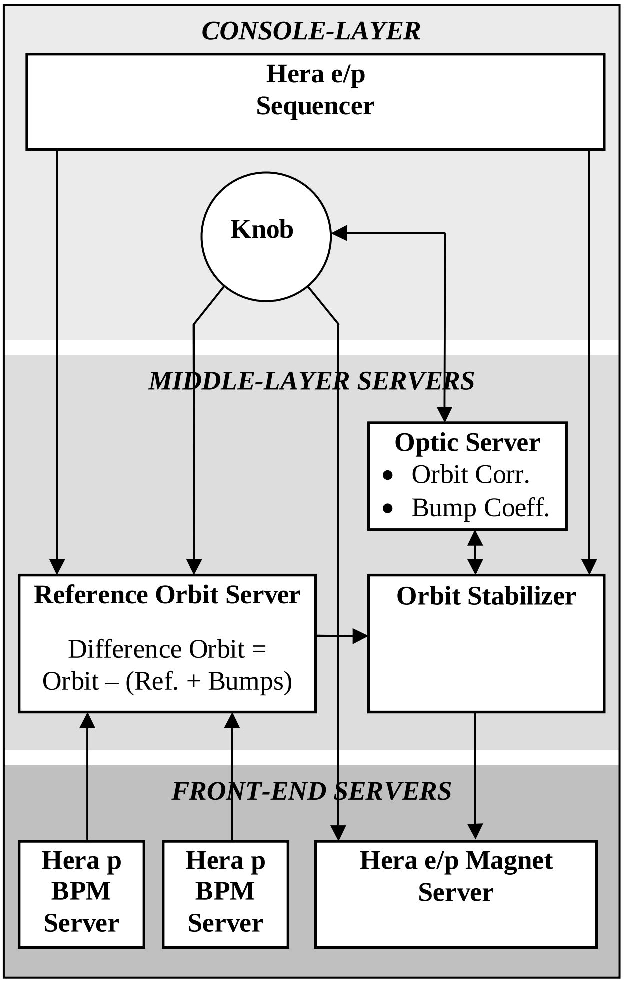


Figure 1: Orbit feedback system.

### *Reference Orbit Server*

The reference orbit server calculates at 4 Hz the difference between the current orbit and the reference orbit supplied by the sequencer. This difference orbit is used by the orbit stabilizer for feedback and by the manual orbit correction program of the operators.

The feedback system is designed to operate in parallel with operator tuning of closed orbit bumps. As the operator turns a bump knob, the calculated orbit changes for the bump are sent from the console task to the reference server, which adds them to the reference orbit, so that they do not appear in the difference orbit. Non-closure of the real (non-ideal) orbit bumps in the machines does appear, and is removed by the feedback.

During the energy ramp, the reference orbit server produces as reference an orbit which is interpolated between the starting orbit and the target orbit. For ramps in which the starting and target machine optics are different, the server also switches at the 50% point the recommended optics for the correction calculations.

### *Orbit Stabilization*

The orbit stabilization server has independent tasks performing feedback on the lepton and proton orbits. In the normal mode of operation, the server sends the difference orbits to the optics server, at maximum rate 1 Hz, and receives back a suggested set of correctors, which are then, in a proportional feedback algorithm, sent to the magnet server. Corrections are normally calculated using a 'most effective corrector' algorithm, which works well against global orbit distortions caused by a small number of magnets.

For special cases an SVD calculation is used; coefficients are calculated on the optics server and sent to the orbit stabilizer, which uses the coefficients locally to calculate corrections. This permits operation at the full 4 Hz rate at which the difference orbits are available.

### *Operator Orbit Correction*

Use of the manual orbit correction system has decreased significantly since the introduction of the orbit stabilization. It is now used for:

- Visual observation of the orbits
- Experimental search for elements contributing orbit distortions
- Calculation and insertion of optimum conditions for lepton polarization
- Performing corrections to the absolute orbit for the various operational states
- Optimization of injection

## DISCUSSION

The history of the Hera sequencer has been the gradual transfer of operations (and lessons from operation) from manual to automated control, while maintaining the capability for operator intervention and modification of procedures. The structure of the sequencer [1] has proved suitable and sufficiently scalable for the task.

The procedures are now comparatively well defined and stable, with changes being made when there are major modifications to the machine (such as the luminosity upgrade in 2002) and as tasks are added to increase the level of automation.

The files attached to the individual operations are however changed quite often, as machine operating parameters are optimized or operating conditions are changed.

The middle layer server structure for implementing the orbit stabilization provides a good separation of functionality between servers, and the inter-server RPC communication provides adequate response for 1 Hz operation of the orbit feedback.

## REFERENCES

[1] J. Maass, "Sequencing and Ramping in Hera" PCaPAC'99, KEK, Tsukuba, Japan, January 1999
[2] S. Herb, P. Bartkiewicz, F. Brinker, and J. Maass, "Automated Orbit Control for the Hera EP Collider", EPAC'04, Lucerne, July 2004, p. 2574