Summary of Working Group 1

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1. Disclaimer

This write-up is an attempt to summarise working group 1. I did not try to summarise all that was said but rather to think of how a document for the baseline configuration could be structured. I tried then to outline what we know in the different areas and which R&D remains. This is supposed to be something like a living document that is modified as we progress. In particular, in some parts names are assigned to certain R&D items. This is by no meas exclusive but only reflects that these person were present and had a chance to volunteer. Anyone who whants to join is warmly welcomed. The input of the working group to the questions on Tom Himmels list is given on the slides in reference[3] a summary of the first week in[4]. The workplan as discussed can be found in [5].

2. Introduction

The beam dynamics working group has to make sure that the luminosity target can be met in spite of the adverse effects in the beam transport from the damping ring to the interaction point and further to the beam dump. This implies three main tasks. First, the working group has to provide the lattices of the beam lines from the damping ring to the beam delivery system; the beam delivery system will be designed by working group 4. Second, it needs to study the performance of the whole low emittance transport system in order to predict the luminosity performance and to be able to specify instrumentation requirements and tolerances. Finally, it needs to validate the codes and methods used in the studies by benchmarking. It seems unlikely that all the tasks can be fulfilled before the end of the year. The emphasis will thus be put on the lattice design; later findings may lead to improved versions of these.

3. Lattice Design

The working group is responsible for the design of the lattices of all sub-systems from the damping ring to the beam delivery system. It is also in charge of ensuring that the luminosity target can be met taking into account all adverse effects in the beam transport from the damping ring Based on the discussion with the working group the following lattices are foreseen:

- A line transporting the beam from the damping ring to the bunch compressor.
  - Extraction geometry and betatron matching region.
  - An emittance measurement section including the measurement of the transverse beam position for a feedforward correction.
  - A collimation section, which can collimate the transverse planes.
  - A turnaround.
  - A spin rotator.
  - The correction station of the feedforward.
  - A diagnostics and skew correction section.

- The bunch compressor.
  - First accelerating section.
  - First bunch compressor chicane including longitudinal collimation.
  - Longitudinal diagnostics section.
  - Second acceleration section.
  - Second bunch compressor chicane.
  - Longitudinal diagnostics section.
  - Transverse emittance diagnostics.
  - Transverse collimation section, including main linac protection.
- The main linac.
  - First part of the main linac.
  - An intermediate diagnostic section.
  - Second part of main linac.
  - In the main linac dispersion and wakefield tuning bumps need to be designed.
- Beam delivery system.
  - Diagnostic section to measure the transverse emittances.
  - The beam switch yard and extraction system.
  - The collimation system.
  - The final focus system.
  - The detector with a luminosity monitor and the surrounding solenoid.
  - The spent beam line including the different diagnostics.

3.1. Beam Transport from the Damping Ring to the Bunch Compressor

The working group feels that it is necessary to have an emittance measurement station just after the damping ring in order to be able to diagnose problems that may arise at extraction.

The group also felt that it is advantageous to extract the damping ring beam to move in oppostie direction than in the main linac. The following turn around will allow the use of feed forward to compensate pulse-to-pulse and bunch-to-bunch jitters, in particular in the transverse plane[9].

Jeff Smith is going to design the spin rotator and Franz-Josef Decker will have a first look at the final emittance diagnostics section with the skew correction.

3.2. Bunch Compressor

Several bunch compressor designs were presented in the working group[6–8]. The common conclusion is that a one stage bunch compressor is sufficient to compress a 6mm long damping ring bunch down to 300 μm but that not much margin exists. A two-stage compressor would provide a significant margin and can even compress a 9 mm bunch down to 150 μm. It was a general consensus to foresee a two-stage compressor.

Since the different bunch comporessor designs were evaluated in quite different levels of details, a more complete comparison will be necessary to chose among the proposals. Peter Tenenbaum, Eun-San Kim and Yujong Kim are going to follow these studies.

3.3. Main Linac

Currently a number of different lattices exist for the main linac. The main tradeoff is between a stronger focusing, which reduces the wakefield effects, and a weaker focusing which reduces the dispersive effects. The optimum depends on the accelerating gradient and the chosen method of beam-based alignment and tuning. The simulations have been carried out show that a quadrupole spacing of 20 to 36 cavities can yield reasonable results. Since the actual optimum depends on the beam-based alignment and tuning strategy—e.g. the use of dispersion and wakefield tuning knobs—only a preliminary choice can be made. While the studies are continuing, it seems reasonable to chose a constant focusing lattice with a quadrupole spacing of 24, 20 or 24 cavities—depending on the number of cavities per module being 8, 10 or 12—as a baseline. It may well be possible that an increase in the quadrupole distance, in particular in the second part of the main linac, is helpful in balancing wakefield and dispersive effects.

Coupling between the two transverse planes of the longrange wakefield modes can lead to an increase in the vertical beam emittance. The beam jitter is expected to be larger in the horizontal plane and can via the coupling affect the much smaller vertical emittance[17]. This effect can be mitigated by the use of different phase advance in the horizontal and vertical plane to avoid resonant behaviour. It was concluded that such a decoupling would be useful in case of other problems as well. Hence a phase advance of 75 and 60 degrees will be used.

Also dispersion and wakefield bumps are needed and at least one emittance measurement station is required in the main linac. The development of the lattice will be followed by several people with a contact via Daniel Schulte.

Preliminary studies indicate that the main linac tunnel does not need to be laser straight but could follow the curvature of the earth or consists of straight sections connected by bends[20, 21].

A final design of the main linac optics requires input of working group 2 conerning for example the module layout and the position of the BPMs. Also the wakefields can affect the design. The presentations [22–24] were therefore very useful.

3.4. Beam Delivery System and Beyond

The beam lines after the main linac will be designed by working group 4. Working group 1 will mainly evaluate the luminosity impact on these designs.

3.5. Main R&D

Most of the lattice are not covered. An additional effort to find volunteers would be necessary. For the bunch compressor and the main linac the remaining problem is to agree on a design. The discussion of the relative strengths and weaknesses is ongoing but it seem well possible to reach a consensus before the end of the year.

4. Foreseen Beam-Based Alignment and Tuning Procedures

The beam-based alignment and tuning procedures have a significant impact on the luminosity performance and hence on the lattice design. To some extend they can be considered independently for each subsystem, for complete understanding integrated studies are necessary. In a number of cases the effects of one Subsystem (e.g. the main linac) are tuned out in another section (e.g. the beam delivery system), In addition, the real value of interest is the luminosity, which requires simulation from the error source to the beam-beam effects.

4.1. Pre-Alignment

Correct modelling of the pre-alignment is essential to understand the performance of the alignment and tuning procedures used to mitigate the static imperfections. Currently only a model for the main linac exists. It is based on the numbers used in the TESLA-TDR and assumes that all elements are scattered around a straight line. The model assumes that all elements are misaligned within their supporting cryomodule and the module itself is also misaligned with respect to the straight line.

A potential pre-alignment system that is currently being developed is LICAS. It has been presented in detail in the working group[32, 33]. A simulation code has been developed to simulate the performance of LICAS. In general the errors can be split into

- a random walk like deviation of the survey reference line from the straight line,
- a misalignment of the module ends due to the error in extrapolating from the reference on the wall to the marker on the module and
- the misalignment of the elements with respect to the module.

Preliminary simulations have been shown using only the random walk contribution. The resulting emittance growth is not negligeable [12] so further tuning of the procedure may be required.

It was agreed to publish the pre-alignment model on the web in order to make sure that a coherent model is used in the simulations and to allow hardware experts to verify it. It was further agreed that a set of standard pre-alignment sets would be provided as soon as the lattices have been fixed. This will ease the comparison of results and allow to understand how to overcome problems with a very bad machine. Armin Reicholt will follow the pre-alignment.

4.2. Bunch Compressor

The necessary alignment and tuning procedures for the bunch compressor need to be studied.

4.3. Main Linac

The studies of the e beam-based alignment and tuning of the main linac are not finished. In particular the understanding of the impact of dynamic imperfections on the static tuning procedures needs to be understood in detail. However it is possible to describe the generic procedure of that will be applied. The process consists of three main stages:

- First the beam will be made pass the main linac by using one-to-one steering in which the beam is simply steered through the centre of each BPM.
- Then the beam-based alignment is used, this could be dispersion free steering, ballistic alignment or some other method. This process tries to optimise the quadrupole positions using the BPMs in a more complex fashion than the one-to-one steering.
- In the next stage dispersion and wakefield tuning knobs are applied. In this process dispersion (or wakefield effects) are added to the beam and its emittance is measured. The added effect is varied step-wise until the minimal emittance is found, then the next knob is used.

Three different sets of beam-based aligment methods have been studied, dispersion free steering, a kick minimisation method and ballistic alignment. A comparison of the methods indicated that ballistic alignment performs better than dispersion free steering and the kick minimisation[15]. However stray fields might significantly affect the emittance growth in particular in the ballistic alignment and in the kick minimisation. Methods of mitigating the effects of potential stray fields are discussed will need study. Regarding dispersion free steering, all the studies concluded that the launch region of the main linac is of particular importance, since it is difficult to achieve the required energy difference between the test beams. The first few quadrupoles would thus be aligned using a different method. It could consist of aligning the BPM to the quadrupole centre by shuning the quadrupole field. This method requires that the magnetic centre does not move significantly when the field strength is changed. Measurements should be performed to verify the centre stability.

In spite of the fact that the studies have been carried out for different lattices and with inclusion of different levels of detail for the imperfections they all showed that the achieved emittance growth is marginally sufficient or too large by a small factor[12–16]. An effort is made to make coherent simulations in the coming weeks.

Simulations showed that dispersion tuning knobs can reduce the emittance growth by a factor of a few[12]. The use of additional wakefield tuning knobs also showed significant improvement[19].

4.4. Beam Delivery System

The beam-based alignment of the beam delivery system needs to be developed. It is obvious that tuning of the beam delivery system is of prime importance. Small errors in the strengths of the different magnets can lead to very significant increases of the beam spot size at the interaction point. A significant effort to develop the tuning and alignment is undertaken in preparation for the ATF2 experiment at KEK.

4.5. Main R&D

- A consistent model of the static imperfections is required. It needs to be published on the web and to be revied by other working groups.
- Beam-based alignment and tuning procedures for the bunch compressor need to be defined.
- The same is true for the beam delivery system.
- Detailed comparison of the different main linac and tuning studies is required.
- Studies have to be performed to verify that a main linac that is following the curvature of the earth is indeed acceptable as preliminary results indicate.
- The importance of the rotating long-range wakefield modes has to be confirmed by other studies. Agreement on the correct physics model is required as well as verification of the results of the presented beam dynamics simulations.
- The first few cells of the main linac pose a particular problem. Detailed studies which integrate the bunch compressor and the main linac are thus essential.
- Also for the other beam lines alignment and tuning procedures need to be defined.
- The robustness of the tuning proecedures needs to be studied. This ranges from understanding of the impact of a few very bad BPMs to understanding how long the recovery time is after a klystron failure.

While resources are quite stretched this area seems to be better covered than the lattice design.

5. Dynamic Effects

A number of dynamic imperfections can impact the luminosity, among them are ground motion, jitter of the accelerating voltage or phase, vibrations induced by the helium flow and others. The studies of the beam-based feedback that are used to mitigate their effects are important to understand the stability of the luminosity. For jitter effects that cannot be corrected by feedback tolerances need to be defined that allow for successfull machine operation.

5.1. RF Stability

The stability of the accelerating voltage is important in particular in the bunch compressor in which a voltage error leads to a longitudinal shift of the compressed bunches. Voltage errors can be generated by errors of the amplitude or phase. The tolerances found for the ILC are tight but still somewhat looser than those for the X-FEL[25–27] planned in Hamburg.

5.2. Beam-Based Feedback

Simulations show that the intra-pulse position feedback at the interaction point is very efficient[29]. In presence of strong ground motion a beam-beam position and angle feedback may not be able to recover the luminosity well enough. In this case intra-pulse optimisation of the beam-beam offset and collision angle is required[30]. It seems possible to perform an optimisation of the beam offset[29].

A particular difficulty found for the orbit feedback was that in the beam delivery system points of high dispersion exist. Small energy variations of the beam will lead to a transverse motion in these points, which the feedback must not attempt to correct. The measurement of the beam energy needs thus to be very precise to avoid confusion of the transverse feedback[28].

5.3. Main R&D

- A consistent model of the dynamic imperfections needs to be developed. It will need to be reviewed by other working groups, e.g. the ground motion model and the RF stability.
- A fully coherent picture of the dynamic effects needs to be developed. For example, multi-bunch studies need to include bunch-to-bunch variation other than those generated by the long-range wakefields.
- The problem of the orbit feedback due to the energy variations of the beam needs to be addressed.

6. Integrated Performance Studies

The importance of integrated performance studies has been pointed out in the ILC-TRC[11]. These studies are important to understand the implications of the different time scales involved in the static tuning and the feedbacks. In particular the potentially significant luminosity fluctuations due to the motion of the beam delivery may impact the optimisation of the knobs that should correct the dispersion and wakefield effects in the main linac. While first studies yield interesting results, the work is still at the beginning[29–31]

6.1. Main R&D

- While particular problems have been studied already, this work needs to be based on the combination of the beamdynamics studies of the static and the dynamic effects.

7. Code Development

A number of codes exist that can simulate the beam transport, the effects of imperfections and the beam-based alignment, feedback and tuning in the different sub-systems. Integrated code packages exist that allow to simulate the beam from the damping ring to the interaction point and beyond. However, these codes do not yet allow the full simulations required. It is therefore necessary to further develop their capabilities and robustness[34, 35].

7.1. Benchmarking

It is of utmost importance to verify the codes as much as possible by benchmarking. Code to code comparison allows to minimise the risk of simple programming mistakes. It would be very valuable to be able to verify the codes also by benchmarking with real machines. A very interesting option for such a test would be provided by ATF2.

Because of the benchmarking need it is felt necessary that each important performance prediction is obtained by at least two independent simulations with different programs.

7.2. Main R&D

- Improvement of the existing codes is required to be able to perform the beam dynamics studies necessary to establish with confidence that the luminosity target can be met.
- A full comparison of the relevant codes for integrated beam dynamics simulation will finally be required.
- The benchmarking is of the main linac simulations seems on a good road.

8. Conclusion

The working group agreed on a first conceptual layout that includes all the sub-systems from the damping ring to the beam dump. This layout will serve as a reference for further studies and should be subject to critical review by the community. Concerning the lattice design of the individual sub-systems, the bunch compressor and main linac seem on a good road. The spin rotator and to some extent one of the diagnostics sections will be adressed by volunteers. The beam delivery system and spent beam line will be designed by working group 4. However, more effort needs to be made to design the missing lattices.

The static alignment and tuning studies are advancing well for the main linac. The main effort will be to merge them into a coherent picture and to add the different tuning knobs. The bunch compressor and launch region of the main linac as well as the beam delivery system will be addressed in the near future. These are regions in which attention is required to the specific design details. Currently each of them is addressed by only one team.

Some work has been done on the feedback and integrated simulations, but this area clearly needs more effort. A coherent and complete model of the imperfections is required and the integration of the different sub-systems and timescales is essential.

To provide the tools for the above studies significant resources need to be put into the code development and the verification by benchmarking.

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