FIFTH INTERNATIONAL WORKSHOP
ON
ACCELERATOR ALIGNMENT

Argonne National Laboratory

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CONCLUSIVE REMARKS

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1. Combining a distance meter of 10-20 µm absolute accuracy with a laser tracker is an effective (and absolute!) step forward. Integrating the laser tracker with the best automatic total stations provides us with a more universal tool that is less cumbersome, lighter, easier to use and much less expensive.

Because it requires special environmental conditions, interferometric accuracy to within a few µm is still only occasionally utilised, and we all know that stability at a µm range never exists during accelerator alignment or during experiments. Most of the accuracy demands in HEP labs and in industry can be met with a tool good to 10-20 µm, which definitely negates the complicated use of invar wires.

2. Photogrammetry has made significant steps and progress with a digital system based on dense and precise CCD arrays. The sensor is the measuring unit, and all the data is processed on a PC. For the size of objects we are commonly measuring in HEP labs, photogrammetry provides an accuracy of 20-50 µm. The forthcoming 4K*4K CCD camera from ROLLEI is very promising.

Nevertheless, improved survey and alignment of quasi-linear structures require greater close-range and long-range measurement capabilities and a perfect stability control of the optical axis (versus focusing changes), together with the related changes of corrective parameters and calibration data, if different. It may still be valid to consider photogrammetry, initiated in Braunschweig, in comparison to automatic theodolites.

3. Transparent (“see-through”) optical sensors are available, either through transparent materials or through a measuring open frame (and a bi-planar beam). These sensors provide us with new “openings”, indeed, for optical monitoring; the intermediate sensors no longer occult the reference (laser) line, and its stability can be permanently checked at the end points.

4. While new theoretical models and analysis strategies better assess refraction effects on optical (distorted) lines, significant advancements are being made in the development of dispersometers/refractometers. Refraction effects are integrated along the path, and from the data observed by this instrument the final angular correction can be derived.

5. For both ring-shaped and linear accelerators the tolerance specifications for absolute/relative or long-range/short-range errors are not clearly defined. Because tolerance specifications could change the approach for designing a geodetic control network and the need and efficiency of a smoothing process, more detailed studies are necessary.

6. Given the radial measurement scheme of an accelerator, the use of precise gyrotheodolite azimuths significantly improves the control of the random and systematic error oscillations of the figure in this plane. An accurate survey is more difficult when trying to minimise the errors over many kilometres. In addition to their use in offset and angular measurements, gyrotheodolites are now accurate and generally fast enough for use in the metrology of large accelerators (cf. LEP measurements at CERN).

7. Control and active feedback over a few µm range is achievable (cf. FFTB at SLAC and now CLIC-CTF2 at CERN) over a few meters. Appropriate sensors and actuators are operational in real accelerator environments, and the immediate expectations are for faster cycles in the control loop.

8. Synchrotron light machines are more demanding for a regular and tighter control of the alignment, primarily for vertical data. This has induced more studies in ground motion and vibrations than for HEP machines. Present projects (LHC, TESLA) are requiring more survey efforts and a better stability control than before, such as the alignment of low ß sections that require very severe specifications.

9. While installation surveys are skilfully achieved, regardless of the method used, at all stages of the process (control networks, pre-alignment, final alignment and smoothing); maintenance surveys for long or large structures are more complicated. These surveys are an economical question because of the limited time available during shutdown. It is already impossible to completely re-survey (in both radial and vertical planes) large accelerators every year. This situation will be far worse for LHC and for TESLA. We need to invest in some imaginative means for setting up a rather cheap monitoring system that would generate “survey alarms”. These alarms would indicate when a designated magnet is over a given misalignment threshold. This threshold would be lower than the limit of what is mechanically acceptable by the bellows or by any other sensitive assembly. By such means, the annual maintenance survey would be split into a full vertical measurement survey (levelling is fast and easy) and a limited radial survey. The extent of the radial survey is determined by the information from the “survey alarms” and from the levelling survey.

10. Manufacturers of good instruments often discontinue production with very short notice and after only a few years. Unfortunately the technology of some product lines is not transferred elsewhere, i.e. in some central Europe countries. Also, because the market is said to be small, some new and better instruments that are technologically mastered are never made. The market is indeed small because the expected instruments are not available, and we are keeping old methods or trying others. For instance, the new and very accurate absolute distance meter will have a large market in industry, in laboratories and in quality control of large structures if the technology migrates from laser trackers to automatic theodolites.