CONSIDERATION OF CONTROL SYSTEM ARCHITECTURES FOR NEXT-GENERATION LINEAR COLLIDERS AND KAON FACTORIES

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Abstract

This paper analyses requirements for control of next-generation linear colliders and Kaon factories and suggests possible architectures of the control systems for these accelerators.

1. Introduction

The scale, space, size and complexity of linear colliders (LCs) and Kaon factories (KFs) are beyond those of existing machines and require high-level next-generation control systems. Although many key techniques are yet under R & D stage, we can identify some control features of LCs and KFs, analyse requirements for controls and suggests possible system architectures for LCs and KFs.

2. Features of linear colliders from the view-point of controls

Four institutes announced their intention to build linear colliders. Their fundamental parameters are listed in the following table (1).

Institute	Name of LC	Energy	MeV/m	Total Length
SLAC[†]	SLC	.05+.05 TeV	17	3.8 km
CERN	CLIC	1 + 1	80	12.5 + 12.5
KEK	JLC	0.5 + 0.5	100	5.0 + 5.0
SLAC	TLC	0.5 + 0.5	186	3.35 + 3.35
INP	VLEPP	1 + 1	100	10.0 + 10.0

[†] the current unique existing linear collider

We identify the first feature of the LC:

1. LC has a linear topology with the total length of 7 to 25 km. It consists of three main sections: an electron linac, a final focus and intersection area, and a positron linac.

   Electron and positron linacs have the same accelerating structures: a 1.5-2.0 GeV S-band linac, a 1.5-2.0 GeV damping ring, several compressors and a 0.5-1.0 TeV X-band linac.

According to the reference (2), X-band klystrons under development have the following specifications:

Type of klystron	Freq.	Max.	Remark
Conventional klystron	11.4 GHZ	100 MW	SLAC
Relativitic klystron	11.4 GHZ	200 MW	LLNL,SLAC
Cluster klystron		750 MW	
Sheet beam klystron	11.4 GHZ	100 MW	

We assume that the unit power per X-band klystron used for practical LCs after 5 years is between 100 and 400 MW (with magnetic pulse compressor); total number of X-band klystrons in LC is equal to:
(peak MW requirement/m) x (total length of accelerator in meter) divide by (unit power per klystron).
Thus we have:

Name	MW/m	Length	Total MW	Qyt(100)	Qty(400)
TLC	586	2x2.7 km	2x1587000	2x15870	2x3968
JLC	242	2x5.0 km	2x1210000	2x12000	2x3000

Remark: Qyt(100)----quantity for 100 MW/klystron
Qyt(400)----quantity for 400 MW/klystron

Here we obtain the second specific feature of LC:

2. Total number of klystrons in X-band sections is the order of 10,000; this is hundred times as many as that in SLC and thousand times as many as that for KEK 2.5 GeV linac.

In LCs beam position must be controlled within a few micron with respect to accelerating structures in order not to cause beam break-up due to transverse wakefields. Therefore, various feedback control loops must be used (3).

Slow feedback is used for stabilizing the beam angle, position, energy and energy spectrum at the entry of beam accelerating structure, for timing of kicker magnets, for compensation phase change in drive line and for active alignment. Fast feedback are used for wakefields suppression, for energy stabilization, for RF and amplitude stabilization in linacs and for beam damping in damping rings. Thus we obtain the third control feature of LCs:

3. There are hundreds of fast or slow, local or global feedback control loops in linacs, damping rings and the final focus area. The control system must provide the necessary conditions and environment for the feedback.

Linear collider is a pulse machine and this leads to the fourth feature:

4. LC control system must support real-time data acquisition, transfer and processing.

To obtain the beam size of a few nm at the collision point is a great challenge to control systems of LCs. Therefore, control system for LC must provide flexible and easy to use man machine interactive devices and enough computing power. This leads to the fifth feature of LC:

5. Control system must provide flexible and easy to use interactive environment and enough computing power for commissioning and tuning of the final focus system.

These are the main five control specific features involved in the linear collider machines. There are also many important systems such as a precision timing system, a constant temperature water system, etc. These need careful design, too.

3. Features of Kaon factories from the veiw-point of controls

Four institutions in the world are proposing Kaon factories (4). All of these KFs consist of a pipe line connection of sub-accelerators.

Instit.	Name	Cascade sub-accelerator sequence
TRIUMP	TKF	450 MeV cyclotron --->accumulator
		--->3 GeV booster-------->collector
		--->30 GeV driver-------->30 GeV extender
KEK	JHF	1 GeV Proton linac--->1GeV compressor
		--->4-8 GeV booster------>30-50 GeV ring
SIN	EHF	1.2 GeV P-linac------>9 GeV booster
		--->30 GeV stretcher ring
LAMPF	AHF	800 MeV P-linac------>1.2 GeV linac
		--->2 GeV compressor----->15 GeV booster
		--->60 GeV main ring

The first feature of Kaon factory control system is the following:

1. Kaon Factory consists of a cascade connection of sub-accelerators with dedicated functions. Number of sub-accelerator is 3 to 6.

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```
            --------  ---------  --------   --------
            |Common|  |Global |  |Final |   | LC   |
            |Resour|  | LC    |  |Focus |   |Info. |
            | -ce  |  |Console|  |Comput|   |Center|
            --------  ---------  --------   --------
 FDDI main      |         |          |          |
 backbone   ***************************************
 segment               |               |
                    --------        --------
                    |Bridge|        |Bridge|
 FDDI               --------        -------- FDDI
 e- IBB segment        |               | e+ IBB segment
+++++++++++++++++++++++++++        +++++++++++++++++++
  |        |        |              |       |       |
 ----    -----    ----- Multi     -----   ----    ----
 |BR|    |BR |    |MFR| Port      |MFR|   |BR|    |BR|
 ----    -----    ----- F.O.      -----   ----    ----
  ^        ^       |||  Repeater   |       |       |
  |        |       |||            ( the same.as e-
  | TDM    | . . . |||                   symmetry)
  v        v       |||-----------------------------
 ----    ----      ||----------------------     |
 |BR|    |BR|      |---------------     |       |
 ----    ----                     |      |       |
  |        |--------             ----   ----    ----
  |               |     . . .    |BL|   |BL|    |BL|
  |               |              ----   ----    -----
  |               |               |      |       |
 sssssss      ddddddddd  xxx    xxxxxx xxxxxx  xxxxxx
  SS for       SS for    SS for X-band ; total X-band
  S-band       Damp ring         divide to several SS
```

Fig 1. Internetworking FDDI system complex

Solution 2: Symmetrical dual LAN complex

Here we suggest another system architecture for LCs. We use the same internetworking implementation with a different topological arrangement to form a symmetrical dual LAN as shown in Fig 2:

```
                              |--WS     WS---|   Location
WS--workstation               |              |   at MCC
C---Console           ----    |--C       C---|  ----
CR--Common            |BL|--|                |-|BL|-|
    Resource          ----    |--CR     CR---|  ----  |
O---others               |    |              |        |
                         |   ---O        O---|        |
 e- LAN                  |   --------                 |    e+ LAN
+++++++++++++++++++++++++|Bridge|+++++++++++++++++++++++
  |      |       |       |   --------      |     |      |     |
----   -----   -----   ----              ----  -----  -----  ----
|RB    |MFR|..|MFR|    |BL|              |BL|  |MFR|  |MFR|  |RB|
----   -----   -----   ----              ----  -----  -----  ----
  |      |       |       |                 |     |      |     |
  |      |       |     o*****************o     |      |     |
  |      |  . .  |          Final              |      |     |
  |      |       |          focus              |      |     |
----   ----    ----         segment          ----   ----   ----
|RB|   |LB|    |LB|                          |LB|   |LB|   |RB|
----   ----    ----                          ----   ----   ----
  |      |  . .  |                             |      |      |
ssss ddd xxx xxx xxx                   xxx   xxx xxx ddd sss

 Section segment                          Section segment
```

FIG.2 : A symmetrical dual LAN complex for LC control

The specific features inside this architecture are:

1. Absolute symmetry for electron and positron. The whole control system is composed of two identical control sub-systems for electron and positron sections.
2. Each control sub-system consists of a LAN complex, the basic arrangement is the same as the previous proposal to keep most of the merits. This system architecture is more flat: electron linac communicates with positron linac through one bridge.
3. All the workstation, consoles, common resources are installed in the same MCC location. In ordinary, there are two sets of common resources, one for each linac separately, as an integral MCC for operator.

In case of the failure of one set, the other set can be used as the whole machine control; there is a hot-standby function inside, thus increasing the reliability.

4. For the final focus region, we use one dedicated segment which are linked to both sides via a local bridge. Such an arrangement is easy to process the final focus problem.
5. FDDI or token ring still can be the protocol standards for these two LANs. The problems involved in this architecture are the same as previous one.

6. Possible system architecture for KFs

We propose a multi-peer control system architecture for KFs as shown in Fig.3.

```
    ----------       ----------  -------------------
    |Control |       | Control|  | Common Resource |
    |Console | .   . | Console|  | Facility        |
    ----|-----       ----|-----  ----------|--------
  ------|----------------|-----------------|-------
  |  LAN 1    MCC and common resource LAN         |
  ----|--------|-------|-------------------|------
    --|--    --|--   --|--               --|--
    |B/C|    |B/C|   |B/C|  . . . .      |B/C|
    --|--    --|--   --|--               --|--
  ----|--- ----|--- ---|----            ---|----
  | Unit | | Unit | | Unit |            | Unit |
  | CTL  | | CTL  | | CTL  | . . . .    | CTL  |
  | No.1 | | No.2 | | No.3 |            | No.n |
  -------- -------- --------            ---------
```

Fig,3: Multi-peer LAN complex for KFs

The main features are:

1. Decompose integral control system to several unit control systems, each of which corresponds to one subaccelerator.
2. All unit control systems are linked to MCC-LAN via a bridge or convertor. Each control system has an indentical logical position. We, therefore, call this multi-peer LAN.
3. We can use any protocol and standard for LAN within each control system. If we use different protocols from that of MCC-LAN, we should use convertors.
4. For MCC-LAN, we can use any ISO 8802 standards. Among 802.3/4/5 standards, Ethernet may be the cheapest and is widely supported by commercial products.
5. Due to high rediation level of Kaon factories, optical-fiber cables can not be used.

In some Kaon factories two sub-accelerators (as booster and accumulator, driver and extender in TRIUMF Kaon Factory) have the same size and are installed in the same tunnel. In this case decomposition based on function may be more reasonable. For example one unit control system are for all the magnet power supplies of both sub-accelerators, while other unit control system for RF equipment of both machines as arranged in the control system of TRIUMF Kaon Factory. It can be a mixture, i.e. some unit control systems are dedicated for one sub-accelerator and some are for same functional devices of several sub-accelerators.

7. Reference

1. Ronald D.Ruth, "Report on the international workshop on next generation Linear Colliders", SLAC-PUB-4975, May, 1989
2. P.B.Wilson,"SLAC R & D toward a TeV Linear Collider" SLAC-PUB-3769, October, 1988
3. K.A.Thompson et al, "Feedback System in the SLC" SLAC-PUB-4217, Feb. 1987
4. M.K.Craddock, "Kaon Factory in 1987", IEEE NS-34, No.6, 819-823, March, 1987
5. J.Joosten, "Bridged Ethernets at CERN and Beyond" CERN Data Handling Division, DD/88/7, April, 1988

The dimension and size of Kaon factory machines are summarized in the following table.

Instit.	Name	Linac Length	Dia.of Max.Ring	Max.Dis.
TRUIMP	TKF	no linac	170 meter	500 m
KEK	JHF	500 meter	< 200 meter	1.5 km
SIN	EHF	400 meter	about 320 m	500 m
LAMPF	AHF	1 km		

Sizes of the unit sub-accelerators are less than 1 km, and all of the sub-accelerators are concentrated in a semi-square area with maximum length of 1-2 km. Here we obtain the second feature:

2. Controlled equipment for KF locates within a semi-square area of 1-2 km.

In routine operation each sub-accelerator is operated independently and signal coupling are limited between two adjacent sub-accelerators. This leads to the third feature.

3. Entire KF control system consists of several sub-control systems, each of which is for one sub-accelerator and can be operated independently.

All sub-accelerators are combined into a Kaon factory complex, which needs a centralized control center. The fourth feature of KF control is:

4. In spite of the relatively independent nature of sub-accelerators, KF needs one centralized room for common resource and operation.

In order to obtain maximum beam intensity, these KFs should use up-to-date accelerator techniques to minimize beam losses and induced radio-activity. The beam current and beam losses should be carefully monitored. When beam becomes unstable by components failure or power excursions, it is necessary to dump the entire beam within one turn. This specfic and unique feature leads to the fifth feature.

5. Control system arrangement must provide facilities to monitor, control and process to avoid beam losses with enough real time response.

The above five features constitutes the necessary control conditions for Kaon factories.

4. Required specification of system architecture for LC control

Corresponding to the five specific features of LC control system, the control system architecture for LC must have the following characteristics:

1. Vast size and scale require an internetworking LAN complex, i.e. a hierarchy of multi-layer network, rather than a single all-encompassing highway. At the same time we should limit the levels of hierarchy to minimum, keeping the advantage of high effectivity of flat topology as much as possible.
2. The network should cover and span all areas of machine, i.e. 10 to 20 km or more.
3. The control network should provide the transfer of different kinds of information: control commands and replies, global timing signals, documentation information (which is very useful for maintenance and trouble shooting in such a huge machine), audio and video signals and global fast feedback signals.
4. Network must have a high EMI emmunity, ground isolation and EMI isolation.
5. Network should have an extra-huge signal capacity; it should carry several millions of signals and still must guarantee the required real-time response.
6. System network must have extra-reliability; it must be easy to commission, operate and maintain.

5. Possible system architectures for LC controls

It is very diffcult to have a system architecture which satisfies all of the above requirements. Here we suggest two possible solutions on the basis of progress in the internetworking technology (5).

Solution 1:Internetworking FDDI network complex

Main consideration are the following:

1. Using modularity methodology, we decompose the entire system network into several segments:
    - Main backbone segment----------final focus area, central control room and common resource.
    - Intermediate backbone segment (IBB)------electron and positron accelerating sections.
    - Section segments(SS)-----------S-band linac, damping ring and X-band linac sections.
2. Using TDM or FDM method as the communication infrastructure in intermediate backbone segment.
3. Using different interconnect network devices to link between different levels of segments. Example of these devices are (5):

MAC-Bridge :interconnect between two LAN segments with the same protocol at the medium access level.

Local Bridge(BL) :interconnect the backbone to a local segment within a short distance.

Remote Bridge(BR):interconnect the backbone to a local segment over a long distance using the TDM link method.

Gateway :interconnect segments with the same protocol.

Convertor :interconnect two LAN segments with different protocol.

Using these interconnecting methods, each segment keeps its independent performance; vast local traffic does not cross the bridge; segment to segment communication is realized at the same hierarchical level, keeping a high efficiency.

4. Taking the EMI effect into account, it is better to use optical fiber cables as the main link medium. The star-shaped topology is easy to manage and maintain. These leads us to use star-shaped multi-port optical fiber repeaters at the section segments level.
5. In principle the throughput on the backbone segment must be highest. Though it is difficult to estimate required value, anyway 10-100 Mbit/s may be enough. Throughput of 1-2 Mbit/s on local segments may be enough.
6. Date of construction of these LCs will be after 1992. Therefore, we should take development of high performance LANs into account for the future control system architectures.

One example is shown in Fig 1. We adopt the FDDI protocol for the main backbone and intermediate backbones. FDDI has a speed of 100 Mb/s and can span 200 km with a delay of 2 ms for 1000 node. It is an ideal LAN for control requirement of LC. In addition reliability and high anti-EMI capability of FDDI are advantangeous. Since both main and intermediate backbones use the same FDDI protocols, they can be interconnected by a MAC-bridge.

We should arrange one section segment(SS) for S-band section, one SS for the damping ring and compressors, and several SSs for the X-band linacs. We can use different methods for interconnecting the IBB segment and the SS segments: TDM remote link, star-shaped multi-port optical fiber repeater or local link. Type of interconnecting devices will depend upon the selected protocol of the SSs. If it is different with FDDI, we should use a "convertor" for a "bridge". It is worthwhile to consider to use the Ethernet at SS levels.

To satisfy the 3rd and 4th control requirments of LC, we will use some 32 bit multi-microprocessors assemblies (as VME, etc.) used for feedback and beam diagnostics. These assemblies are linked to the backbone segment and transfer the feedback control signals to the damping ring area via the special feedback channel inside the multi-channel backbone segment. It provide a fast environment for feedback and beam diagnostics.

To satisfy the 5th control feature of LC, people can connect workstations and super-minicomputers to the main backbone.