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MODEL-BASED ACCELERATOR CONTROLS*
What, Why and How

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Conventional accelerator control systems are collections of hardware and programs intended to:-

- receive operator requests for changes in magnet current settings and to set the currents to requested values.
- convey information about the state of the beam from the instrumentation to the operator (usually after some processing).
- perform similar functions in respect of other sub-systems of an accelerator, e.g., the RF, vacuum and cryogenic systems.

These programs have evolved to possess varying degrees of "user friendliness" in that they permit the operator to enter and receive information in a form that is related more or less logically to the particular sub-system being controlled.

The operator is a key component in the feedback loop of such a system, at least during the phase when things are changing, e.g., when a machine is being commisioned for different modes of operation or when unexpected behaviour is observed during routine operation. He is expected to take appropriate action to bring things back to normal.

The "appropriate" action is something that the operator decides upon on the basis of a complex set of information -- his knowledge of the particular accelerator, its normal behaviour, and the current operational requirements; codified rules for operation at his disposal; his prior experience with similar situations; his grasp of accelerator physics bearing on the particular situation, etc. He may call upon any subset of these in dealing with the problem on hand. Once he has assesed the situation, the action he takes is usually the entering of a request for some machine parameter to be altered. He then observes the effect of this action on the beam. If the result is not what he had expected, he proceeds to consider the reason for the discrepancy. In the light of this immediate experience, coupled with more searching (heuristic or analytical) in his "knowledge base" he plans and takes further actions. This iterative process usually leads to a successful resolution of the problem. In control systems terminology, the system as a whole has returned to a desired "stable" state from an excursion to an unwanted state.

The important point is that the operator is not a passive link in the system. Instead, he is to be seen as an important information processing node. Even more, he is a node at which information is selectively injected into the system to bring it to the desired state.

A key component of the knowledge base of the operator is a *model* of the accelerator. This term is to be understood in a wide sense; it includes the operator's mental conception of the system, his understanding of how it will respond to a given command. This may be rooted in experience with the machine or it may be based on a grasp of the physical principles underlying machine behaviour. In assessing a particular situation, he may refer to this model informally to extract rules of the type "*If I do this, then that will happen*" or he may formally employ the physical model to arrive at and verify such rules. In the latter case, the application of the model may range all the way from a back-of-the envelope calculation to the running of a program like MAD with inputs appropriate to the situation. I want to emphasise the fact that any human being, when performing a control function -- whether in driving a car or running an accelerator -- works

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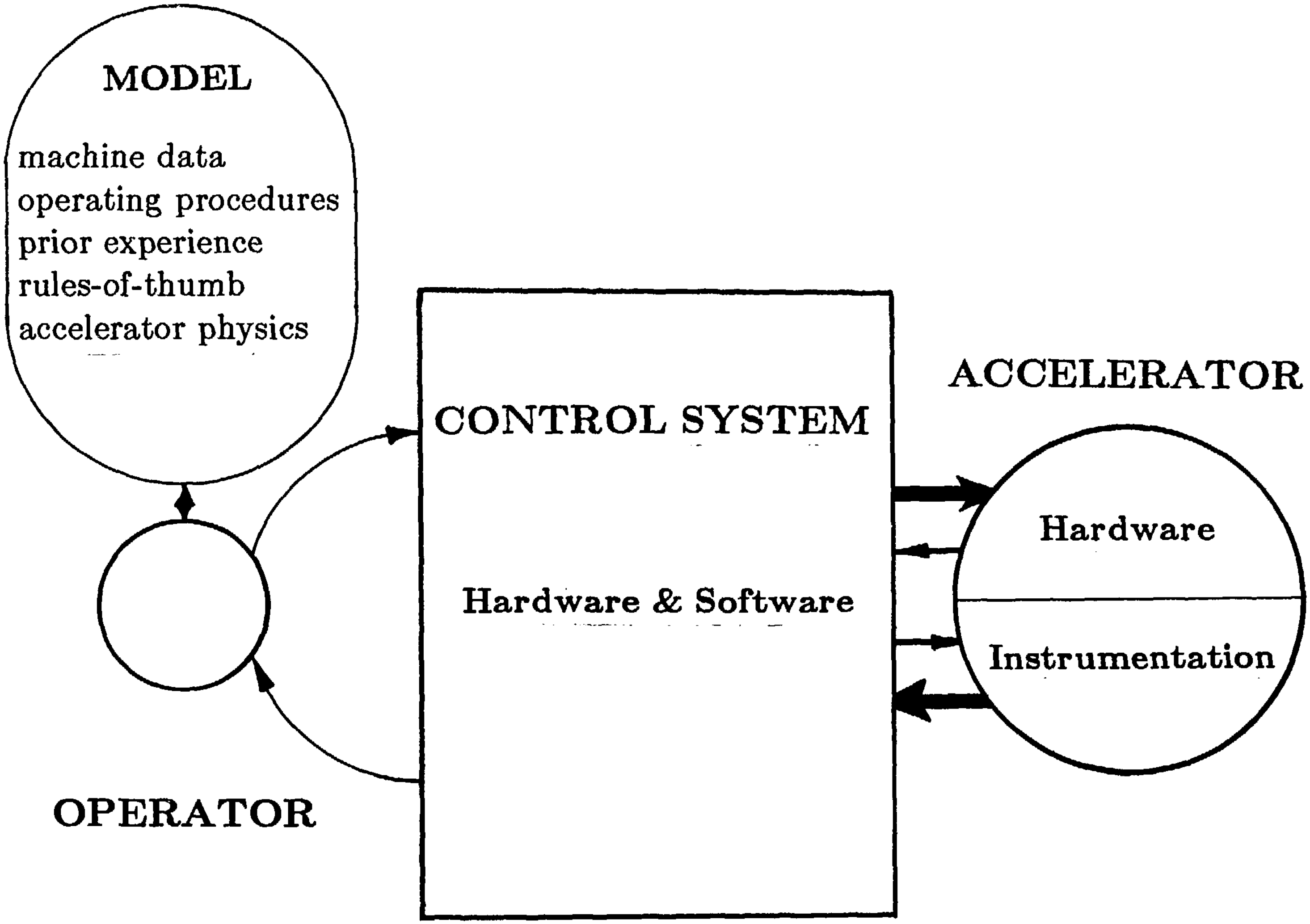
with a model of the system, and uses this model as a filter to screen contemplated actions.

As accelerators become more complex and the operating requirements become more stringent, the reliability and performance of this node becomes a crucial factor in fast commisioning and start-up and continued stable operation at *optimum efficiency*. Model-based control (MBC) is, in my view, the term for the gamut of techniques whose aim is to improve the reliability and enhance the capabilities of the operator, and therefore of the whole control system.

The aim of model-based control is, then, to gradually move the function of model-reference from the operator to the computer. One could argue that the aim should be to make the operator redundant. This could well be a distant goal, but making it the immediate aim may easily doom the effort, for the techniques are still being developed, and much still has to be learned about their application to this domain.

For the operator, model-reference is a more or less informal activity, performed as the need dictates. A weak form of model-based control could have the model available in a program on the workstation that forms the operator interface of the control system. The operator would run this model with appropriate inputs to verify that an action he proposes to take will indeed have the desired consequences. The model may have an interface resembling that of the real control system, with similar inputs and outputs. Such a model would be an accelerator-simulator, much like the flight simulators used to train pilots. If it is easily modifiable, it can be used to simulate not only the ideal machine but also one with errors, thus aiding in commissioning and diagnosis. And, it can be used to determine (by fitting) what settings of accelerator variables will lead to a required operating condition, e.g., minimum orbit errors or a desired beam emittance at a particular point in a line.

A stronger form of model-based control would certainly include such physical modelling, complete with the best available machine description, a good accelerator physics program and a convenient interface. But it would go much beyond these things to include such features of the model-reference activity as heuristic searches in a rule-base, applying the rules to the facts on hand to form deductions and to propose courses of action. It is here that programming and information processing techniques being developed in the very fertile and active field of Artificial Intelligence hold great promise for model-based controls. The application of these techniques to accelerator controls will have a significant impact not merely on how information is organised in the control system but on the architecture of control systems as well. System architecture will be closely linked with how knowledge about the system is to be represented in a computer, how this knowledge is to be processed to derive operational rules and, finally, how the rules are to be applied toward the goals of accelerator control.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