

COMPUTER-AIDED ENGINEERING IN HIGH ENERGY PHYSICS

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ABSTRACT

Computing, standard tool for a long time in the High Energy Physics community, is being slowly introduced at CERN in the mechanical engineering field.

The first major application was structural analysis followed by Computer-Aided Design (CAD). Development work is now progressing towards Computer-Aided Engineering around a powerful data base. This integration work will considerably ease future machine design.

Examples of the power of this approach applied to engineering for accelerators and detectors are given.

1. INTRODUCTION

The last thirty years have seen the huge expansion of computers in the technical and industrial world. This computer revolution has considerably modified working methods. The High Energy Physics community, always aware of new techniques, was among the first to use the power of the 'number-crunchers'. However it took some time to enlarge the field of computer applications from controls, data taking and processing to mechanical engineering design. Now, slide rules and drawing boards are being replaced by powerful intelligent work-stations.

Each of the last three decades has seen the arrival of new design tools into the High-Tech industries: computation of structures by the Finite Element Method (FEM) in the 60's followed by Computer Aided Drawing then Design (CAD) in the 70's and now, during the 80's, Computer Integrated Manufacturing (CIM), Computer Aided Engineering (CAE) and many other Computer Aided things (CAX!!!)...

For each of these packages, some years were necessary to evolve from prototypes under development to user-friendly industrial products. Consequently, an early introduction into production induced heavy debugging and adaptation work but despite all the problems encountered, benefits were gained rapidly. After quite a slow start in computing for mechanical engineering, CERN followed this trend, adapting software to accelerator and detector technology especially for the present very large projects. In the mid 70's, the first FEM packages, namely SAFE-SHELL, SAP4, DOT, were installed on the CDC 7600 [1]. They proved to be very useful in the design stage of fancy structures but time had to be spent to debug and to write input and output routines. Ten years later, directly usable packages (CASTEM, ANSYS) provided by software firms have been installed on the central computers running VM together with smaller ones installed on PCs. Engineers and designers are now currently running cases ranging from beam analyses to complex structures with thousands of degrees of freedom. Non-linear analysis (plasticity, buckling,...) are also tackled by some specialists.

In fact, the major breakthrough has been Computer Aided Design (CAD). A Decision to install a CAD system in the technical divisions was made in 1981 and, one year later, after a detailed technical evaluation, a true 3D solid modeller was implemented. Solid modellers were in their initial stages, but their potential was considered much wider, in particular the assembly capabilities allowing integration of various parts of accelerators and detectors. The chosen software was european, EUCLID, installed on a VAX 780 from DEC. The initial work-stations were terminals with storage displays. This young and very powerful software with a new version issued every quarter required a big effort from the designers to adapt themselves not only to a new tool and a new working method but also to a product with too many bugs.

Six years later, the new user-friendly version, EUCLID-IS [2], runs on more than thirty dedicated work-stations connected to two clustered VAX machines, a 8650 and a 785. The computing power has been multiplied by 8 since 1982. The software has reached a more mature and stabilised stage: a new version arrives only once a year!

2. USE OF CAD IN THE LEP PROJECT

2.1 LEP project in numbers

The 'Large Electron-Positron collider' has already been presented at many occasions; see for example [3]. But to show the actual dimensions of the project it seems useful to give some numbers.

In the 27 km long underground accelerator, one can find almost 60,000 different components of various dimensions: from some millimeters to kilometers and summarized in the Table below. The main objective in the introduction of CAD was, from the beginning, the complete memorisation of the whole machine [4]. The modelisation of every component is used not only to produce standard production drawings but also in all the subsequent assemblies.

ACCELERATOR SYSTEMS	NUMBER OF DIFF. COMPONENTS	TOTAL NUMBER OF COMPONENTS
Civil Engineering	40	120
Magnets and RF system	40	5000
Beam instrumentation	30	620
Vacuum system	220	15240
Accelerator support	100	5500
Water cooling	330	14900
Electrical distribution	110	13700
Transport (monorail)	25	1700
Survey	10	780
Total	905	57560

2.2 Component modelisation

CAD is run interactively by the designers to perform their studies. Thinking in 3D is a major change in the working method when you have learned to work in 2D in multiple views, but most of the designers succeeded to adapt. Now, despite the late start of CAD, about two years after the beginning of the LEP project, most of the machine components exist in the data base as objects. The degree of definition varies from one component to another. The most detailed ones have been studied on CAD from scratch, the 3D object being transformed into a suitable form to produce manufacturing drawings (with a perspective which allows everybody to understand the drawing!).

One example of the LEP components designed by computer techniques is shown here: the moving support of the low- β quadrupoles for which the design was performed using EUCLID (Fig.1). Deformations and vibrations were checked with FEM (Fig.2), and the component was then integrated in its environment (Civil Engineering, Pipe work, other components ...)(Fig.3).

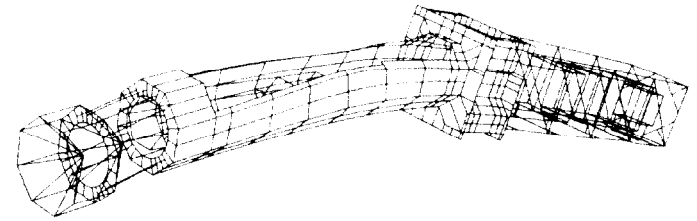


Fig. 2 FEM computation of LEP element

been compiled. In the case of those components which were completely designed with CAD, essentially belonging to the accelerator systems, the objects are readily available. For other components which were designed on a drawing board, a CAD model was produced from existing drawings. In order to keep the drawings readable and to stay within the limitation imposed by the CAD system on the complexity of the models, up to 4 levels of representation exist for each component. For example for schematic layouts at a scale of 1/250 the components are represented by a box, and for a detailed layout at a scale of 1/10 they include all geometric details down to a few millimeters.

2.3 Components integration

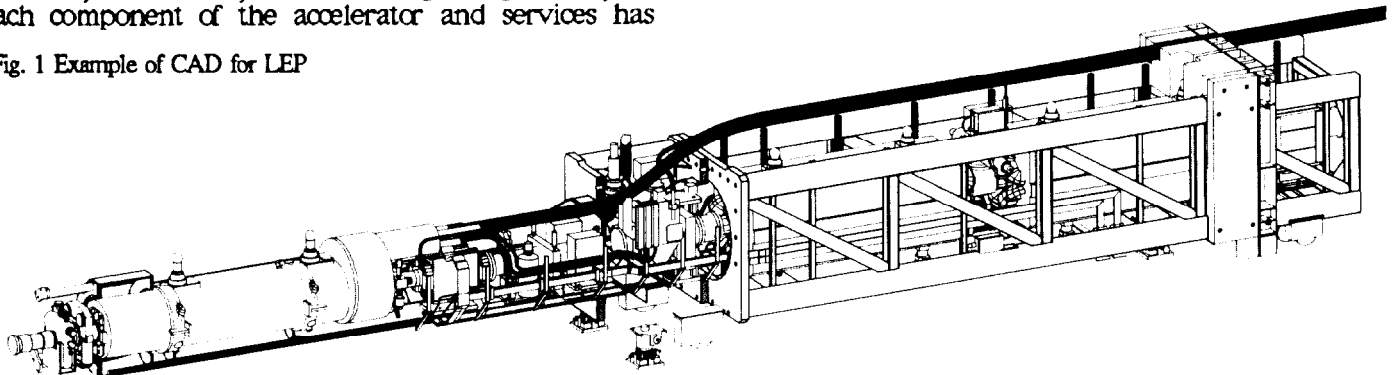
When building a large installation such as LEP, incorporating many interrelated systems in a confined environment, it is vital to keep track of the space occupation of individual components in order to detect and resolve possible conflicts as early as possible at the design stage. Thereafter, time consuming and costly modifications carried out in the field at the installation stage are kept to a minimum. Traditionally, this was attempted by setting a number of draughtsmen the unenviable task of producing and keeping up-to-date a set of so-called layout drawings of the accelerator being built. When assessing the potential of CAD this activity was recognized as an area where major savings in manpower could be achieved, providing at the same time improved results when making use of the facilities offered by a full 3D modelling system.

The method developed at CERN for the automatic production of accelerator layouts is based upon 2 databases and 2 application programs.

2.4 The CAD Database

A library of CAD objects describing the geometry of each component of the accelerator and services has

Fig. 1 Example of CAD for LEP



2.5 The accelerator systems database

A database defining the spatial location of all the components of all systems was developed. Wherever possible use was made of existing data. For example the magnet, beam observation and vacuum systems are directly obtained from the LEP parameters database used by machine physicists. Data for other systems was either derived from existing systems (for example the magnet supports are derived from the magnet system) or built up from scratch.

2.6 The CAD application program for layouts

Using the accelerator systems database and the CAD library of components, the application program produces 3D assemblies of equipment correctly located in the machine tunnel. When working interactively those assemblies are visualized on a graphic work-station and can be manipulated with the tools offered by the CAD system for the detection of interferences, or for testing new arrangements of equipment.

To produce the large number of layout drawings necessary for a machine 27 kms long, a batch version is

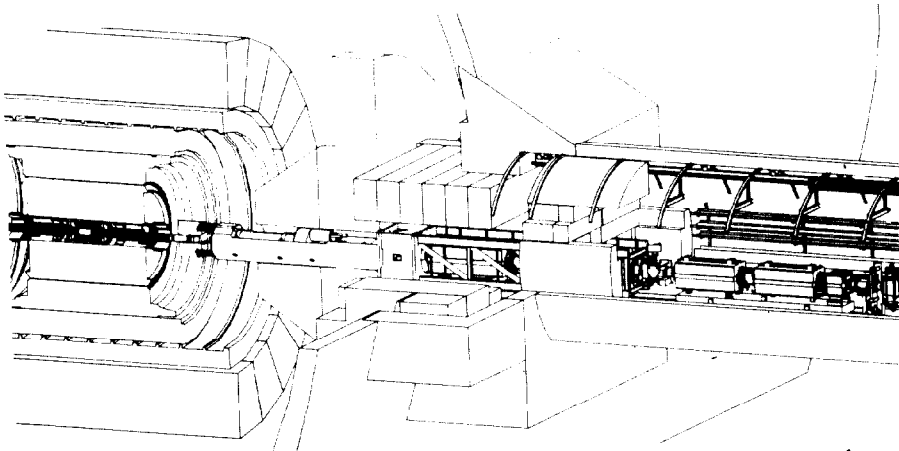


Fig. 3 System integration:
(LEP Machine and DELPHI experiment)

used. It can run overnight thereby giving interactive users of CAD the full use of computer resources during the day. Using the application and an electrostatic plotter a schematic layout of LEP at a scale of 1/250 can be produced overnight on 24 A0 format drawings. More detailed layouts at a scale of 1/50, including all systems and covering one half-cell (40 meters) of LEP are produced in about 15 minutes each. The layouts are not normally stored in the CAD database. When an update is required the layout is recalculated from the modified systems database and/or components library.

2.7 The CAD application program for assemblies

The current limitation in the size of the model that can be manipulated by the CAD system has required the development of a second application program to deal with large 3D assemblies of the accelerator regrouping up to 400 components. These assemblies are a factor of ten larger than the current limitation.

Starting from a set of view windows (top, front, axonometry, etc.) and a list of LEP systems to be seen in this set of views, the application creates and stores in the database a tree structure of each assembly to be visualized. The assemblies are then computed in a combinatorial way by recalling the leaves two by two, computing and storing the intermediate result. The final result is then extracted from those partial results. The production of a 6 view assembly of a LEP half-cell amounts to 200000 3D points, 160000 facets and requires 40 minutes of a VAX 8650 CPU time.

At present the layout production system deals with 39 systems or sub-systems containing approximately 60'000 components belonging to 900 different types (see table). It would be quite impossible to deal with this task interactively.

The productivity of the CAD system is drastically improved when one can automatically produce routine jobs which would otherwise consume hundreds of hours for an interactive user and his expansive workstation.

3. NEAR AND FAR FUTURE

Communication is a must in large engineering projects like accelerators or detectors. Therefore, it is unthinkable that CAD lives in autonomy. The general industrial trend is moving towards a complete integration of the

various engineering tasks. The aim is to gather around a unique data base under the term Computer Aided Engineering (CAE) diverse activities such as design, computation, drawings, simulation, manufacturing, planning, budgeting, maintenance, etc. In view of future large accelerators and huge detector projects, CERN must follow this trend.

A 3D geometric description allows for partial integration and examples described above represent the first steps of a future evolution. Connections towards low-cost, low-level drawing software are under development, together with links to FEM computations and NC machining. A complete object definition encompasses more than geometric data. Technical (specifications, tolerances, etc.) and administrative (drawing number, supplier, etc.) data should be added. The open structure of a Data Base Management System (DBMS) is the obvious core for such an integration. The standard Data Bases (such as ORACLE, the CERN standard) must however evolve to correctly handle the combination of geometric, text and numerical data found in Engineering.

4. CONCLUSION

For a High-Tech organisation such as CERN use of High-Tech tools for its engineering is a must. Computer Aided Engineering is developed around a powerful solid modeller and a standard data base. Direct and indirect benefits have already been shown but it is felt that any new large project must use such an integrated approach.

References

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