# A FRAMEWORK DESIGN FOR A CYCLOTRON VIRTUAL CONTROL PLATFORM BASED ON OBJECT-ORIENTED METHODOLOGY *

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## Abstract

This paper introduces a new software solution for cyclotron control system design and validation that named Cyclotron Virtual Control Platform (CVCP) and gives implementations in framework design. This software platform has abilities to simulate the processes and conditions in normal cyclotrons such as start up and shut down, routine operations, beam current regulation with combination of built-in component models and sequential control logic. A Human Machine Interface (HMI) with Supervisory Control and Data Acquisition (SCADA) functions and 3D interaction features provides a good operation channel. And an intelligent fault diagnosis module that can both generate errors and give solutions will be integrated into the platform in further plans. We use Object-Oriented technology to build this complex system and represent it in Unified Modeling Language (UML). It is easy to extend the functions in this open system. The platform is applied to Cyclotron Virtual Prototyping technology.

## INTRODUCTION

Virtual Prototyping (VP) is a new design paradigm being developed these years with the increasing demand for manufacturing products in a short period of time and in a cost effective manner. During the complex system's entire life circle, Virtual Prototype based on CAD/CAM data is applied to replace the physical prototypes for system design, modeling, analysis and validation.

Cyclotron is a sort of very important facilities used in fundamental physics researches and some civil medical applications. How to establish an integrity cyclotron prototype is an urgent problem we must face to. Considering the system complexity and cost-effective design, VP is a more appropriate way to achieve this. This paper describes control system design and simulation issues in Cyclotron Virtual Prototyping.

Control system is a vital section in cyclotrons, which provide a safe and effective way to manipulate the machine. Correspondingly, CVCP was put forward to take roles for control system design, modeling and simulation, logic validation, intelligent diagnosis and Human-Machine Interface design in Cyclotron Virtual Prototype. Using the platform, Engineers can test their ideals, find defects and then make modifications in earlier time that far reduces design works. As known, cyclotron control system is complicated with interaction subsystems and a number of feedbacks and logic interlocks. Traditional process-oriented method is difficult to build or extend this complex system, so we adopt object-oriented

methodology. It makes system easier to be modeled, organized, maintained and extended by using encapsulation, inheritance and polymorphism features of objects. UML is used to describe the framework of CVCP and also applied in the entire software engineering.

## GENERAL DESIGN FOR CVCP

The control of Cyclotron is a typical complex real-time system. Generally, it is a hybrid system including both continuous control and dynamic discrete events. But for time response requirements, closed-loop controls are implemented by hardware such as PLC and DSP in most cases of Cyclotron. The purpose of computer control system is mainly to carry out the SCADA functions.

### Conceptual Model

As a good example, EPICS (Experimental Physics and Industrial Control System) [2] is a powerful architecture and software toolkit to build distribute real-rime control systems applied in accelerators, telescopes or industrial processes. But different from the real industrial application, we need a specific control platform to accomplish tasks for Cyclotron Virtual Prototyping. Therefore CVCP is advanced with some explicit goals below:

- Control principles and mechanisms simulation
- Control logic and interlocks establishment
- Start-up and routine operations simulation
- Beam current monitoring and regulation
- Intelligent diagnosis

Based on these purposes, Figure 1 shows the conceptual model of CVCP.
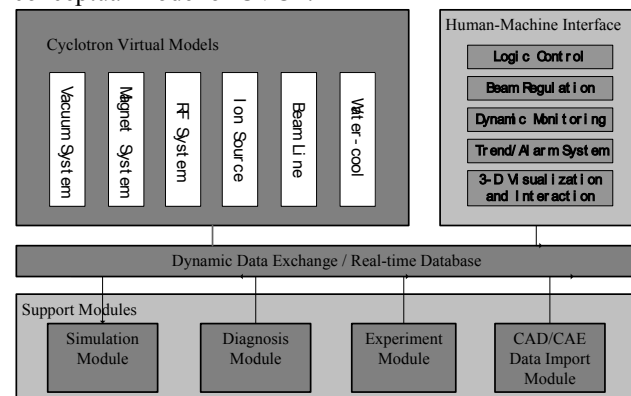


Figure 1:Conceptual Model of CVCP

### CVCP Framework Using Object-Oriented Methodology

Considering the complexity and extensibility of the

platform in Figure 1, we used object-oriented design methodology to decompose this complex system and defined classes to describe different levels of cyclotron models, HMI factors and I/Os with hierarchy architecture as shown in Figure 2. In this diagram, we comply with the *Unified Modeling Standard* [3] and three relationships are used to represent organization among classes: *Composition*, *Generalization* (or inheritance) and *Usage*. Specific components in cyclotron such as vacuum subsystem or stripper are instances of these classes' inheritance or combination.
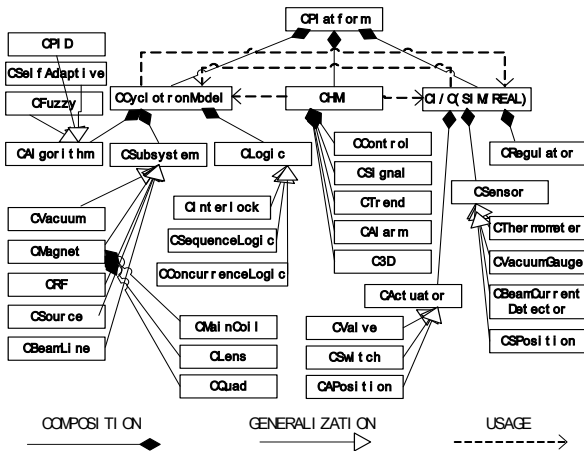


Figure 2: Class Structure Diagram

Figure 2 only illustrates the brief static model of the system, and some classes and their details in properties and methods are omitted. *Interaction Diagram* and *State Machine Diagram* are applied for dynamic level design of the system. Both the static model and the dynamic model constitute the framework of CVCP.

## CYCLOTRON VIRTUAL MODELS

Cyclotron Virtual Models is the kernel of the platform, which represents entities for simulation and shows evaluation for control strategy design. It is divided into three parts in the framework: subsystems, logic and control algorithm that shows below:

- Subsystems and Controllable Components: It mainly includes cyclotron control subsystems like vacuum, magnet, RF etc. and all controllable components such as gas valves, electro motors and stripper. These models have information on objects' control methods, I/O, geometrical and physical characters.
- Control Logic and Interlocks: It is a regulation library including interlocks that promise correct and safe system running and sequential logic for cyclotron routine operation such as system startup and shutdown in automatic/manual modes.
- Control Algorithm: This is a software library covers control-system algorithms most widely used in engineering, which can be embed into particular component model.

## HMI DESIGN

Human factors [4] are important in semiautomatic control systems like cyclotron. The system need human to make some pivotal decisions in supervisory control, and machine plays a clear role in accomplishing dangerous real-time operations safely and efficiently. A Good HMI design can make an easier and more effective way for Human-Machine interaction. In the following, we separate the HMI of CVCP into three sections and give a functional representation.

### SCADA Interface

Supervisory control and data acquisition is the basic requirements for distributed control system of industrial process and large-scale equipment like cyclotron, which has high channel counts that demands for keeping track of a large number of data points. Normally, SCADA provides effective approaches to system's high-level monitor and control by combining real-time/historical data collection, logging and trending with friendly dynamic graphic indicators. Correspondingly, alarm system, event report and security are important assistant components. We plan to achieve the interface by combining *Visual C++* with *Measurement Studio*.

### Specific Cyclotron Manipulation Interface

Especially CVCP is applied in cyclotron control. Therefore, found on SCADA, some specific operations such as beam current regulation, stripper location and interlocking of cyclotron components should be available on GUI. Clear-cut and full-function graphic interface makes the operations more easily and safely. *Virtual Instrumentation* is applied for this interface.

### 3-D Visualization and Interaction Interface

The *CAD/CAE Data Import Module* in CVCP provides a dynamic channel to load 3-D format data created or computed in CAD/CAE system. It is useful to visualize and handle these data interactively because this method offers extra information to engineers who deal with the optimization works in cyclotron prototyping. For example, the CAE experts utilize *Finite Elements Method (FEM)* to compute the beam track under current virtual conditions, and then we can see the track in an intuitive way and make some adjustments through control system to maintain good beam status.

OpenGL [6] is a widely used industrial-standard 3-D graphic library with good compatibility to C++ language. It can be used to accomplish the visualization and interaction tasks with high performance and quality.

## SUPPORT MODULES AND DYNAMIC DATA EXCHANGE

### Simulation Module

Substantially CVCP we implements in the first step is a *virtual system* that has no connections to external physics sensors and actuators like PLC, DSP and other hydraulic

or pneumatic equipments. For the purposes in simulation and validation of the control system, we use software method to generate internal signals and then give stimulates to cyclotron virtual models. This module is designed to have the following abilities.

- Signal Source: In order to construct a real external environment, mathematic method is used to generate two types input signals including analog measurement data and digital status data.
- Control System Feedback: We endow a simplified mathematic model to each cyclotron controllable components with close-loop or open loop methods. Thus responses that simulate real cyclotron can be achieved with input from signal source.
- Parameters Initialization: The function mainly sets up conditions for system start-up.

## Experiment Module

At the final real prototyping level, external sensors and actuators distributed in industrial field bus will replace simulation codes. In the same way, *Experimental Module* is a transformation of *Simulation Module* at this time. This module provides hardware I/O interface and drivers of CVCP that communicate with measurement instrumentations and controllers.

## Diagnosis Module

The role of this module is to establish schemes that can validate control system designed for cyclotron and solute problems on fault detection and correction. Diagnosis mainly considers logic and interlocks because we focus on macro correlations of the distributed cyclotron components.

In virtual mode, faults will be generated in a random way firstly. Then the module use the pre-defined logic regulations to find the position that error occurs and provide a suggest solution to user.

## CAD/CAE Data Import Module

Cyclotron Virtual Prototyping needs multiple specialties' co-operation and interaction to achieve system-level optimization. As discussed in *3-D Visualization and Interaction Interface*, CAD/CAE data is useful for CVCP. Therefore this module sets up a channel that imports data and provides to HMI.

## Dynamic Data Exchange/Real-Time Database

As illustrated in *conceptual model*, we segment the platform into three sections: *Cyclotron Virtual Model*, *HMI* and *Support Modules*. Predictably huge data will exchange among these sections. We must find a method to solute requirements on date throughput and time-response limitation.

*Dynamic Data Exchange* (DDE) supported by *Win32 Platform SDK* is adopted to implement data exchanging by a Server/Client mode. Considering the future requirement for data exchange efficiency, a *real-time database* will replace DDE.

# FUTURE DEVELOPMENTS

## Codes Implementation

C++ is a widely used object-oriented programming (OOP) language with many advanced features and concepts of contemporary OOP supported. In addition, C++ codes can be easily transplanted among different Operation Systems. Accordingly we use it for CVCP codes implementation. Considering the complexity of CVCP, codes implementation is a hard work that needs team collaboration and proper software engineering method. UML is also a good tool for software full life cycle design.

## Industrial Application

Industrial prototyping normally includes three levels: Virtual Prototyping, Simulation and Real Prototyping thus the ultimate purpose of CVCP is for engineering control application. With less modifications to the core codes, CVCP can be embed into real-time system and take on control missions on the real cyclotron. Experiment Model plays an important role in implementing hardware interfaces to the outside sensors and actuates. Many factors such as the instrumentations and Electromagnetic Compatibility problems should be well considered.

# CONCLUSION

We introduce a virtual control concept in cyclotron virtual prototyping and use object-oriented methodology to establish a conceptual model and framework design of CVCP. Three sections Cyclotron Virtual Model, HMI and Support Modules are demonstrated in succession.

Our works give a clear direction for future implementation of CVCP. And this design method can be adapted and used in other nuclear engineering applications and generic virtual control system development.

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