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THE EVOLUTION OF LEP SEPARATOR CONTROLS IN THE WAKE OF THE BUNCH TRAIN PROJECT

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M. Laffin, M. Lamont, V. Mertens and H. Verhagen

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I. INTRODUCTION

Since its initial commissioning in 1989 the electrostatic separator system [1] of LEP has undergone many modifications to help achieve higher luminosities. In 1991 and 1992 the "Pretzel" separator system [2], consisting of 8 additional tanks recuperated from the SPS, came into operation, allowing to double the number of colliding e+e- bunches from 4 on 4 to 8 on 8. One year later, two "Trim Pretzel" separators were added [3], which permitted to adjust more precisely the orbits at the collision points, counterbalancing small imperfections of the machine, thus contributing significantly to the LEP record luminosities in 1994. An additional test separator, called "TAZ", was installed in 1992 to allow measurements of separator performance under various beam and high voltage conditions [4, 5].

After these evolutionary steps, the control of the overall separator configuration was in a very inhomogeneous state for various reasons: the upgrade programmes coincided with other important projects; the resources were limited; the preparation time was generally very short including the step-wise realisation of the projects through test phases; and the global accelerator control system was undergoing a major rejuvenation [6] influencing the choice of hardware and software products.

Whereas the original separator control system [7] was very comprehensive, fully specified prior to commissioning and quite stable over the first few years of operation, ad-hoc solutions had to be adopted for most of its extensions.

The control of the original separators used G-64 type equipment controllers with software written in Pascal under Flex, XENIX PCs as interfaces to the global accelerator network (Token Ring) and application software running on Apollos using "Dialogue" for the implementation of the user interface. A very complete and user-friendly piquet software was available for expert actions and backup solution, written in C, running on the XENIX PCs. A disadvantage, in retrospect, was that it was entirely hard-coded, therefore specific and not easy to adapt, and that for I/O it made heavy use of CGI (Computer Graphics Interface), a standard which was not available on the front-end computers introduced later for LEP.

In contrast the control of the Pretzel separators [8] re-used the old SPS type electronics recuperated together with the tanks themselves from the SPS. A VME system running OS-9 and connected to an Ethernet served as process controller. Due to manpower and time limitations no proper application software was written; instead a piquet program based on ASCII menus was used for the control of the system. Since this system contained no equipment controllers the voltage tracking of the Pretzel separators during LEP energy ramping was completely controlled from software in the OS-9 system, in contrast to the original separators where this was performed in the individual equipment controllers.

The Trim Pretzel separators, which came into operation in 1993, used newly developed equipment controllers [9], for the first time largely based on industrial off-the-shelf components [10]. Interfacing to the global control system was achieved using industrial PCs running LynxOS; the operating system meanwhile adopted as standard operating system for front-end applications in the SPS/LEP control system [6]. A dedicated application software was made available, based on the recommended "Xsl" environment [11] for X Window based application programs. All control algorithms, the link between the equipment and the user interface as well as all surveillance and diagnostics software was implemented in the framework of the TS Toolkit [12, 13, 14] which had been developed in the years 1991-93 and which was already being used in other applications, e.g. [15]. This meant at least that the Trim Pretzel control system could be rather quickly commissioned, without writing any specific conventional code.

Whereas each of these systems was commissioned in time and fulfilled its role satisfactorily, this rather ramshackle conglomerate of individual solutions meant that modifications, of which there where many over the years, were very time consuming, that nobody understood the details of all systems in full, and that the overall system was not easy to handle or debug due to the different user interfaces, control and diagnostics facilities. The rapid succession of new projects and the difficult manpower situation also made any significant improvement of this situation basically impossible.

This was the situation in summer 1994 when it was decided to introduce the LEP bunch train scheme [16, 17, 18] for 1995 to push luminosities even higher, particularly in view of the future running of LEP at W-pair production energies. The Pretzel scheme would be given up at the same time, rendering the Pretzel and Trim Pretzel separators obsolete, together with their control system.

In the following, after recalling briefly the major changes to the separator equipment, the implications of the bunch train project on the existing separator control system will be discussed, outlining the efforts which have been undertaken at this occasion to render the overall system more homogeneous. The current state of the system will be presented, together with a description of the mode of operation. Finally, it will be indicated where more work is required to arrive at an even cleaner control system which would make operation, fault finding and modifications simpler and more efficient, with a number of years of separator operation still ahead.

II. MODIFICATIONS IN THE SEPARATOR CONFIGURATION

II.1. The Bunch Train Scheme

The bunch train scheme [16, 17, 18] consists in its present form of four trains of four bunches of e+ colliding with the same number of e- bunches. To avoid unwanted parasitic encounters close to the four experimental zones and at the non-experimental insertions, sufficiently long local orbit bumps must be created. The present separator positions and the e+e- trajectories are illustrated for an experimental zone and a non-experimental insertion in figures 1 and 2, respectively.

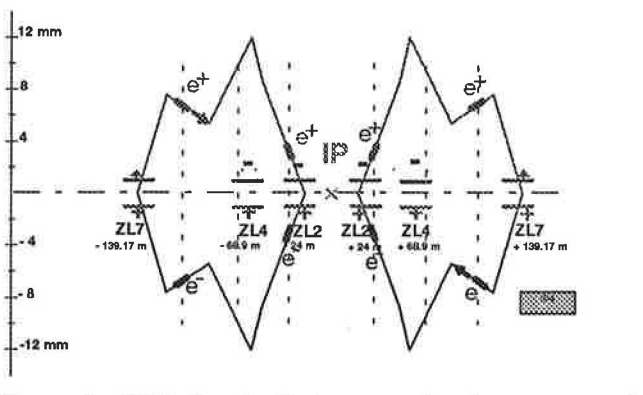

Figure 1: 1995 Bunch Train separator bumps around experimental zone 4, beams colliding.

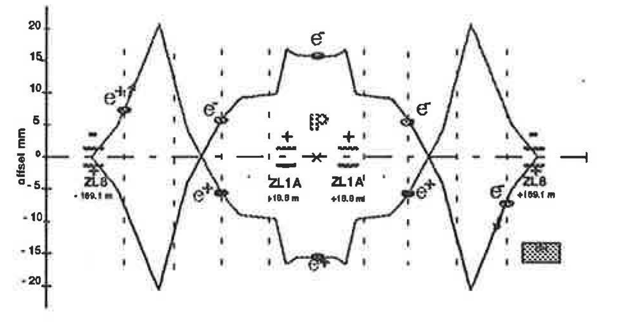

Figure 2: 1995 Bunch Train separator bumps in the non-experimental zone 1.

II.2. Modifications in the Separator Configuration

The essential changes in the separator configuration in the course of this project are listed below.

a. Vertical Separators (ZLx (x = 1A, 2, 4 and 8))

- The eight external separators in the non-experimental insertions (ZL8) were displaced further outwards close to the quadrupoles QL8 to account for the required long orbit bump.
- Due to the different way of operation (the voltages on the separator plates in the experimental insertions will not be decreased to zero to achieve collisions) the synchronous discharge switch [19], the vernier generators and the vernier switches have become obsolete (they remain physically in place, however, to serve for test purposes).

b. Bunch Train Separators (ZL7)

- Eight new vertical separators (ZL7) were installed close to the quadrupoles QS7 to provide the initial deflection for the separation bumps. These are powered by the HV generators used previously for the Pretzel scheme. One of the two electrodes remains connected to ground.

c. Pretzel Separators (ZX)

- These eight (horizontal) separators are no longer needed and will be removed in due course. As from 1996 they will be used for other purposes.

d. Trim Pretzel Separators (ZXT)

- These two tanks have also become obsolete and have been removed to serve later for other purposes.

e. Test Area for Separators (TAZ)

- This tank is still operational, but may be removed in 1996 for other test purposes.

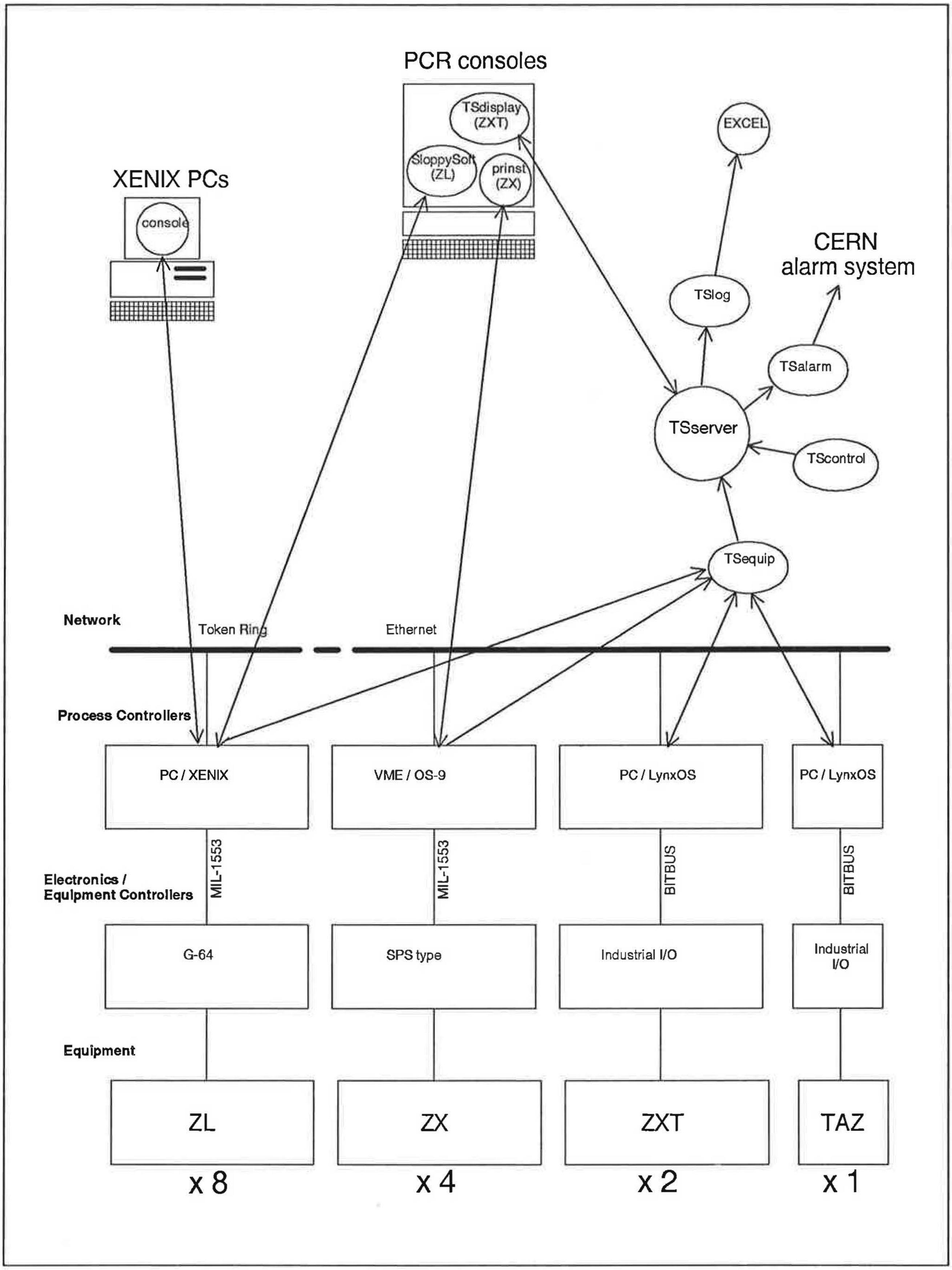

Figure 3: Overview of the separator controls environment before the shutdown 1994/95.

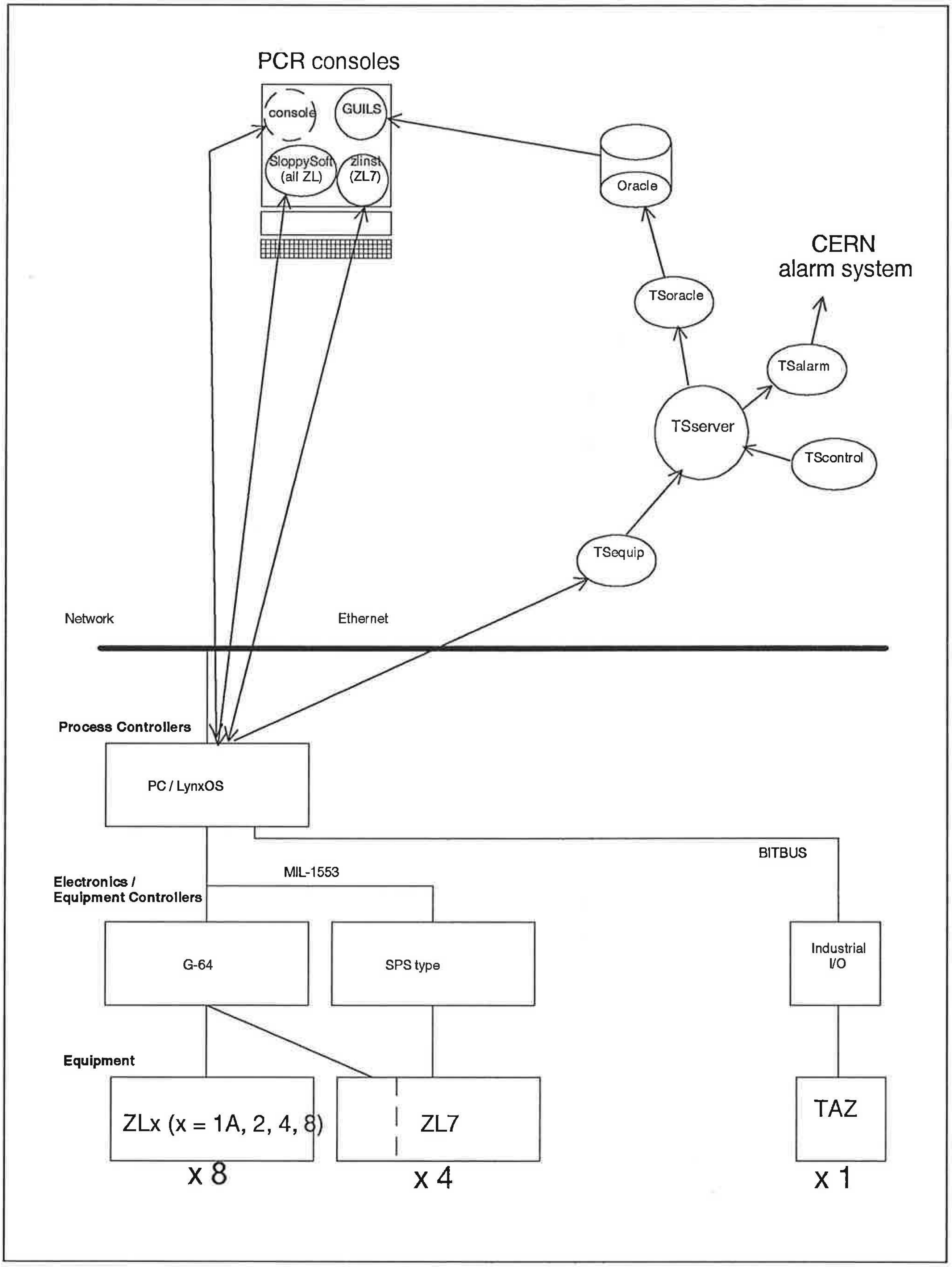

Figure 4: Overview of the separator controls environment after the shutdown 1994/95.

III. MODIFICATIONS IN THE SEPARATOR CONTROL SYSTEM

In the following, the major implications of the changes listed above will be discussed separately for the levels on which they occurred. Full details on other improvements and bug fixes carried out at the same time can be found in [20]. For illustration, figure 4 gives an overview of the current layout of the separator control system. For comparison the layout of the previous year is given in figure 3.

III.1. Equipment Electronics and Equipment Controllers

a. Electronics for Vertical Separators (ZLx (x = 1A, 2, 4 and 8))

- The equipment controllers for the synchronous discharge switch (ZLSWIT) and the vernier generators (ZLGENV) are now obsolete, but remain physically in place to serve for test purposes.

b. Electronics for Bunch Train Separators (ZL7)

- The control electronics for the HV generator, previously used for the Pretzel system and made from SPS-type electronics, has been replaced by an G-64 type equipment controller as used for the original ZL system. This has the advantage that the same software and procedures can be used for ramping (tables) which make the application software simpler.
- New electronics to control the additional cooling stations for the Bunch Train separators was developed.
- All other electronics previously used for the Pretzel system (spark counters, interlocks, ...) was re-used.
- New timing functions have been implemented in the controllers of the high voltage generators to allow small variations of the tension in a synchronous manner.

c. Electronics for Pretzel Separators (ZX)

- Since the Pretzel system became obsolete practically all electronics was re-used for the control of the Bunch Train separators (as described above).

d. Electronics for Trim Pretzel Separators (ZXT)

- As this system has also become obsolete all electronics have been dismantled.

e. Electronics for Test Area for Separators (TAZ)

- No changes.

f. Development Environment for Equipment Controllers

- The software development for the equipment controllers is being changed from the previous native Pascal compiler, running under Flex on the MC6809 development systems, to a new cross development environment with dedicated hardware and software running on a MC68000 microprocessor on a PC card [21, 22]. User access is through MS-Windows. Apart from reducing the efforts for file management, the development cycle time from editing to EPROM will decrease, from over one hour down to a few minutes.

III.2. Process Controllers (Front-End Computers)

As already mentioned in the introduction, three different types of operating system, running on two different kinds of computers, were used at this position: XENIX on 386 type office PCs, OS-9 on VME systems and LynxOS on 486 type industrial PCs. Since SL/CO plans to phase out XENIX from the LEP control system over the coming years and to replace it by LynxOS [23] it was decided to massively streamline this part of the control system. LynxOS PCs were installed in all interaction points which were not yet equipped in this way, and practically all equipment electronics was connected to them by means of the MIL-1553 field bus. All XENIX and OS-9 installations are still physically installed but will be dismantled as soon as the software previously running on them has been completely transferred, and the Pretzel separators physically removed.

Before this definite decision could be made, a number of important hardware and software issues, some of them quite new, had to be checked, tested or arranged for, with intensive mutual assistance between SL/BT and SL/CO (other implications of this decision, on other levels of the control system, are mentioned in the following chapters):

- The coexistence between MIL-1553 message mode (as used by the ZL equipment controllers) and command/response mode (as used by the SPS-type electronics) on the same bus was re-verified.
- The new PC-TG3 card [24] was used to receive the LEP timing directly in the LynxOS PC (rather than in one of the ZL equipment controllers, as before), together with its driver software [25] (an earlier idea to use the Ethernet broadcast mechanism for this purpose was given up due to insufficient reliability).
- A program running on the LynxOS PC was written [26] which initializes the PC-TG3 card, reads the timings and distributes them to the concerned equipment controllers via the field bus. The program also supervises the timing card and generates an alarm in case of malfunction of the timing system.
- The new MIL-1553 bus controller card [27] for PCs was used for the first time. The old card used in the XENIX 386 machine was, in the faster LynxOS 486, too limited in its transfer length.

- The new MIL-1553 driver for LynxOS PCs had to be developed.
- A program permitting to receive and view the broadcast messages emitted regularly by the ZL equipment controllers was developed, running under LynxOS.
- The co-existence of the new MIL-1553 bus controller, the PC-TG3 timing card and the BITBUS card on the same LynxOS PC had to be verified. BITBUS has already been used in the control of the Trim Pretzel separators and will again be used for new electronics for future separators.

In addition to these changes, X terminals were installed in all interaction points close to the equipment. This allows to use, directly and without restriction, all software written for global control, expert intervention and diagnostics for the separator systems also close to the equipment. This possibility did not exist before, requiring special software for access from areas without graphics capabilities. It should be noted at this occasion that the installation of X Window on the LynxOS PCs was not deemed desirable [28]. Besides all separator software, the X terminals obviously also allow the inspection and remote control of other installations under the responsibility of the SL/BT group while the experts are working on the separators.

After these modifications, all systems for which the SL/BT groups is responsible use the same kind of process controller, running LynxOS as unique operating system. Also, the user access facilities are now identical everywhere, allowing to obtain the same graphics output in all points, without the need to maintain different products. This opens up the way to reduce the number of maintained programs even further in the future.

III.3. Application Software

The term "application software" refers to all software used to control the separators in the context of LEP as a whole, and can be divided into a higher level part and a lower level part.

The lower level application software consists of the equipment server, which receives commands from the higher level via an Remote Procedure Call (RPC) and propagated them, up to last year, directly to the MIL-1553 driver, and the so called "black box" which hides equipment particularities from the higher levels of the application software (which might have large parts in common with other equipment).

The equipment server runs on the front-end computer. Therefore, when switching over from XENIX to LynxOS, this program had to be recompiled. It was then relinked with the NEQUIP library [29] (in its MEQUIP version) to use this new standard way of accessing equipment.

The black box was modified and extended to account for all equipment which has been added or removed, i.e. the equipment controllers for the synchronous discharge switch and the vernier generators, or the controller of the Bunch Train generator, respectively. Also a number of changes in the timing events had to be respected at this level, by removing commands that enabled and disabled certain events in the various equipment controllers, and adding others.

The higher level of the application software comprises, in the case of the vertical separators, the so-called "SloppySoft" environment [30], together with a graphical user interface. The SloppySoft framework uses an online ORACLE database to store all necessary control information and equipment settings. It is used for a large number of different LEP equipment. In case of the separators, the equipment is driven through "SuperActions" (tables of commands), sent to the black box. As with the black box itself, all SuperActions had to be updated according to the changes at the equipment controller level and the way the separators have to be operated now. For example, as the voltage on the separators in the non-experimental insertions is no longer switched off for collision by means of the synchronous discharge switch, new tables had to be implemented for the slow, but synchronous down-ramping of the generators. Also other procedures, like "Tune Collision" or "Tune Bump", are now triggered via timing events.

Both type of separators, the usual vertical separators and the new Bunch Train separators, are now controlled via this mechanism. At this level it was particularly advantageous that the control of the Bunch Train generator has been implemented with the same type of controller as already used in the vertical separators.

The user interface, implemented at the beginning of the LEP operation in 1989, has been kept so far. It has been developed using "Dialogue" and runs only on Apollo type workstations. Of course, the necessary modifications have been made to follow the evolution of the equipment. An alternative way of triggering high-level actions is the use of the LEPExec sequencer.

The software used to control the Pretzel separators up to last year, an ASCII menu based piquet program called "prinst", has been modified to serve for expert interventions on all Bunch Train electronics which is not covered by the high level application. It is now called "zlinst" and, due to its simple interface, available on virtually all platforms.

All software used to control and supervise the Trim Pretzel separators has been removed.

III.4. Expert Software

A large part of all necessary changes concerned this area, since it deals with the access to all equipment channels. Many detailed changes were applied to the ZL piquet program "console" [7] to account for the most important modifications in the separator equipment and the control system. It should be noted that this software, in spite of its monolithic structure and manpower-intensive maintenance, has been used since the start of LEP for many critical interventions, and is often used by the operators if the primary control programs fail for any reason, or for rapid in-depth diagnostics.

Like the application software, the expert software to date for the vertical separators used an individual client-server mechanism rather than SL-EQUIP. This was improved for the moment by compiling client and server into one program and linking the whole with the SL-EQUIP library.

As mentioned above, "console" uses heavily a set of graphics routines named "CGI" (Computer Graphics Interface) for all input/output, which is available on XENIX but unfortunately not on LynxOS. The possibility to write or subcontract the development of a CGI emulator under LynxOS has been discarded; it would be expensive and/or time-consuming, which anyway would not lead to a platform independent solution. To port the essential part of "console" to practically all platforms, it has been decided to use in the future the widely available "curses" library which provides less functionality (fewer lines, no graphics, no colour) but sufficient freedom in the screen usage. Work in this direction is underway (see below). For the moment, "console" is still run from XENIX PCs. This is also one reason why the XENIX PCs have not yet been physically removed.

As mentioned above, at present the functionality of "console" is complemented by the piquet program "zlinst" for part of the Bunch Train control system.

III.5. Automatic Conditioning

The same problem as described in the previous section applies to another important piece of software, the automatic conditioning package called "acond". This software is used to increase automatically, through the application of an algorithm, the voltage level at which a breakdown occurs between the separator high voltage electrodes or between an electrode and the tank. As with "console", "acond" was written using the convenient CGI package for screen handling, user input and display of various graphs. A different solution, using entirely existing ingredients, is currently been worked on to allow the definitive outphasing of XENIX from the separator controls. Such a revision has also become necessary since the previous program was written without any alternative separator configurations in mind, being tailored solely for use with the original setup.

III.6. Surveillance, Alarms, Logging and Diagnostics

All software used for automatic surveillance and diagnostics of the separators has been adapted according to the modifications. This uses the facilities of the SL/BT TS Toolkit [12, 13, 14], a generic package for distributed applications. Modifications were therefore relatively straightforward without the need for recompilation. The relation of the TS Toolkit with the CERN alarm system [31] and the different diagnostics facilities have been described already in [32] and will not be repeated here.

From the start of this year, all logging and replay of logged data concerning the LEP separators is performed in the framework of the SL ORACLE databases and the recommended and centrally maintained display program "GUILS" (Graphical User Interface to Logging Systems), also making use of the TS Toolkit. An in-depth description of the facilities and how the different data can be correlated has been given recently [33]. This is in contrast to the situation in previous years when all logging was done to local flat files and graphs were produced using EXCEL. The new solution has, besides the reduced maintenance inside SL/BT, the advantage that correlation with other equipment or machine parameters is straightforward.

IV. CURRENT OPERATION

The major difference in the mode of operation in the bunch train separator configuration is that the synchronous switches are no longer used to bring the beams into collision by rapid discharge of the electrode voltage. Instead, the bunch train system requires that the separators remain powered during collision, so that the voltage changes must now be accomplished by means of tables of values (ramps) and timing events. Several constraints are imposed on this method, primarily from the need to ensure compensation of the separator kicks. The necessity to reduce the voltages on certain separators during the collision procedure effectively limits the rate at which this process can occur, since the voltage can only decrease at an exponential rate determined by the time constant of the high voltage circuit. Thus tables of voltages are calculated on-line to incorporate these time constants.

For illustration, figures 6 gives an overview of the states in which the separator system in a given experimental (even) interaction point can be, and the possible procedures to move from one state to the other. The corresponding diagram for 1993 and 1994 operation is shown in figure 5; it will be noticed that for this period each change of state was accomplished via the synchronous discharge switch, which for 1995 has been removed from the operational procedures.

Another important difference in the mode of operation this year is the necessity for frequent vernier scans. This is accomplished using an 'automatic' command line procedure which makes use of the existing black boxes to drive the equipment, and which takes care of the coordination between the equipment voltage changes and the luminosity readings. The results are written to an Oracle table where they can be accessed either via a fixed display or a high level graphics package PV Wave to allow Gaussian fits to the data.

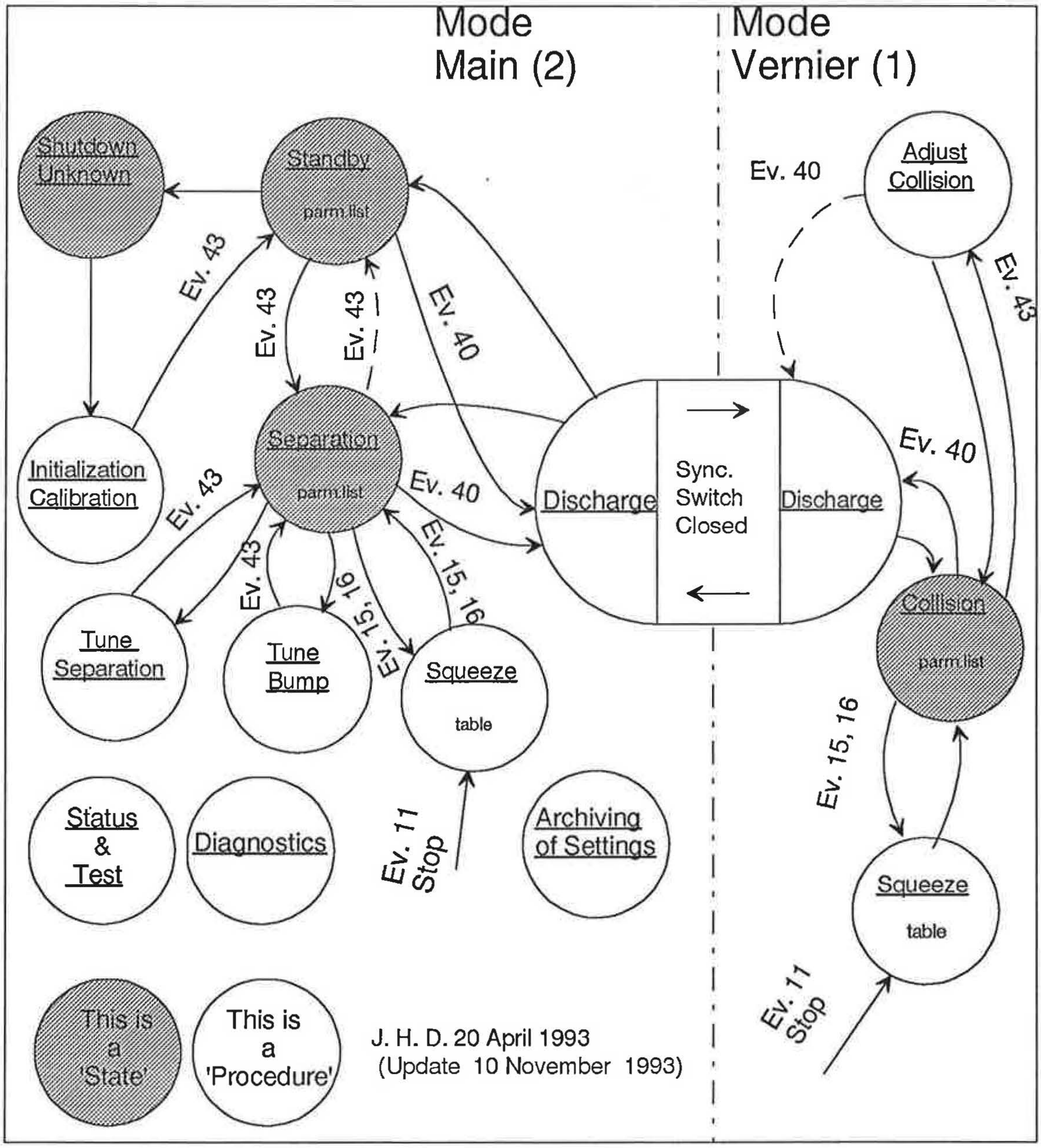

Figure 5: Operational states and procedures in 1993 and 1994.

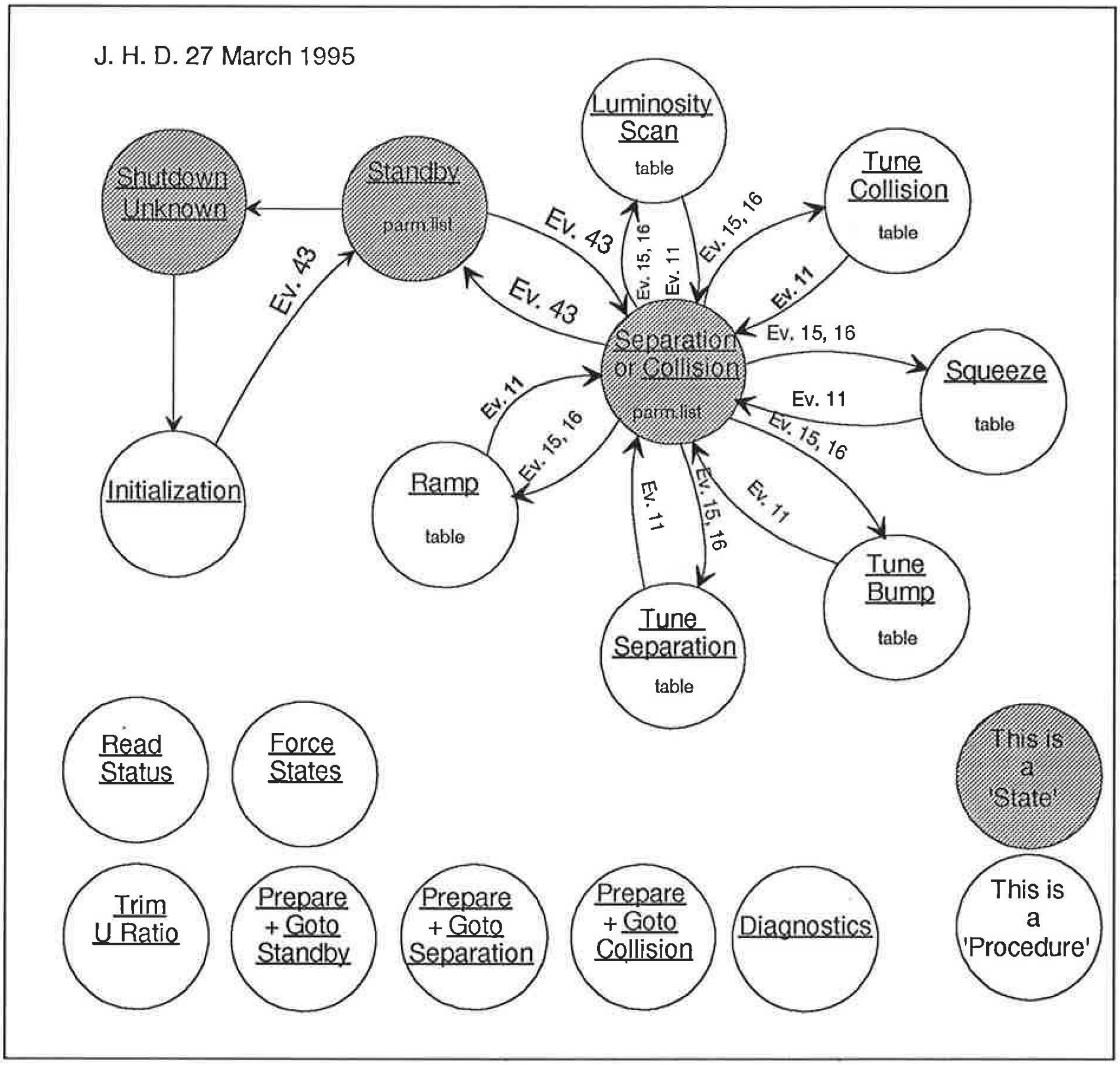

Figure 6: Existing operational states and procedures in 1995.

V. FURTHER WORK

Despite the good progress achieved in the shutdown 1994/95, much work remains to make the current system more homogeneous and user-friendly. Improvements will make it more efficient to operate and debug, its maintenance less manpower-intensive and the reaction time for any necessary future modification shorter. The most important items will be discussed below, again separately for the different levels.

V.1. Equipment Electronics and Equipment Controllers

Although it would be very desirable to replace the 20-year old electronics used for the Bunch Train separators, at the source of many complicated interlock and software constructs, this cannot realistically be hoped for due to manpower and budget restrictions. Instead, work will be concentrated on software improvements to follow operational needs and to simplify maintenance.

As an example, the software of the vacuum controllers will be changed to allow dynamic loading of pump and gauge names. This data was fixed in the EPROM in the past and to be fully operational had to be adapted, at each stop, to account for changes in the vacuum system.

V.2. Process Controllers (Front-End Computers)

The OS-9 systems, previously used for the Pretzel separators, will be dismantled when the Pretzel separators will be physically removed, foreseen for October.

The XENIX systems, previously used for the vertical separators, will be dismantled when all critical software, i.e. “console” and “acond” have been rebuilt on other platforms, foreseen for the course of this year. The old software should then also be removed from other XENIX systems, e.g. in the control room and certain office PCs.

V.3. Application Software

This area will be massively influenced if the Apollo computers are to be removed in the future as presently discussed [34]. In this case the user interface, at the moment implemented using the "Dialogue" tool, needs to be completely rebuilt, using the new XUIMS [35] environment. This will be also a good occasion to review the details of this application.

V.4. Expert Software

The expert program "console" is currently being ported to HP-UX, ULTRIX and LynxOS by replacing all CGI calls by calls by various "curses" routines [36]. This work needs to be finished soon to be able to physically remove the XENIX computers. Subsequently, it is envisaged to rebuild all necessary expert actions in the framework of the TS Toolkit and the generic command presenter "menu" [37] which would significantly contribute to a more homogeneous user access across SL/BT equipment. At that moment specialist access to all Bunch Train equipment also needs to be included, which is currently achieved by a separate program ("zlinst").

V.5. Automatic Conditioning

The program "acond", which uses CGI, is currently being redesigned [38]. Apart from the unavailability of CGI under LynxOS a complete review of this program became necessary due to the evolution of the separator configuration which had made the use of the original "acond" more and more difficult. The basic functionality needed for an automatic separator conditioning is being developed using the TS Toolkit. This has the advantage that no conventional code at all has to be written and that the product can be easily modified in the future to account for additional separators.

V.6. Surveillance, Alarms, Logging and Diagnostics

Apart from the area of automatic in-depth diagnostics, which is still quite rudimentary, this sector is in quite good shape. The use of the TS Toolkit for all these purposes has allowed to follow the separator evolution over the last few years with relative ease. This will be continued over the coming years. A more elaborate automatic fault diagnostic might be added when more time is available.

VI. SUBCONTRACTING - A SOLUTION?

The question may be raised whether part or all of the work described above could have been done, or can in the future be done, outside CERN, saving CERN's manpower resources.

This possibility has recently been investigated, among many other subjects, in the framework of a divisional Task Force [39]. Presently such an approach does not seem realistic, given the rapid evolution of the separator configuration, often via "crash programmes", the ongoing evolution of the controls environment, the lack or bad shape of part of the documentation, and the speed by which operational needs have to be followed to help to achieve the best possible equipment performance.

Instead, approaches like the use of generic, fully parametrizable and re-usable software like the TS Toolkit seem to be more beneficial in this situation, since setting up of applications and their modification become simpler, much less conventional code needs to be maintained and more people, also non-software specialists, can make immediate contributions.

VII. CONCLUSIONS

After several years of rapid implementations of new separator equipment and control systems we are now in a phase of consolidation. Good progress has already been achieved in the 1994/95 shutdown, with, as a key element, the decision to migrate from XENIX and OS-9 to the LynxOS operating system. As a result, all SL/BT systems are now interfaced to the general control system via LynxOS PC type process controllers.

However, considerable work still needs to be invested, in particular in software, to render the control of the separator system yet more homogeneous and less specific, thus more user-friendly and efficient. The stronger use of the generic SL/BT software packages in the LEP separator control will be one of the cornerstones of this development.

VIII. ACKNOWLEDGEMENTS

The work described in this note implies the use of several products developed or installed and maintained by other people. The efforts provided in this context by many members of the SL/CO group are gratefully acknowledged.

The assistance provided by C. Taylor, previously in the SL-PC group, and the kind collaboration with I. Barnett, also SL-PC, was very helpful.

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