SUMMARY OF SESSION 4
HOW DO WE MONITOR BEAM QUALITY?

Emanuel Karantzoulis
ELETTRA, Trieste, Italy

Up to the end of the 80’s beam quality was mainly believed to be connected only to the intensity i.e. beam quantity. However, with the new colliders already functioning or programmed, new and more (also in safety) demanding production machines (e.g. isotope) and the many new 3rd generation synchrotron radiation sources that accommodate many experimental lines, the beam quality (BQ) issue has to be re-examined, re-evaluated and re-defined.

Accelerator Operations and the Management have also realized that accelerators are built to serve the experiments by providing beam and as in any ‘commercial’ business quality is an important factor. Different experiments however have different beam needs and tolerances thus BQ demands and definitions differ.

It would be desirable to define beam quality from the accelerator point of view; firstly for the experimenters needs and secondly for the simple reason that at experimental positions (detectors, beam lines) many things can go wrong, which may lead to a mis-interpretation of the beam.

In general BQ can be seen as the contribution from three main factors:

- Beam availability (uptime)
- Beam monitoring (to verify or improve quality)
- Communication (meetings, messages, displays, info to the users)

Some of the aspects of good beam quality are that it eases the problems with the experimentalists, attracts more users and thus makes more money available. In some cases like Jefferson Lab. or ELETTRA, beam quality is strictly connected to the lab performance and production bonus.

1. BEAM AVAILABILITY

The beam availability or Uptime has been defined as the usable beam delivered according to the schedule (even if it is not actually used for a certain period by the experiments). The uptime depends heavily on the organization of operations, automatism used, money available for maintenance/interventions, the number of pre-accelerators and it is ranging from 60-95%. To improve on uptime one needs also archiving of the machine (e.g. magnet settings) and frequent ‘operations meetings’ where problems of the machine are discussed and responsibilities are defined. It is recommended that a cost-effective evaluation be performed for the desired uptime level just like for the safety issues. To increase the uptime performance one can think of:

- Redundancy of equipment
- Non interruptable mains
- Universal Power Supply spares
- Preventive maintenance
- Operations team that can troubleshoot and repair
2. BEAM MONITORING

In general parameters and methods depend on the specific machine. The users, however, are usually interested to know the following:

- Energy
- Intensity
- Intensity decay (lifetime)
- Luminosity-brightness-brilliance
- Stability

In order to get the necessary information the following beam parameters are involved (or displayed):

- Global/local orbit
- Beam dimensions – spot size
  - *Transverse*: pinhole imaging of Synchrotron radiation, wire scanners, residual gas monitors, quadrupolar pick ups, OTR screens
  - *Longitudinal*: streak cameras, topography methods that also reveal the longitudinal bunch shape in phase space.
- Emittance-coupling-tunes
- Momentum and momentum spread (OTR, synchrotron radiation spectra)
- Polarization
- Spectral quality on dedicated synchrotron radiation line
- Radiation losses
- Collimators position
- Bunch purity
- Transfer functions
- Intensity stability (top-up, lasers on the gun)
- Beam bunch stability control (rf plungers/HOM shifters, rf cavity temp. tuning, super conducting cavities, feedback)
- Magnet cycle-beam destination

It is also recommended to have some supporting software available like an Alarm handler, Process log and beam parameter archiving.

3. COMMUNICATION AND PROCEDURES

All agreed on the following strategy towards experimentalists:

- Display messages from the Control Room
- Display relevant machine parameters
- Allow archive searching since also experiments need machine/beam data

From the tactics point of view one should:

- Anticipate the problem – inform of a bad quality beam
• Communicate with transparency
• Carefully hear any complains and be honest
• Only a careful selection of messages and alarms should be available (not alarming unnecessary the users, might not be interested, not blaming equipment groups)
• Intra-division meetings (at the most once per run)

From the organization point of view the following roles were mentioned for contacts with the experimentalists:

• **Operations** liaison (operations person that is directly communicating with a certain experiment)
• **User support** or run or experiment or floor *coordinator* (a user representative that brings the user’s demands to the control room, preferably the only user allowed to phone to the control room)
• **X-ray beam line position expert** (for light sources). A machine division person who verifies the good functioning of these monitors in case of complains.

As available tools for communicating with users were mentioned: the TV screens, telephones, loudspeakers and Internet. Especially about Internet there is a great interest that all communications and displays go also via this way.

4. **IN CONCLUSION**

Beam Quality applies to all accelerator facilities - small and large.

A single parameter may be sufficient to characterize the BQ for a certain experiment. However, there are usually many experiments and that single parameter may depend on many others (e.g. luminosity). Thus in practice many parameters are defined.

It is possible to connect these parameters in a weighted way to a single fictitious quality indicator that continuously ranges the beam quality from 0-100% (blue line on the right) as it is done at ELETTRA (Fig. 1).

![Beam Quality Controller](image)

**Fig. 1:** Beam Quality Controller
One must not forget that ‘clients’ may well be always right but on beam quality issues only 10% of the complaints are due to a bad beam. However this needs to be proved by beam quality monitoring and the following presentations will give us a more detailed account on how this is done.

Finally it is the wrong tactic to ask the opinion of users on the quality of the beam they are using. One should first define it according to their needs and then monitor it independently.
OPERATION OF THE ANKA SYNCHROTRON RADIATION SOURCE UNDER A STANDARD QUALITY MANAGEMENT SYSTEM

M. Hagelstein and V. Saile
Angströmquelle Karlsruhe GmbH, Hermann-von-Helmholtz-Platz 1, D-76344 Karlsruhe

Abstract
ANKA (Angströmquelle Karlsruhe) is a state-of-the-art synchrotron radiation facility at the Forschungszentrum Karlsruhe (FZK). Based on a 2.5 GeV electron storage ring it delivers photons from the infrared to the X-ray range. Five straight sections are available to accommodate insertion devices. The facility will be operated by a for-profit company, ANKA GmbH. In compliance with its mission, commercial services to customers will represent the majority of the overall activity, complemented by providing beam time to research users. Nine beamlines have been installed, eight will be operated by ANKA GmbH, one by the Max-Planck-Institute for Metals Research, Stuttgart. Three lithography beamlines for X-ray based production of microstructures will be jointly operated by ANKA GmbH and FZK’s Institute for Microstructure Technology IMT, which is certified under ISO 9001. Current plans for the application of standard quality management procedures are presented.

1. INTRODUCTION

The synchrotron radiation (SR) source ANKA is located inside the premises of Forschungszentrum Karlsruhe (FZK), a member of the Helmholtz Society. Construction and commissioning of the accelerators and beamlines is under the responsibility of a special project group of FZK and will be completed in 2001 and finally, ownership of the entire facility will be transferred to ANKA GmbH in April 2001. This company is organised as a for-profit, commercial entity and will operate the facility for private-sector customers. Access to academic institutions will be co-ordinated by the Research Group Synchrotron Radiation (Forschungsgruppe Synchrotronstrahlung, FGS), a newly established organisation within FZK.

2. THE SYNCHROTRON RADIATION SOURCE

The main technical parameters of the synchrotron radiation source ANKA are summarised in Table 1 [1]. Nine beamlines have been installed, eight will be owned and operated by the ANKA GmbH and one by the Max-Planck-Institute for Metals Research in Stuttgart (see Fig. 1). In addition, two front-end beamlines serve for beam diagnostics. Three beamlines for X-ray based production are jointly operated by ANKA GmbH and the Institute for Microstructure Technology, IMT at FZK. IMT is certified under a strict ISO 9001 Quality Management System (QMS) and will also apply this system to these three beamlines housed in a clean-room, including scanners and ancillary equipment.
Table 1: Technical parameters characterising the synchrotron radiation source ANKA

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Injection energy</td>
<td>0.5 GeV</td>
</tr>
<tr>
<td>End energy</td>
<td>2.5 GeV</td>
</tr>
<tr>
<td>Max. electron beam current</td>
<td>400 mA</td>
</tr>
<tr>
<td>Storage ring circumference</td>
<td>110.4 m</td>
</tr>
<tr>
<td>Horizontal emittance (D_ξ=0.5)</td>
<td>46 nmrad</td>
</tr>
<tr>
<td>Bending magnet deflection radius</td>
<td>5.559 m</td>
</tr>
<tr>
<td>Bending magnet magnetic field</td>
<td>1.5 T</td>
</tr>
</tbody>
</table>

Fig. 1: Schematic view of the facility with beamlines for LIGA-based production and SR-based physical and chemical analysis.

3. QUALITY MANAGEMENT SYSTEM AT THE INSTITUTE FOR MICRO-STRUCTURE TECHNOLOGY AT FORSCHUNGSZENTRUM KARLSRUHE

The institute for microstructure technology IMT, conducts applied research and development in the field of micro-structure technology, compliant with the rules and goals of the FZK. It is operated under a DIN EN ISO 9001 and 9004 certified quality management system (QMS) since 2000 [2]. The tasks of IMT span the large range from conception and design of new devices and systems to the development of series production of components. The micro-structured components and technologies may be transferred to industrial or public customers including fabrication of samples and manufacturing of components in pilot production. IMT is organised into seven divisions, three for research and development, one for micro-systems production, one for marketing, sales, and administration and finally one for quality assurance. The quality management rules are summarised in the Quality Management Handbook (QMH), which is...
authorised by the institute director. The QMH is complemented by a large set of additional documents describing procedures, processes, task, specifications, plans, etc. The responsibilities of the leading staff and of the divisions are defined in the QMH. Compliance with the quality management rules is compulsory for all IMT personnel.

4. QUALITY MANAGEMENT SYSTEM FOR ANKA GMBH

Synchrotron radiation laboratories have reached a degree of maturity, where stability of the electron source, quality of the photon beam, predictability of the schedule, service, and cost-efficient operation are mandatory requirements for long term success. In particular, facilities like ANKA GmbH serving paying customers must embrace well-proven concepts such as ‘customer satisfaction’. Producing goods or providing services that satisfy the specifications of a customer provides a definition for quality. In the private sector, quality is of overwhelming importance and has led to standard quality management systems such as DIN EN ISO 900X. Nowadays companies manufacturing goods or providing services must be certified for compliance with such a norm in order to stay credible and competitive. With the widespread success of quality management systems in industries it is a straightforward idea to implement such a system also at a synchrotron radiation facility.

The management of ANKA GmbH has decided to develop a QMS for the facility by 2002. The final objective is certification of ANKA GmbH. More important, however, is establishing the system as such, as well as implementing and applying it. The success of this effort will critically depend on the acceptance of the QMS by ANKA's employees. ANKA GmbH will strongly benefit from the experience at IMT over the past 3 years with establishing ISO 9001 at the institute, which is one of the main partners of ANKA. Furthermore, the documentation for the technical systems of ANKA will focus up-front on QMS requirements. Continuous education and training of the ANKA GmbH employees will allow for efficient and reliable operation. Clear and well-documented procedures and responsibilities will be the basis for the ANKA GmbH organisation. The QMS will be implemented step-by-step, starting with the three beamlines for X-ray lithography. Ultimately, it will cover all procedures conducted at ANKA. The goals are customer satisfaction, in particular:

- Delivery of a beam of perfect quality with high reliability (beam availability, spectral quality, position accuracy, beam stability)
- Safety management, high safety standards for personnel, customers and academic users, evaluation of failure modes
- Environmental management, define, implement, operate, control, publish
- Conduction of production processes with tight tolerances under auditing control
- Conduction of analytical services, transparent and traceable for the customers
- On-time delivery
- Cost-effective operation

As far as radiation safety is concerned, strict procedures had to be followed since commencing operation of the accelerators and beamlines. The operation rules are defined in legal texts and radiation safety instructions. An officer responsible for radiation safety and the interaction with the local governmental bodies assures compliance.

5. CONCLUSIONS

The implementation of a standard quality management system at the synchrotron radiation source ANKA is driven by the main goal of supplying high-quality services to customers from industries and to academic users. A company culture with well educated and highly motivated employees is a major
prerequisite for reaching this goal. The very positive experience gained at the Institute for Microstructure Technology of FZK encouraged us to continue along this route.

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MONITORING BEAM QUALITY IN THE PS COMPLEX DURING THE LHC ERA

M. Benedikt, G. Cyvoct, S. Hancock, A. Jansson, M. Lindroos, G. Metral, PS operations team
PS Division, CERN, Switzerland

Abstract
Continuous monitoring of beam intensity and beam losses is provided today at the PS complex with beam current transformers and beam loss monitors. The beam intensity is continuously displayed over a video network, together with relevant information concerning the machine status. In the future, during the LHC era, further important beam quality parameters will be brightness, bunch length and momentum spread.

For maximum beam brightness, any increase of emittance must be avoided, and its value should be monitored continuously. Transverse coherent beam position oscillations, due to injection steering errors, can be measured with conventional pickups. A new system, using two quadrupole pickups, will allow continuous monitoring of both position oscillations and beam size oscillations, the latter caused by injection matching errors. Beam size, after smear-out consequent to any injection errors, is measured with fast wire-scanners on a daily basis. The possibility of monitoring it non-invasively and continuously using the signals from the quadrupole pickups will be explored.

A longitudinal phase space plot can be created on-line by applying phase space tomography to bunch shape data from a longitudinal pick-up. This allows many important longitudinal parameters - among them emittance and momentum distribution - to be deduced with unprecedented precision.

We discuss the problems associated with i) automating all these measurements, ii) the limits of the different systems and iii) how the results can be used for on-line beam quality monitoring.

1. INTRODUCTION
The PS Division is responsible for the operation of seven accelerators which deliver beams of protons, antiprotons, lead ions and electrons either directly to the users, or to the SPS for further acceleration. Four areas are fed with beam directly: the East Hall where there is an experiment (DIRAC) and numerous tests of experimental equipment, the ISOLDE facility, the new AD area and the LEA and SLF areas where tests of detector and vacuum components take place. During 2001, the Division took over responsibility for operating the ISOLDE facility. The breadth of the CERN physics programme requires that normally several of the different particle beams operate simultaneously, which requires pulse-to-pulse modulation of the machines and a complicated interweaving of different machine cycles in a supercycle. The accelerators operate for close to 6500 hours per year, which requires the reliable operation of all the component parts of all the machines for extended periods. In general the many different users have high requirements on beam quality, but with different emphasis on particular beam characteristics. In this paper the monitoring of the future LHC beam will be discussed. In particular, the issue of providing on-line beam quality data for the subsequent machine in the injector chain will be addressed.
2. ON-LINE BEAM MONITORING FOR THE PS USERS

At present a display showing the actual magnetic cycle in the PS, the ejected beam intensity and the beam destination is broadcast over a video network to experiments and subsequent machines (the Users). Measurements of transverse and longitudinal beam characteristics are done on a daily basis at all machines by the PS operation crew, by some experiments and at injection into the next machine in the chain. The PS operators correct for all irregularities and work on improving general aspects of the beam quality. Such general aspects can be a poor beam profile or an undesired beam halo. Irregularities observed by the Users which cannot be verified or understood by the operation crew are discussed in specially arranged meetings. Weekly meetings are also held to inform the Users about the machine programme and status, and the work in progress.

3. THE LHC BEAM

The emphasis at the PS division has historically been on high-intensity beams. Major investments have been made to increase the intensity over the years with impressive results. The LHC beam is of low intensity but high brightness. This translates into a small emittance beam with a high longitudinal and transverse particle density. To enable the control and observation of such a beam, a project was launched in 1993 to adapt the machine hardware, the longitudinal and transverse beam control, and the instrumentation of the PS machines forming part of the LHC injector chain.

4. MONITORING TRANSVERSE LHC BEAM CHARACTERISTICS

In order to verify that the beam emittance is not blown up by bad matching between machines, a new measurement system has been developed to monitor PS injection (since the Booster uses multiturn injection, matching is not as much of an issue there). This system is currently being installed and consists of two quadrupole pick-ups positioned in consecutive straight sections of the machine. A quadrupole pick-up is a non-intercepting device that measures, apart from the beam position, the quadrupole moment of the beam. The PS pick-ups [1] have been designed [1] so that \( \kappa \) can be measured on a turn-by-turn basis for each bunch separately (see Fig. 1).

\[
\kappa = \sigma_x^2 - \sigma_y^2 = \epsilon \beta_x - \epsilon \beta_y + \sigma_y^2 D_x^2
\]  

(1)

Any oscillatory part of \( \kappa \) as a function of machine turn is due to mismatch. If the lattice dispersion is non-zero (as in the PS case), beam size oscillations due to injection errors in \( \beta_x \) and \( D_x \) develop differently as a function of turn. Consequently, it is possible to separate these two effects in the horizontal plane. The vertical dispersion mismatch cannot, however, be easily distinguished from a vertical betatron mismatch, but it is expected to be very small.

Since the ratio of \( \beta \) values (horizontal to vertical) are different at the two pick-up locations, the system of equations given by Eq. (1) for the measured \( \kappa \) values can be solved for the emittances. This requires a knowledge of the \( \beta \)‘s, which may be oscillating due to mismatch. However, by using the values of \( \beta \) and \( \kappa \) averaged over many turns, the filamented emittance can be calculated. This is theoretically very straightforward, but has yet to be demonstrated experimentally. Since \( \sigma \) is the rms beam size, the result is the true rms emittance, independent of distribution.

The momentum spread, which is needed to quantify the dispersion part of the signals, is calculated from the cavity voltage and the bunch length. The latter can also be determined from the pick-up data. Thus, the measurement system is self-contained in the sense that it will not require any additional input of measured beam parameters by the user. Therefore, it can employ a very simple user interface, or even run continuously in the background as an emittance watchdog, alerting the operator when correction is needed. The application program for this system will be integrated with the ABS (Automatic Beam Steering and shaping) one developed for the PS Complex [2], allowing the simple correction of detected injection errors.
Since the quadrupole pick-up system was developed primarily with injection studies in mind, some of its components (hybrids and amplifiers) are bandwidth-limited to about 30 MHz. This means that it is not possible with the present configuration to make single-bunch measurements in the very last part of the cycle, when multiple splitting has significantly shortened the bunch length to fit the SPS requirements. An increase of the bandwidth is possible if required, but the emittance at PS ejection will anyway be monitored using the Optical Transition Radiation (OTR) screens [3] in the transfer line towards the SPS.

![Quadrupole moment of a proton bunch in the PS measured with a quadrupole pick-up over several machine turns.](image)

**Fig. 1:** Quadrupole moment of a proton bunch in the PS measured with a quadrupole pick-up over several machine turns.

Apart from the on-line monitoring of the injection using the quadrupole pick-ups, it is foreseen that the operators measure the emittances at different times in the cycle on a daily basis using the wire scanners [4]. This will provide a valuable cross-check of the on-line results, verify the beam profile that cannot be studied with the pick-ups, and provide day-by-day emittance statistics.

5. MONITORING OF LONGITUDINAL LHC BEAM CHARACTERISTICS

The main longitudinal beam characteristics can be determined from a measurement of the longitudinal bunch shape. The longitudinal pick-ups in the PS and the PS Booster can be read with a digitizing oscilloscope and the resulting image can be displayed for one entire turn. It is also possible to acquire turn-by-turn data with an oscilloscope triggered by a revolution train synchronous with the bunch, or bunches, in the accelerator. The software for the first system permits the operator to save reference images, which can be compared to the present image yielding information on the phase and bunch shape. This is particularly important for the LHC beam where there is a second bunch-to-bucket transfer which must be synchronised at the energy of the first batch waiting in the PS. The on-line software for the turn-by-turn system includes a tomographic reconstruction algorithm [5] which permits the measurement of longitudinal phase space density (see Fig. 2). Additional input of some machine parameters, e.g. the RF voltage and the magnetic field, is necessary for the reconstruction. The longitudinal rms emittance together with the momentum distribution can easily be deduced from the resulting tomograms. Our tomography algorithm has proved extremely robust for errors in the input data [6]. An example of the on-line display is shown in Fig. 3 where the Booster beam was captured at the wrong frequency.
Fig. 2: A tomographic reconstruction of an unusual bunch distribution. Without
tomography it would not be trivial to visualize the longitudinal phase space
distribution from the turn-by-turn data.

Fig. 3: A small error in the RF capture frequency at injection caused this phase space
distribution. From the profile data alone it would not be possible to diagnose this
fault.
6. CONCLUSIONS

The LHC beam is more sensitive to a deterioration of the beam quality than the present beams. The new instrumentation developed for this beam will, as we have shown, yield reliable on-line data for the beam characteristics. This can be used for on-line alerts (and correction) but it can also be directly broadcast to the subsequent machine. This would enable the crew at that machine to monitor and even store the initial beam conditions and relate that to observed abnormalities in their accelerator. This would require a different form of broadcast compared to today, which will need a common control structure (under study). It would also differ from the present situation due to the type of data that is being monitored and broadcast e.g. longitudinal and transverse beam emittance, beam shape and longitudinal phase shift (compared to a given reference). Maybe the most important difference is that, with this new type of monitoring, the operator of the subsequent machine would not have to rely on a manual intervention to have important beam characteristic data at hand.

Longitudinal tomography not only yields emittance data, but it could also serve as a powerful visual aid to see small longitudinal beam perturbations. The present style of video screens with a summary of the most important machine data will probably continue to be broadcast over the existing, or an improved, video network. The tomograms are visually attractive and would form a natural focus on such a screen. The present progress in computing power should permit us to compute on-line tomograms for every machine cycle at the LHC start-up in 2006.

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MONITORING BEAM QUALITY AT HERA

M. Bieler
DESY, Hamburg, Germany

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 emittance, 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 emittance (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.](image)

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

This paper reflects the work of many people over a long period of time. Instead of a very long list of references I would like to thank all the people from the diagnostics and instrumentation’s group for all the information they contributed to this paper. References about the instrumentation of HERA can be found on the webpage of this group: http://desyntwww.desy.de/mdi/
Abstract
The high level of sophistication of many experiments is a first motivating factor for accelerator physicists to improve intrinsic beam parameters. In order to process data and understand results, Users need to be actively informed of such parameters.

At the ESRF, demand for beam time is three times greater than is available. It is this aspect, among others, that spurs accelerator engineers to do their utmost to improve beam time availability in order to best satisfy the User community. This is also part of the so-called beam quality. Beam uptime has now reached such high figures in many centres that Users tend to forget that there is an accelerator behind the wall … until it fails! This is why maintaining a good level of communication with Users is crucial: explaining what we are doing and listening to their needs are our two major interests.

The manner in which this business is managed at the ESRF will be detailed in this paper.

1. INTRODUCTION
The European Synchrotron Radiation Facility (ESRF) is an X-ray source of the third generation. The accelerator complex is composed of a Linear accelerator (e- 200 MeV), a synchrotron (300 meters – 6 GeV) and a Storage Ring (844 meters). The ESRF accelerators have been in full routine operation for over six years. The source delivers 5600 hours of X-ray beam to nearly 40 beam lines simultaneously. Our first goal is to ensure good availability of the Machine as well as a satisfactory Mean Time Between Failures (MTBF) all of which under safe conditions.

2. INTRINSIC BEAM PARAMETERS AND BEAM QUALITY
2.1 Why is it important for the Users?
For fundamental research as well as for applications (including medical treatments) using particle accelerators, the knowledge of intrinsic beam parameters is essential. Almost all experiments are fitted for dedicated beam characteristics (beam size at the location of the sample for LIGA techniques, beam stability for cancer treatment, etc). Experimental devices, such as monochromators, targets, detectors, will be especially designed for given beam parameters and scientists will generally exploit beam characteristics so as to develop new ideas for experiments (time-structured beam for storage of hard X-ray photons in a crystal cavity, bunch length for biochemists, etc). Then, for the processing of obtained data, these parameters will again be of prime importance in order to analyse and understand results and to finally validate models.

2.2 What is monitored online in the ESRF Control Room?
One computer screen displays the main beam parameters online (intensity, lifetime, rms orbit values, tunes, emittance). It is located at a central location in the Control Room so that it is permanently visible to the Operator. For all these parameters, a tolerance range has been predefined. Should the value be in this range, the value will appear on a green coloured background. Otherwise the background colour
turns to orange so as to catch the attention of the Operator. Some of these parameters (such as the orbit value) are even linked to a voice synthesiser audio alarm.

Whilst the beam is running, several important beam parameters are monitored online:

- The betatron tunes: should this parameter be wrongly tuned, this will have an impact on the lifetime. The Operator has the possibility of changing the tunes.

- Information about orbit values. A plot of the orbit seen by the 224 Beam Position Monitors (BPM) is displayed. Rms values and peak values are then automatically computed. The Operator can retrieve good orbit values by applying a SVD correction process. However, in the case of abnormal behaviour of a steerer, the orbit plot can be used as an input in a simulation code, which will determine the faulty steerer (which can then be invalidated by the Operator).

- Furthermore, three beam lines require particularly good beam stability. They are equipped with local feedbacks (making local corrections at a rate of 4.4 kHz). A graph in the frequency or in the time domain is permanently monitored for these 3 beam lines.

- Viewed by a pinhole camera located in the Storage Ring, the X-ray beam spot is displayed online. This gives a considerable amount of information. When the beam displays optimal conditions, a Region of Interest (ROI) is defined on the screen. Beam drift or jumps outside this ROI will indicate orbit anomalies. When inside this ROI, the emittance is permanently computed in both planes. Horizontal deformation will indicate the presence of High Order Modes. Vertical palpitations will indicate a lack of chromaticity. A tilted spot will indicate that a skew resonance is badly corrected, etc.

- When delivering a time-structured mode (such as the single bunch), Users need a perfectly cleaned bunch, i.e., no parasitic electrons besides the main bunch (a ratio below $10^{-7}$ is paramount. Again, the bunch purity is monitored online thanks to an APD diode located in the Storage Ring. However, when the Operator is sure that the bunch is pure enough, the diode is extracted in order not to degrade it unnecessarily.

- Hundreds of others signals can be accessed and monitored online through a common application. However, this is done only with special goals in mind and not during the normal Users delivery.

2.3 Which information can be accessed by the Users?

In order to open/close their Front End, the Users are obliged to go through an application in which, basic beam parameters are automatically updated online, such as intensity, lifetime and the messages sent from the Control Room to all beam lines.

In addition, the Users, as well as the Control Room, can access the archived data of about 1500 signals. For each signal, the time scale can be chosen between the present time and 1 year ago. This is of interest to them since, to give but 1 example, the X-ray beam position in their Front End can be displayed. However, it has been noticed that Users rarely use that possibility and prefer raising the questions directly with the Control Room. Most of their questions concern beam stability. The Operators will generally be able to answer all their questions. However, in tricky cases, Users have the possibility of sending e-mail to position@esrf.fr which groups a few Machine experts. An answer is usually provided within a few hours maximum.

Moreover, all online Machine information may be viewed by the ESRF personnel via videos and scrolling screens installed in most major corridors of all the ESRF buildings (including the Users Guesthouse).

As yet, no WEB tools have been developed to archive and retrieve data.
3. RELIABILITY OF THE BEAM DELIVERY

Having perfect beam characteristics would be useless if good beam delivery reliability was unobtainable. Beam time availability and the Mean Time Between Failures (MTBF) constitute the 2 basic figures of importance (the MTBF being of prime importance for the Users). This must be taken into account in the definition of ‘beam quality’.

At the ESRF, the starting point is a hand-written sheet filled in by the crew on shift. Amongst other information, this sheet contains: the real delivery time, the average intensity and the failures (equipment description + time and duration of event). This information is regularly extracted and summarised in order to produce periodic statistics such as the figures mentioned above. All the failures and their characteristics (time, duration, description, etc) will be compiled in a spreadsheet, which includes every failure since the beam is delivered to Users at the ESRF 6.5 years ago. This spreadsheet can be exploited in many different ways, the most interesting one consists probably in displaying the evolution of the MTBF per piece of equipment along the years, which will trigger preventive maintenance actions. This spreadsheet will give information about the origin of the repetitive failures and the long failures (respectively spoiling the MTBF and the beam availability). It is worth noticing that the definition of the availability at the ESRF is 100% - dead time for the refills (~1% in 2000) – time interruption due to failures (~2.5% in 2000) – time interruption in the case of the Control system crash preventing the Users from working (even if the beam is running) – the time between 2 failures IF 2 failures occur within 1 hour. Our goal, which is adhered to for 3 years, is to stay above 95%. Several examples of this achievement can be found in ref. [1].

4. COMMUNICATION TOWARDS AND FROM THE USERS

Now, what to do with a high quality beam and perfect delivery conditions if it does not fit User’s requirements? This shows the usefulness of two-way communication: firstly, in order to communicate to the Users our scheduled improvements or our problems and secondly, to listen to their requirements.

In short, the first step is to anticipate the problems. To do that, once a week, a meeting is held within the accelerator’s Division and chaired by Operation Managers. All the accelerators’ physicists, engineers and technicians are invited to this meeting. The beam delivery of the last week is reviewed in detail. All interruptions, failures and problems are discussed in depth. The main goal is to make sure that all problems are understood and above all, that experts have undertaken actions to solve them! Finally, the results of the Machine Physics Studies of the week (one day per week) are reviewed.

Then, once per Machine run (i.e., every two months), another meeting takes place where a larger audience is invited: Directors, Users, Machine experts, and any other persons interested. This is called the Inter Division meeting. The beam delivery of the run in progress is summarised (10 minutes). The Machine Physics results which have a direct impact on the Users are also summarised. This meeting is a good opportunity to propose medium to long term strategies to the Users (new filling modes, better beam stability) AND to listen to their feedback, complaints, and requirements.

At every meeting one User presents scientific results obtained on his/her beam line. Whenever possible, they are asked to give focus on results, which were obtained thanks to a given particularity of the beam characteristics, for example a perfectly cleaned single bunch or a given time-structured beam. This kind of meeting is of real interest to both communities.

5. CONCLUSION

We have seen that, at the ESRF, the so-called ‘beam quality’ is the result of three indissociable approaches: having good intrinsic beam parameters, maintaining a good level of beam delivery reliability, two-way communication with the Users. For each of these points, a positive approach must be taken: a complaint may be the first hint and is a good starting point in order to improve the accelerator’s performance hence leading to better scientific results.
References

BEAM QUALITY AT JEFFERSON LAB

M.F. Spata
Thomas Jefferson National Accelerator Facility, Virginia, USA

Abstract
The Continuous Electron Beam Accelerator Facility (CEBAF) at Jefferson Lab is a $600M CW electron accelerator in Newport News, Virginia. The machine is a recirculating, superconducting 5-pass linac initially commissioned for 4 GeV with a maximum beam power of 1 MW. With improvements in our RF cavity performance and an upgrade to magnet power supplies we are now capable of reliable operations at up to 5.7 GeV. We employ a three-laser photocathode gun to provide a CW electron beam with 80% polarisation to three experimental endstations in currents ranging from 100 pA to 200 mA. Establishing clear criteria for beam quality and developing the means to verify and maintain beam quality is essential to a successful physics program.

1. INTRODUCTION
Beam quality criteria are developed early in the life cycle of an experiment and are realised through a co-ordinated effort between the various departments within the Physics and Accelerator Divisions. I’ll discuss the overall experiment approval process, in the context of the identification of beam quality specifications, and the realisation and maintenance of these criteria through the development and implementation of diagnostics, feedback systems and communication mechanisms.

2. EXPERIMENT APPROVAL PROCESS
Experiments are awarded beam time as a result of a careful review of overall scientific merit, technical feasibility, and manpower requirements. All experiment proposals come under the review of the Program Advisory Committee (PAC). The PAC is an advisory group to the Lab Director. It consists of members external to Jefferson Lab appointed by the Director, plus the current Chair of the User Group Board of Directors.

The PAC solicits input from the Technical Advisory Committee (TAC). The TAC reviews an experimental proposal from the perspective of challenging technical issues, unusual demands on Jefferson Lab resources, and unusual Environmental Health and Safety issues. Specific beam quality criteria are contained in the body of the proposal and the TAC evaluates these on the basis of the present capabilities of the accelerator and decides if additional hardware or diagnostics are required to meet the beam quality specifications.

When technical challenges are evident for an approved experiment the effort is managed by the Accelerator Division Experiment Co-ordinator. A much broader audience is now exposed to the experiments needs and meetings are scheduled with members of Mechanical Installation, Electrical Installation, Cryogenics, Diagnostics, Radiation Control, Personnel Safety, Survey and Alignment, Software, Accelerator Electronics Support, and Operations Groups as necessary.

A key step in the process of communicating beam quality specifications to the Operations Group is the assignment of an Operations Experiment Liaison. The liaison is either a crew chief or operator who is responsible for facilitating information exchange between the experimenter and Operations staff during an experiment as well as during the planning stages. The liaison works closely with the
Accelerator Division Experiment Co-ordinator in streamlining the flow of information between the Operations Group and the Experimental Collaboration. Standard forms have been developed as tools to aid in the information exchange.

- **Physics/MCC Experiment Planner Form** – This form is completed by the Accelerator Division Experiment Co-ordinator (this is a full-time position that should not to be confused with the Experiment Liaison, which is a temporary responsibility). The form provides a brief description of the experiment, contact names and information, beam quality requirements, run times, and any special concerns related to the Machine Protection System (MPS) or the Personnel Safety System (PSS).

- **Experiment Liaison Check List** – This form is completed by the Accelerator Division Experiment Co-ordinator prior to the start of an assigned experiment. The form consists of a list of questions that help identify areas of special concern (e.g., additional procedures, new MPS interlocks, additional magnets...).

- **Experiment Liaison Binder** – The binder is located in the MCC control room and includes a specific section for each upcoming experiment. The Experiment Liaison is responsible for adding the completed Physics/MCC Experiment Planner Form, the Experiment Liaison Check List, and any other important experiment-specific information to the binder, prior to the start of the experiment.

Having clearly defined the flow of information to Operations staff regarding beam quality specifications, we then need to focus on mechanisms for maintaining beam quality and overall facility efficiency. This is accomplished through implementation of diagnostics, software, communications feedback mechanisms, and time accounting systems.

### 3. BEAM TIME ACCOUNTING

JLAB is operated by the Southeastern Universities Research Association (SURA) under a performance-based contract with the Department of Energy (DOE). The DOE employs a 1000-point system to rate our performance in the following key areas for overall success.

- Science and Technology Peer Review 300
- Reliable Operations (Simultaneous Availability) 250
- Production of Scientific Manpower 75
- Corporate/Community Citizenship 75
- Environmental Heath and Safety Peer Review 100
- Fiscal Responsibility Peer Review 100
- Institutional Management Peer Review 100

1000

The category for Reliable Operations specifically addresses our accountability with regards to maintaining the highest level of beam quality and efficiency of operations and counts for 25% of our overall assessment. A system of time accounting has been developed to keep us apprised of the overall facility efficiency, and helps us utilise our resources wisely when it comes to improving machine availability and beam quality.
### 3.1 Accelerator/End Station Status Definitions

The time accounting system is defined by the following categories:

- **Acceptable Beam in Use (ABU)** – Both the accelerator and experimental end station are meeting program requirements.
- **Beam Available but Not in Use (BANU)** – The accelerator is considered to be able to meet program requirements, but the experiment is not in an *Experiment Ready* status and therefore cannot make productive use of the beam.
- **Beam Not Available or Unacceptable (BNA)** – The accelerator is unable to meet program requirements which may include beam quality issues.
- **Accelerator Configuration Change (ACC)** – The accelerator is making a planned configuration change in the beam(s) being delivered.
- **Experiment Ready (ER)** – The experimental equipment is meeting program requirements or is considered capable of meeting program requirements if the Accelerator is in a BNA status.
- **Planned Configuration Change (PCC)** – The experimental end station is making a planned change to the software or hardware configuration, and this activity interrupts data taking or other activities in progress.
- **Unplanned Experiment Down (UED)** – The experimental equipment is unable to meet program requirements because of an unplanned system or administrative failure.

### 3.2 Metrics Definitions

Simple relations can be developed from these definitions to determine the overall success of the program. If $T$ is defined as the total time in the run period planned for physics activities then by definition:

$$T = ABU + BANU + BNA + ACC$$

$$T = ER + PCC + UED$$

The Accelerator Availability (AA), Experiment Availability (EA) and the Simultaneous Availability (SA) are then defined as follows:

$$AA = \frac{ABU + BANU}{ABU + BANU + BNA} = \frac{ABU + BANU}{T - ACC}$$

$$EA = \frac{ER + PCC}{ER + PCC + UED} = \frac{ER + PCC}{T}$$

$$SA = \frac{ABU}{T - ACC}$$

The most relevant metric with regards to beam quality is Beam Not Available or Unacceptable (BNA). In most cases this means that the accelerator is unable to deliver acceptable beam to the user. This includes time required for investigating, troubleshooting, and repairing a software or hardware problem. It also includes time used for unplanned beam tuning. This is the time spent tuning the accelerator after an unexpected event, such as an equipment failure or when beam characteristics have drifted out of specification so that the beam is no longer useable. It also includes time when an accelerator configuration change takes longer than planned.

BNA events involve two major categories. The first is *Downtime*, which is relatively straightforward to track and is related to a hard subsystem failures or Fast Shutdown (FSD) events (beam trip). The second is *Tunetime*, which is related to events where nothing is apparently broken but
the accelerator is still unable to meet program requirements due to unacceptable beam quality at one or more experimental end stations.

4. **DOWNTIME AND TUNETIME TRACKING**

Our electronic logging system is used by Operations staff to record lost beam time due to Downtime and Tunetime events. These entries are automatically entered into a database designed to track such instances. The entries are also emailed to relevant system owners, the Operability Manager and the Operations Group Leader.

The Operability manager is responsible for tracking Downtime while the Operations Group Leader is responsible for tracking Tune Time. Both are reported on at the weekly scheduling meeting, which is attended by senior staff from the Physics and Accelerator Divisions as well as members of all of the associated support groups.

The Downtime report includes lost time for each system failure and indicates if there are any trends associated with the failure. Top-level categories for Downtime reporting are hardware, software, tuning, FSD, and End Stations. Major sources of downtime are specifically called out with responsible parties identified, and action items are developed to deal with improving recovery from such events and minimising the chance of the incident reoccurring. Failure statistics are kept on a system-by-system basis and long-term trends are presented during monthly and semi-annual reports.

The Tunetime report indicates lost time due to unscheduled tuning. Events are tracked until sufficient improvement in procedures, software, hardware, or diagnostics make it unlikely that the event will reoccur. The particular problem is stated as well as proposed solutions and responsible parties for each tuning event. These incidents are usually related directly to the accelerator being unable to deliver beam to an end station according to one of the experiment’s beam quality criteria.

Both Downtime and Tunetime reporting are our primary means of ensuring that the accelerator availability remains acceptable and that we are able to maintain beam quality within specification.

5. **RUN CO-ORDINATOR WEEKLY REPORT**

Each experiment assigns the role of Run Co-ordinator to a collaboration member for a period of two weeks. This person is responsible for attending our morning summary meeting and providing a weekly beam availability report at the scheduling meeting. The Run Co-ordinator Weekly Report is used to indicate beam time accounting metrics, major causes of downtime in the hall, percentage of data collected to date, percentage of scheduled time the experiment has been running, special task results (e.g. energy measurement, spin measurement…), any potential problems related to beam quality or communications with Operations staff, as well as plans for the upcoming week.

This feedback mechanism is relatively new but has proven quite effective in bridging the gap between experimenters and Accelerator Division staff.

6. **BEAM QUALITY MONITORS**

A program of beam quality control relies heavily on diagnostic implementation, software development, feedback mechanisms, and communication. Following are some of the beam quality criteria with a description of the method used to monitor and communicate the information to the User.

6.1 **Beam Position Stability**

Beam Position Monitors (BPM’s) are used to indicate position stability in Halls A and C. These devices are strip line detectors with 4 orthogonal electrical pickups. The resolution of these BPM’s is on order 10 microns with an absolute accuracy of ±1 mm in the current range of 2 – 200 mAmps. The critical points as far as the experiment is concerned are the two BPM’s located immediately in front of the
nuclear physics target. These two are used to indicate the position and angle of the beam as it enters the target chamber.

Position stability in Hall B is indicated by the nA BPM system since their typical beam current is well below the resolution of the style of BPM’s used in the accelerator and Halls A and C. There are three such devices, each of which is composed of three pillbox cavities. One cavity is used to indicate horizontal position, one is used to indicate vertical position, and the third is a current monitoring normalisation cavity. They have 10-micron position resolution and a 50 pA current resolution.

A slow feedback system is used to lock position and angle in Hall B since the response time of the nA BPM system is slow. We employ a Fast Feedback System (FFB) to keep beam position and angle stable at harmonics of 60 Hz. with an additional slow lock to keep the FFB system actuators in the centre of their range.

All three Halls have direct access to the BPM information as well as calibration factors that go into beam position calculations. The operations staff monitors beam position as well, and are alerted to errors in the relative beam orbit as they occur.

6.2 Momentum

The relative momentum error in our 9 main accelerator arcs and 2 of the experimental endstation transport arcs is provided by a model-based software application. The application reports the total energy error as well as the integral contributions from the beam orbit, correctors, and earth’s field. This application is presently being redesigned with a better calculation engine and the output will be made available to the experimenter.

6.3 Momentum Stability

Momentum stability is monitored at high dispersion points in the transport arcs for Halls A and C. We use Optical Transition Radiation (OTR) monitors and pipe the image to a digitizer system to measure the width of the spot due to energy error. Halls A and C have dedicated digitizers so they can monitor the energy error online. The operations staff has access to the same information and can easily respond to errors in momentum. We use synchrotron light monitors in arcs 1 and 2 to monitor the stability of our linacs with a resolution of 1e-5 and minimum detection current of ~ 1 nA. The data from the OTR systems is readily available to the user and typically is part of their data stream. We are presently designing a synchrotron light monitor for the injection region.

The Fast Feedback System is used to suppress any power line harmonics that may be present on the beam by modulating an RF vernier system while monitoring BPM’s in dispersive locations.

6.4 Emittance

At present we have no way of monitoring the beam emittance online, but we are in the midst of developing a solution. In the meantime we perform harp swipes at multiple locations in Halls A and C and calculate the emittance based on the beam aspect ratio at five locations. We also have the capability of measuring the emittance in the injection region using a similar multiple harp technique. The measurement results are posted in the electronic log and are accessible by the experimenter and all accelerator staff.

A system that monitors beam transfer functions from the injector to the experimental end-station is under development for improving optics reproducibility and monitoring at Jefferson Lab. The measurements are based on small amplitude excitation of the transverse beam motion using four correctors in the injector and subsequent observation of beam motion in Halls A and C. Using four correctors allows one to extract a full set of betatron transfer functions. Four different frequencies of less than 1 kHz are used to distinguish each of the four correctors’ excitations. The excitation amplitude is far less than the beam size, so there is no beam quality deterioration. This diagnostic will utilize hardware from two existing systems – the Beam Scraping Monitor (providing excitation) and the Fast
Feedback System (providing beam position monitoring). The two systems lack inherent phase synchronisation; however using more monitors than correctors allows one to determine the excitation’s amplitudes and relative phase for each of the four frequencies. These are used in a least squares fit against the optics model, which yields the amplitude and phase of the incoming betatron motion from each of the four correctors. The output will be monitored by operations staff and provided to the experimenter.

6.5 Current Stability

Beam current is monitored with cavity based systems in the injector and Halls A and C. Hall B uses a photomultiplier based measurement to monitor beam current as well as the output from the nA BPM system. The operations staff and experimenters both have access to the data. Feedback systems are used to stabilise the beam current by adjusting the intensity of three independent lasers at the injector photocathode.

6.6 Helicity Correlated Current Stability

The Polarised Electron Source is typically configured to flip the sign of the polarisation at a 30 Hz. rate. Any changes in beam current as a function of helicity are undesirable as it adds an additional error term for the experimenter. We minimise this effect by monitoring a photomultiplier system in Hall B, which is fed back to optical elements on the Polarised Source laser table. Operations and Hall B staff monitor this error signal from their control rooms.

6.7 RMS Spot Size

The beam spot size on target is measured with Harp systems in all three experimental end stations. The measurement and correction process is invasive and slow. We are presently developing solutions to minimise the time for optimising the beam aspect ratio. We will be using an OTR system in Hall A and insertible scintillators in Halls B and C. All three monitors will be fed to digitizers with automated quadrupole adjustments to optimise the spot size. Monitoring will be part of the Emittance monitoring application. The information will be provided to both the experimenter and Operations staff.

7. AREAS OF CONCERN

While we would like to believe that we have a good handle on providing quality beam to the experimenter there is always room for improvement.

7.1 Specification Creep

A process of continuous improvement of beam stability is what we strive for. We identify as early as possible reasonable beam quality criteria. When we meet a particular specification consistently there is a tendency for the User to want to tighten the acceptable error window. Getting all parties to agree to the extent to which we tighten specifications is challenging. We could do a better job of providing a more consistent process for identifying when specifications can be changed.

7.2 Operations Liaison Program

The success of the Operations staff member as a liaison to an experiment depends on the availability of collaboration members for meetings and the operator’s schedule. With a distinct person assigned to each experiment the Accelerator Division Experiment Co-ordinator winds up working with many people for a relatively short duration, which can yield inconsistent results. We have recently changed the program by assigning one Operations Liaison to each experimental end station for a one or two year term. This person will have the opportunity to develop a working relationship with the Accelerator Division Experiment Co-ordinator and will also work closely with technical staff from each experimental end station.
7.3 Visibility of Beam Quality Criteria

We could benefit from making beam quality specifications more apparent through the development of a web-based tool. This would allow easy access to the information for all staff and enable specific persons to change specifications remotely as required. This level of consistency and availability of information will ensure that the Users and Operations staff are in agreement as to what the expectations are. More timely reviews can then occur at our morning summary and weekly scheduling meetings.

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QUALITY CONTROL AND CUSTOMER SERVICE AT BESSY

J. Feikes and K. Holldack
BESSYII, Berlin 12489, Germany

Abstract
The Users of BESSYII are used to a small source point with a position stability in the order of some microns. This is monitored by staggered pair systems on each beamline and a high-developed beam position system. There is a constant collaboration between experimental and machine group to guarantee constant working conditions using the information of these systems.