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UPDATED POWER ESTIMATE FOR ILC-250

The estimate of the total power consumption of the ILC in its 250GeV configuration and possible later upgrades in energy and luminosity is updated to reflect design changes since the TDR.

RATIONALE

Power consumption is a key performance parameter of the accelerator. An up-to-date calculation is needed to assess the performance, also in comparison to other projects.

SCOPE: WHOLE ILC

VALUE/SCHEDULE IMPACT

Operation cost estimates depend on power consumption.

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Attachments:

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IMPLEMENTATION PLAN

Can be left blank for first submission.

Concerned Parties (Work Packages, Coordinators, Suppliers etc.)

WF/Area	

Affected documents

EDMS ID	Title	Remark
D00000000965055	ILC AC power estimate summary	

ATTACHEMENT 1

Introduction

We present here update calculations for the ILC, in its baseline 250GeV configuration with a short tunnel, as proposed in Japan, and for possible upgrades in luminosity and energy.
For each configuration, power estimates are given: one based on performance figures as laid out in the TDR [2] ("baseline"), and one based on the assumption of successful R&D concerning cavity and klystron performance ("with R&D").

1.1. Accelerator Configuration

1.1.1 ILC-250 baseline configuration

We calculate the power consumption of the ILC with the following features for the baseline 250GeV configuration, as set out in the ILC Machine Staging Report [1] as option A:

- The accelerator is built with the minimum main linac tunnel length necessary for 250GeV operation, taking into account the DR timing constraint for an undulator positron source.
- Positrons are produced by an undulator source, with a 231m long helical undulator, from the 125GeV electron beam.
- The RF scheme is the "Distributed Klystron System" (DKS) of the TDR.
- One electron and positron damping ring is built.
- The machine operates with 1312 bunches per pulse at 554ns bunch spacing (5.8mA beam current), at 5Hz repetition frequency.

This configuration is denoted as ILC250.

1.1.2 Luminosity upgrade: double the number of bunches

The luminosity of the ILC can be doubled by doubling the number of bunches to 2625.

This requires:

- Installation of 50% more modulators and klystrons in the Main Linacs (3 instead of 2 klystrons per short cryo string of 9 cryo-modules)
- The installation of a second positron damping ring to mitigate instabilities from electron clouds (this measure may be unnecessary if electron cloud effects can be controlled well enough)

- Installation of additional RF power in the damping rings, with correspondingly increased cyogenic power.
- An upgrade of the electron and positron sources, with increased power consumption in the 5GeV accelerators (no new klystrons are required).
- Increased RF and cryogenic power in the bunch compressors, but no new klystrons.

Nota bene, the cryogenic power requirements do not change significantly: Since the gradient and the RF pulse length are the same as in the baseline configuration, the dynamic heat losses in the cavities remain the same. Only the heat losses from input couplers and higher order mode (HOM) antennas increase.

This luminosity upgrade is considered for the 250 and the 500GeV machine configuration; the 1TeV machine is assumed to run at a high bunch number from the beginning.

1.1.3 Energy upgrade to 500 GeV

Two energy upgrade stages are considered, to 500GeV and 1TeV, as laid out in the TDR.

We consider a ILC500 machine mostly as described in the TDR, with the same two sets of assumptions for cavity and klystron performance as at ILC250, and the same 1312 bunches per pulse, and one positron damping ring.

This configuration would be a natural choice if the ILC250 were to be upgraded in energy without an intermediate luminosity upgrade.

In addition, we consider a 500GeV machine running at 2625bunches per pulse, with two positron damping rings. This configuration could be realised as a luminosity upgrade of an initial 500GeV machine or could directly follow a 250GeV machine that was already upgraded in luminosity.

1.1.4 Operating the 500GeV machine at 250GeV and 10Hz

As laid out in Ref. [3], a 500GeV machine, when operated at lower CM energy and Main Linac gradient, has surplus croyogenic cooling capacity that can be utilized to increase the repetition rate. The damping rings are designed to allow operation at 10Hz repetition rate, by the installation of additional damping wigglers to reduce the damping tine, with correspondingly increased RF power to replenish the increased synchrotron radiation loss.
Here we calculate the power consumption for a 500GeV machine that would operate at 250GeV with 2625 bunches per pulse and a 10Hz repetition rate, giving four times the baseline luminosity.

1.1.5 Energy upgrade for 1TeV

An energy upgrade to 1 TeV is assumed to follow only after extended operation at 250 and 500GeV. The TESLA shape cavities employed at the ILC have already been demonstrated to deliver gradients of 49MV/m [4], 1.3GHz cavities with shapes optimized for maximum gradient have reached 59MV/m [5].
Therefore, the TDR assumes that the additional linacs installed to bring the overall energy to 1TeV would operate at

- cavity gradients of 45MV/m, with a quality factor $Q_0=1.0 \cdot 10^{10}$.
- 2450 bunches per pulse, with a 4Hz repetition rate.

In the TDR, the number of bunches per pulse and the repetition rate were reduced compared to the corresponding values of 2625 and 5Hz of the 500GeV machine in order to limit the total energy consumption of the machine to 300MW.

1.2. SRF and Cost Reduction R&D

The baseline performance of those key components that most affect the power consumption assumed in the TDR are:

- Cavities reach a mean gradient of 31.5MV/m in beam operation, at a quality factor $Q_0=1.0 \cdot 10^{10}$.
- Klystrons operate at a 65% efficiency

Under the assumption that current and future cost reduction R&D is successful, we define a second parameter set (“with R&D”) based on the assumption that

- cavities reach a mean gradient of 35.0 MV/m in beam operation, at a quality factor $Q_0=1.6 \cdot 10^{10}$, and
- Klystrons operate at 80% efficiency.

For the linac portion installed for 1TeV upgrade, we assume a gradient of 45MV/m in both cases, but with different values for Q_0 and klystron efficiency.

Method

The Power estimate results from a scaling of the power estimate as presented in the TDR; the scaling relations were developed and verified during the TDR preparation.

2.1. Main Linac RF power

The main linac RF power is calculated from the RF power transferred to the beam, assuming perfect matching, plus the power needed to fill the cavities, divided by the wall plug to beam efficiency of 43%. This efficiency includes the klystron operating efficiency of 65%, losses in the modulators and waveguides and overhead from variations in cavity gradients.
For the TDR, the ML RF power amounts to 52.1MW (32% of the total 163.8MW).

2.2. Main Linac Cryo power

The main linac cryogenic power is calculated by scaling the various contributions of cryogenic losses. Five kinds of cryo losses with different scaling behaviour are considered:

- Static losses, proportional to the number of cryo modules
- Cavity wall losses, proportional to the squared gradient, the overall pulse length (including fill and decay times), and inversely proportional to Q0.
- Coupler losses, proportional to the total RF power
- Losses in HOM couplers, proportional to the squared bunch charge
- Losses from HOM in the cavity walls, proportional to the beam current

Cryogenic loads as evaluated in the TDR are scaled according to the relevant factor, based on the contributions of these loads to the overall cryogenic losses from the TDR.
In addition, a 10% margin has been added to the cryogenic power consumption to account for reduced efficiency for operation at non-optimal working points.
For the TDR, the ML cryo power amounts to 30MW (18% of the total power).

2.3. Sources

The contributions of the sources were adjusted for the increased number of bunches per pulse and higher repetition rate.

2.4. Damping Rings

The power consumption of the damping rings was evaluated with the same method as in the TDR, to account for higher RF power resulting from the larger beam currents in the DR for 2625 bunches operation.

For a 10Hz repetition rate, additional wigglers have to be installed in the damping rings for lower damping times, leading to further increased RF power demands.

2.5. BDS and Interaction Region

Power estimates for BDS and interaction region are taken from the TDR.

2.6. Main Campus

A 2.7MW estimate for the power consumption of the main campus has been added.

2.7. General Margin

An overall margin of 3% has been added to account for further power demands not included in the other terms.

Results

The complete updated power estimate is detailed in Ref. 6.
The main result is given here for the following configurations:

- 500 TDR: Machine with 500GeV centre-of-mass energy, as detailed in the TDR
- 250-A: 250GeV machine, option A (baseline configuration)
- 250-A’: 250GeV machine, option A’, assuming successful R&D
- 250-A, Lx2: 250GeV machine, running with twice the number of bunches per pulse (after luminosity upgrade)
- 500@250: 500GeV machine, running with twice the number of bunches (after luminosity upgrade), operating at 250GeV centre-of-mass energy with 10Hz
- 500 Lx2: 500GeV machine, running with twice the number of bunches per pulse (after luminosity upgrade)

	500 TDR	**250-A**	**250-A' w/R&D**	**250-A Lx2**	**500@250**	**500 Lx2**
Rep-Rate / Hz	5	5	5	5	10	5
Bunches / Pulse	1312	1312	1312	2625	2625	2625
Lumi / 10^{34}	1.8	1.35	1.35	2.7	5.4	3.6
Gradient / MV/m	31.5	31.5	35	31.5	14.7	31.5
Q_0/1E10	1.0	1.0	1.6	1.0	1.0	1.0
ML E-gain / GeV	470	220	220	220	220	470
ML Power / MW	104.1	49.4	48.5	62.6	103.0	133.8
e- Src / MW	4.87	5.6	4.8	5.6	5.6	5.6
e+ Src / MW	9.32	10.2	9.6	10.2	10.2	10.2
DR / MW	15.72	13.6	13.6	21.5	30.3	21.5
RTML / MW	10.40	10.4	8.4	13.9	13.9	13.9
BDS / MW	12.38	9.3	9.3	9.3	9.3	12.4
Dumps / MW	1.21	1.2	1.2	1.2	1.2	1.2
IR / MW	5.76	5.8	5.8	5.8	5.8	5.8
Campus / MW		2.7	2.7	2.7	2.7	2.7
Gen. Margin/MW		3.3	3.1	4.0	5.4	6.2
Total	163.8	111.5	106.9	136.7	184.5	213.2

References

1. Lyn Evans and Shinichiro Michizono [LCC]: *The International Linear Collider machine staging report.* arXiv:1711.00568 (2017).
2. C. Adolphsen et al.: The International Linear Collider Technical Design Report – Volume 3.II: Accelerator Baseline Design. arXiv:1306.6328 (2013).
3. M. Harrison, M. Ross, N. Walker: *Luminosity upgrades for the ILC.* arXiv:1308:3726 (2013).

4. A. Grassellino et al.: Accelerating fields up to 49MV/m in TESLA-shape superconducting niobium cavities via 75°C vacuum bake. arXiv:1806.09824 (2018).
5. G.V. Evremeev et al.: High gradient studies for ILC with single-cell re-entrant shape and elliptical shape cavities made of fine-grain and large-grain niobium. Proc. IPAC 2007, p. 2337 (WEPM006), DOI: 10.1109/PAC.2007.4441242 (2007).
6. N.J. Walker et al.: ILC AC power estimate summary. EDMS D00000000965055.