Abstract: Boundary Control of Operating Envelopes increases process profitability

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Normally processes are operated to achieve conditions near an ideal or 'optimal' point to achieve a set of business objectives. The operating space, the range of conditions around this point that still achieve target objectives, is rarely considered and nearly never used in process control. Relaxing this constraint, implicit in today's control methods, can achieve great operational benefits by reducing demand on dynamic process controllers and achieving secondary objectives such as catalyst lifetime while still achieving the primary goals.

The volume of operating space within which one or many objectives can be simultaneously realised is the Operating Envelope of those objectives. It involves many variables so requires more than 3 dimensions to describe it geometrically. Human beings cannot imagine anything requiring more than three dimensions – as demonstrated by Picassos' attempts to portray 4-dimensional space-time or Mitterands' Arch in Paris – so the geometric description of Operating Envelopes was for a long time pushed off-stage in favour of description with more and more algebraic equations and corresponding mathematical specialisation.

In the interim, companies have still had to provide process operators with guidance on how to operate. They have generally done this by specifying operating ranges for many individual process variables with the assumption of independence between variables. This effectively defined a rectangular solid of many dimensions (a hypercube, more commonly known as an Operating Window) enclosing the much smaller operating target hypercube. An Operating Window is therefore a first approximation to the shape of an Operating Envelope but when defined as in this paragraph without knowledge of the shape of the actual envelope is often not a particularly good approximation as we will show with some examples from the industry.

A new coordinate transformation with the unusual property of being a transform from n-dimensions to 2-dimensions has altered the stage dramatically by allowing accurate representations of very high domensionality Operating Envelopes to be visualised and compared for the first time. Non-linearities such as local optima can be seen and compared and much better Operating Windows found and optimised by process engineers using simple visual geometry for rapid returns on investment. Process and result varaiable interactions can be taken into account allowing Operating Envelopes to be modelled as geometric solids using only the variables familiar to everyone in the control room.

Operating Windows ignore variable interactions and so provide a first approximation to an Operating Envelope by forming a multi-dimensional rectangular shape or hypercube. Because of the additional constraints imposed by variable interactions, operating envelopes are always smaller in volume than their enclosing operating window. This is used to advantage in applications such as predictive alarming, fault detection and prediction and condition monitoring where the window of good or normal operation consists of the fixed ranges defined by operator alarms or by the operating limits placed upon many individual variables. The smaller operating envelope then provides a very sensitive detector of operation that is non-normal before violation of any of the individual alarm limits or operating limits has occurred. Examples from case studies will be shown for predictive alarming and compressor surge prediction.

Operating envelopes for production purposes are chosen for economic reasons such as increasing the yield of product meeting specification. This requires conventional process control operating inside the envelope and a new capability of boundary control intervening with a different control action to push the process back inside the envelope when it attempts to violate the boundary. Knowing the location of the boundary at any moment is of fundamental importance but difficult because the boundary is made up of many time-varying constraints so that the usable volume and effective boundary of the envelope varies continuously as the process moves in time.

Conventional multi-variable controls frequently use static constraints to describe an approximate fixed location for the boundary of the envelope and while this was a valuable advance on the previous generation of controls which were constrained only by the operators mental model of the process, it is now possible to use dynamic methods to locate the boundary at any moment.

Finding the usable volume of the envelope provides a convenient real--time graphic to allow the process operator to see where the process is operating within the overall multu-variable operating envelope and which variables are most and least constrained.

The missing boundary control capability is then provided by geometry by finding the least movement of one or more of the manipulable variables that will either immediately move the operating point inside the new usable space or will cause the volume of the usable space within the operating envelope to change and reduce the number of violations. The manipulable variables would normally be the setpoints of the conventional PID or multi-variable controls for operation inside the envelope. The setpoint movements can be seen on the operator graphic and can be used in open-loop for operator advisory control or in normal closed loop control.

A case study of an actual implementation will be shown which produced benefits of the order of $1Mpa.