Report for ATF Review 2020

October 6, 2020

This is the review report for the ATF Review 2020 held on September 29, 2020 as a Zoom meeting. The program and materials are available at https://agenda.linearcollider.org/event/8626/ with charges given to the committee:

1. Evaluate the scientific results at ATF/ATF2
2. Evaluate future ATF operation for LC R&Ds
3. Evaluate future ATF operation (other than LC)

The committee appreciates the scientific progress made by the ATF/ATF2 team, as well as the presentations and documents given to us, under the unusual circumstances.

1. Overview

Below are the answers to the charges:

Scientific results at ATF/ATF2

The committee has been impressed on outstanding and unique results achieved in ATF/ATF2:

- The smallest spot size, 40 nm, in any accelerators.
- Intra-train bunch orbit feedback (FONT).
- Vertical emittance in the ring, 4 pm, smallest at the beginning of the century.

The committee also applauds pioneering developments on various accelerator components:

- Fast extraction kickers with rise/fall time less than 3 ns
- Laser wires measuring 1 μm beam size
- Cavity BPMs with 20 nm resolution
- Single- and multi- OTR/ODR beam profile monitors

Some of these devices have been spread to other accelerators including CERN PS and light sources.

Educating graduate students and young scientists under international collaboration was another achievement of ATF, which is the best project at KEK in this aspect.

Future ATF operation for LC R&Ds

The committee recognizes that the achievements at ATF/ATF2 have already verified the minimum technical feasibility on the beam focusing and control for the ILC. However there will be a number of possibilities for further extensions to investigate:

- intensity dependent effects on the spot size
- optical aberrations, esp. with smaller horizontal β^*
- beam halo and collimation
- even smaller spot sizes with higher chromaticities

Besides the studies on the beam spot, the committee notices some possibilities of ATF to explore other components which will benefit the ILC preparation:

- polarized electron source, transport, and storage in the damping ring.
- beam collimation study using fancy devices such as using a laser or another beam.
- beam feedback within one turn of the ring circulation to simulate a fast feedback at the extraction of the ILC DR.

Future ATF operation (other than LC)

The committee would like to appreciate the effort to explore possibilities to utilize the unique facility for other fields of science. The recent domestic workshop has already gathered more than 10 proposals. The committee encourages the ATF team to expand this effort internationally. Such activities may conflict with the preparation of the ILC, depending on the situation, but the committee would like to say that the scientific value of ATF will not end even after the ILC starts. KEK should not consider any shutdown before exploring the full scientific possibility of ATF.

Remarks

Although the committee is confident on the scientific achievements and future possibilities of ATF, it also feels a large gap or contradiction between the preparation plan for the ILC in coming years and the operation history of ATF in the past five years, which showed declines in operation weeks per year, human resources, and budget. This committee cannot judge the feasibility of such a future plan of the ILC, but still expresses heavy concern on the situation. It is inefficient to operate such an accelerator facility only five or ten weeks per year. It is just a waste of time, budget, and resources.

2. Timeline

Findings & comments

ICFA International Development Team (IDT) for the ILC was introduced as a successor of the Linear Collider Board (LCB) and Linear Collider Collaboration (LCC). IDT-WG2 is discussing the accelerator activities of the ILC Pre-Lab, where the ‘ATF3’ is expected to have a key role as an upgraded ATF2. The presented plan consists of three phases: "Pre-preparatory by 2022, Main preparatory by 2026, and Construction by 2035.

This committee cannot assess the feasibility of these global plans, as it is out of scope of this review.

‘ATF3' would be a major upgrade of ATF2 to provide a test facility for demonstrating long-term stability of delivering nanobeams for achieving the ILC (and CLIC) design luminosity.

Recommendations

- **Refine the goal of ATF3 whether to cover other subjects presented in the review.**

3. ATF Introduction, Instrumentation R&Ds

Findings & comments

The ATF/ATF2 is a unique test facility that can demo the crucial technologies that are indispensable for linear colliders, including low emittance beam generation and nanometer beam development. ATF was developed from 1990 and started operation in 1997. It achieved very low vertical emittance (4 pm) beam in damping ring around 2000, in 2008 it was extended to ATF2 by constructing a final focus test beamline and obtained the vertical beam size of ~40 nm at the final focal point. These pioneering progress and achievements are of great importance and impact to conquer the major technical challenges for linear colliders. The work on ATF from the facility construction, technology R&D and performance studies is excellent and indispensable.

The ATF/ATF2 consists of a 1.3 GeV S-band linac (6.25 Hz rep. rate, up to 10 bunches per pulse), a 140 m circumference damping ring(3.125 Hz injection-extraction rate), extraction line and final focus line. Many important studies have been performed at ATF and ATF2, including photo-cathode RF gun based multi-bunch beam production, low emittance tuning at damping ring, CSR effects and final focus scheme tests.

Many instrumentation R&Ds have been completed and demonstrated at ATF/ATF2 with great success and the most advanced level in the field. The fast kicker magnet with rise/fall time of 3 ns has been demonstrated and operated at ATF, the cavity BPMs with best resolution of 8.7 nm to 20 nm have been developed and installed close to each Q-magnet at the ATF2 beamline and its final focal point, the vertical collimator for controlling beam hallo has been installed tested in the final focus system of ATF2, the laser wire has been developed and demonstrated to meet the requirement of 1 μm beam size measurement, the optical radiation monitors, such as OTR/ODR, for emittance & Twiss parameter measurements have been developed and tested with a submicron resolution. In addition, beam size monitors and orbit feedback have also been developed and successfully tested. All these demonstrated instruments are in the best rank of their performance if compared with other similar R&Ds worldwide, This committee congratulates the ATF team and applauds these world leading achievements.

The committee believes that the ATF team should keep the momentum, and continue the efforts on long term stability issues, such as injection/extraction system, orbit drift and beam size variation at final focus point.

Recommendations

- **Improve the instrumentation with AI technology application.**

4. ATF2 small beam, Wakefield

Findings & comments

The optics has similar chromaticity L^*/β^* in both x and y directions as ILC (250 in X and 10,000 in Y)

Quality and stability of the IPBSM laser: Suspected to be one of major problems in small beam size.

A drift of the laser position was observed. The Modulation (then, the measured beam size) is sensitive to the change of laser path. The size and position of laser beam waist are different in two directions Y and Z. The 41 nm beam size was demonstrated in 2016 (300 nm w/o chromaticity correction), BUT: with the beam size growth by bunch intensity, ~21 nm/1x10^10 e. In 2016: by removing some BPMs, bellows, flanges, shield bellows, shield flange gaps, etc., a wakefield reduction by a factor of 3 was achieved.

The orbit jitter is 0.1-0.3 sigma, which has small direct effect, but big effect on the size due to wakefields. Wakefield at the ILC Final Focus will not be significant (x 1/30 -1/10) as the energy will be 250 GeV vs 1.3 GeV.

The drift of laser orbit of the size monitor was around 40 nm. The uniformity and stability of the laser is another issue.

They have verified the basic, minimum requirements for the beam condition for the ILC, even with the presence of wake effects.

Problem of repeatability of the beam size, before/after 2016.

Recommendations

- **Develop a long L* optics to evaluate optical aberrations.**
- **Try to squeeze βx* for a better understanding of the optics.**

5. ATF2 stabilization (FONT)

Findings & comments:

The ATF2 employs FONT (feedback on nanosecond timescale) with world record strip line BPM resolution ~ 0.2 μm, some 150 ns latency (that is about 1/4th of the ILC 554 ns bunch spacing), and the drive power equivalent to >300 nm at the ILC. The system and its operation is well described in peer-reviewed publications (PRAB). The double DoF system (two kickers, two BPMs) reduces the jitter by x4 (locally to ~40 nm; equivalent to ~1 nm at IP, limited by the BPM noise). The upstream IP FB system reduces observed intensity dependence of beam size by a factor of ~1.6. Additional beam time would allow: optimization of FB system performance and study of long term beam trajectory control. There is a very strong international team in place that effectively carries out FONT research at the ATF2.

Recommendations:

- **Give priority (and additional beam time) to allow optimization of the feedback system performance and detailed study of long-term beam trajectory control.**

6. ATF2 ultra-low beta optics

Findings & comments

Impressive experimental demonstration with optics 10x1 of a record beam size of 40 nm but the ultra low beta optics with 25x0.25 shows 50 nm beam size not in agreement with simulations that predict about 30 nm. The tuning of the beam sizes to 50 nm with the ultra-low optics, and also with the old 10x1 optics, has highlighted some difficulties in the beam size tuning, measurements and/or unknown effects.

Simulations show that much smaller beam sizes can be achieved with the studied optics, in this respect more understanding is needed in the FFS optics and beam sizes evolution to identify the relevant ingredients leading to this difference. Several studies have been carried out to address the discrepancies. Unstable conditions of the beam, weak fields, feedback, non-linearities and lastly the reduced dedicated beam time for tuning have been identified as possible sources that lead to the much larger final beam spot.

The goal of reaching the nominal ILC optics 4 mm x 100 μm should still be pursued together with a robust understanding of the scaling on the final beam spot with the optics used specially with much stronger aberrations (smaller βx).

The momentum bandwidth has shown no big chromatic errors for off momentum dynamics. But something still limits the lower beam size reach. Octupole magnets are used to correct for higher order aberrations, but they should be more effective below 50 nm. This might be the reason why in measurements there was no evidence of their impact on the beam size.

Recommendations

- **Continue the exploration of the ultra-low beta optics and scaling of beam size with different optics with reduced βx value (larger aberrations).**
- **Improve stability of beam size measurements (IPBSM) to resolve beam sizes even below 40 nm.**
- **Explore the method with a longer L* optic to keep the beam size resolution.**
- **Small beam tuning (below 50 nm) with nominal optics should be demonstrate to possibly demonstrate the octupole effectiveness**

7. ATF2 future R&D

Findings & comments

The measured intensity dependence was roughly twice as strong as that for the simulation for the wakefield model for overall ATF2 beamline. The discrepancy is expected to be investigated in the operation over the next a few years. In particular, ATF/ATF2 in the ILC preparatory phase (2022-2026) will study a) long term stability of beam size and orbit at the ATF2 interaction point and b) long term stability of fast injection and extraction systems. The next phase ("ATF3") would hence provide the opportunity to attract additional resources from overseas collaborating institutes to deliver the program described above in a modular and sensibly time ordered fashion.

Overhaul and upgrade of the existing ATF2 beamline to model more accurately the energy-scaled ILC final focus system will include: a) Some magnets with poor magnetic field qualities will be replaced. b) Wakefield sources will be removed. c) ILC style diagnostic devices (BPMs etc.) will be installed. d) IP BSM laser will be upgraded to provide more stable, long term operations.

Later - beam studies in ILC construction period might require SC final focus QD0/QF1 magnet system to be installed at the ATF3 IP. ATF can also serve as both a test stand for key accelerator components and a platform for long term stability tests with beam: a) Superconducting device test bench; b) Final doublet (He flow vibrations); c) Crab cavity (Fermilab design 9-cell 3.9 GHz); d) Helical undulator for polarized positron source; e) and as permanent magnet test bench and polarized electron source test bench. The committee would like to point out that some other facility having cryogenics capabilities might better serve the purpose than ATF.

Recommendations:

- **Develop a detailed resource-loaded plan for the ILC-related studies in the ILC preparatory period, under the given limited operation budget, availability of experts, and beam operation time.**
- **Consider an opportunity to carry out superconducting elements (magnets and cavities) in some other facility with existing cryogenic capability.**

8. R&D other than LC

Findings and comments

The ATF team started the effort to survey the potential applications of the ATF other than ILC. Availability of a high quality and stable electron beam from ATF and its flexible machine operation schedule attract research groups in various fields. They have already received several proposals, although currently all are from domestic groups. The proposed R&D’s for the existing accelerator facilities in KEK (KEKB, J-PARC and Photon Factory) may be difficult to carry out at their own facility (mainly because of the operation schedule) but relatively easy at ATF. Some of the proposals would utilize the ultra-low vertical emittance of ATF beam, which is its unique nature. However, others would not.

For those R&D’s, additional devices would be implemented in various parts of the facility. The proposers would prepare their devices by their own, and ATF would provide electron beams. It is not clear whether the proposers would financially support the accelerator operation, but they should contribute the running cost, depending on the scale.

The committee has some concern whether the proposed subjects can coexist with R&D's for ILC, for example, some devices newly implemented may become a new impedance source.
It should be noted that other test facilities in KEK, such as STF or cERL, may be able to provide similar research environments for such proposals.

ATF is specialized in producing a flat beam with ultra-low vertical emittance. However, only a few proposed applications utilize this unique beam property. In the long term, it should explore a possibility to convert ATF to a more flexible and multi-purpose facility, such as adding a capability of a storage ring. It may be possible to realize a users' facility, such as a gamma-ray source or a diffraction-limited vacuum ultraviolet synchrotron light source, in which higher average beam current is essentially important.

Recommendations

- **Continue the effort on collecting research subjects other than ILC. The calling for proposals should be open and international.**
- **Try to find more applications which require the flatness of the beam at ATF.**
- **Start to think about a possibility to convert ATF to a flexible, multi-purpose facility as exploring the possibility to collaborate with other facilities, institutes or universities.**

9. Operational status and concerns

Findings & comments

The committee understands the difficult situation of the facility in the past 10 years. It is easy to imagine that, after 25 year operation, each component is getting aged and it becomes more difficult to procure replacement parts for them. It was regrettable to find that it became hard to keep the stability and the quality of the ATF beam. The ATF team expects that the situation would improve when the main ILC preparatory phase begins. They propose replacements of some of the subsystems, mainly aiming to ensure stable operation in the pre-preparatory phase. They have not shown improvements or developments associated with such replacements. Concerning the limitation on the human resource, it is also easy to imagine that the operation and maintenance of the facility would become difficult if they cannot keep the present manpower.

It is obvious that ATF cannot continue their activity without the financial support from KEK. On the other hand, the budget of KEK is also limited. We note that KEK has electron accelerator test facilities, STF and cERL (compact energy recovery linac) other than ATF.

Recommendation

- **Consider merging activities at ATF, STF, cERL, etc., and flexibly use the limited budget and manpower.**
- **Continue the efforts to get funds from outside of KEK.**
- **Pay full attention by the entire KEK members to avoid repeating accidents.**

Review Committee

Masahiro Katoh	Hiroshima U.
Katsunobu Oide (chair)	KEK/CERN
Tatiana Pieloni	EPFL
Vladimir Shiltsev	FNAL
Zhentang Zhao	SARI

Scientific Secretaries (KEK):
Shinichiro Michizono
Nobuhiro Terunuma
Seiya Yamaguchi

Secretary (KEK):
Gin Ishikawa