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A new method for defining and managing process alarms and for correcting process operation when an alarm occurs

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Abstract

A new mathematical treatment of alarms that considers them as multi-variable interactions between process variables has provided the first-ever method to calculate values for alarm limits. This has resulted in substantial reductions in false alarms and hence in alarm annunciation rates in field trials. It has also unified alarm management, process control and product quality control into a single mathematical framework so that operations improvement and hence economic benefits are obtained at the same time as increased process safety. Additionally, an algorithm has been developed that advises what changes should be made to Manipulable process variables to clear an alarm.

The multi-variable Best Operating Zone at the heart of the method is derived from existing historical data using equation-free methods. It does not require a first-principles process model or an expensive series of process identification experiments. Integral with the method is a new format Process Operator Display that uses only existing variables to fully describe the multi-variable operating space. This combination of features makes it an affordable and maintainable solution for small plants and single items of equipment as well as for the largest plants. In many cases, it also provides the justification for the investments about to be made or already made in process historian systems.

Field Trials have been and are being conducted at IneosChlor and Mallinckrodt Chemicals, both in the UK, of the new geometric process control (GPC) method for improving the quality of both process operations and product by providing Process Alarms and Alerts of much high quality than ever before.

The paper describes the methods used, including a simple visual method for Alarm Rationalisation that quickly delivers large sets of Consistent Alarm Limits, and the extension to full Alert Management with highlights from the Field Trials to indicate the overall effectiveness of the method in practice.

Keywords: Alarm limits; Alarm definitions; Alarm management; Alarm rationalisation; Geometric process control

The state of Alarm Systems today is well-described by Bransby and Jenkinson [1] and can be summarised as a focus on single variable alarming. There do not appear to be any generalised multi-variable alarming methods yet the multi-variable nature of alarms has been widely recognised as evidenced by the following quotation:

"The purpose of Alarms is to maintain the plant within a safe operating envelope. A good alarm system helps the operator to correct potentially dangerous situations before the Emergency Shutdown System (ESD) is forced to intervene. This improves plant availability and economics. It also reduces the demand rate on the ESD and thus increases plant safety" [2].

An alarm occurs when a variable breaches an alarm limit so that the value at which the alarm limit is placed relative to the other variables is of considerable importance if a set of alarm limits are to define a safe operating envelope. The implication is that alarm limit values should be related to each other but today's methods of setting alarm limits are primarily single-variable and empirical. There has been no general method available to calculate values for alarm limits either in single- or multi-variable cases and this

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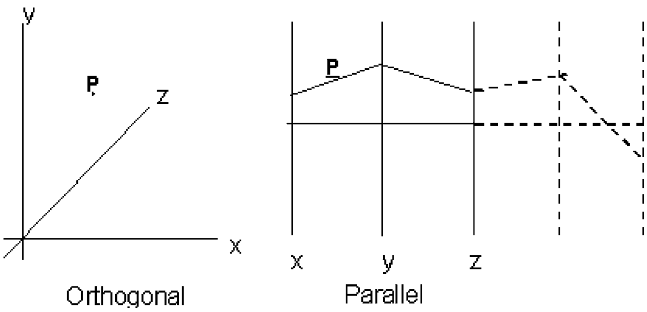

Fig. 1. The parallel coordinate transformation.

is the root cause of the poor performance of alarm systems today and hence of the low regard in which operators hold them.

An operating envelope is of necessity, a multi-variable or multi-dimensional envelope that would be difficult to synthesise but can be defined instead by the set of multi-dimensional process operating points that it contains. Each operating point is simply the set of values of all of the process variables and can be written as $(x_1, x_2, x_3, \ldots, x_n)$ implying that a multi-dimensional visualisation method is required for ease of use. Inselberg's parallel coordinate transformation [3] provides a mathematically sound visualisation method that is capable of representing all needed aspects of *n*-dimensional geometry. It transforms the *n*-dimensional orthogonal space described by Riemann into a format that is easily visualised yet mathematically sound. In Inselberg's transformation points transform into polygonal lines as can be seen in Fig. 1 where the point P in orthogonal 3D space has transformed into the polygonal line *P* in parallel space.

Fig. 2 shows an example of a single operating point for the Crude Distillation Column of Fig. 3 that will be used as the example in this paper. It is a 25D graph with only one point plotted. Putting many more points onto the graph, in this case 1183 points representing nearly 2 months of operation sampled at hourly intervals gives the graph of Fig. 4. A considerable advantage of the parallel coordinate transformation is that a layman can easily understand the graphical representation without the need for mathematical knowledge.

We might in some circumstances use the envelope of all the points in Fig. 4 as the envelope of desired operation but usually have some choice criteria to apply first. In this example there were concerns about the maximum tube wall temperatures in the fired heater, which translated into maximum transfer temperatures (FdT) of 345 or 350 °C.

These two regimes are shown coloured blue and yellow, respectively, in Fig. 5 to show how two criteria applied on one variable (FdT) will select different usable ranges on other variables, for instance, KinF, BotF, LStm and KinT, which give us immediately high–high/low–low alarm limit values for all variables. These alarm limit values are all consistent with the one objective criteria of maximum tube temperature and thus are also consistent with each other so they are better alarm limits than the individually set high–high/low–low alarm limits in use today. They are probably not very different to those in use already for a plant with one mode of operation that has been very diligent in repeatedly revising its alarm limits and so has iterated towards a consistent set.

There could of course be many criteria to be satisfied in which case the envelope is in general reduced in size by the application of each successive criterion.

Note that the selection of the acceptable dataset to define the envelope is the whole of the model-building process. A process engineer in one of the trials commented that he could build and install a new model in half-an-hour.

A little thought will reveal that the values of the high–high/low–low alarm limits on each variables axis creates a multi-dimensional rectangular box or hypercube which emphasises that fixed alarm limits must be asserting non-existent independence between variables. Interactions be-

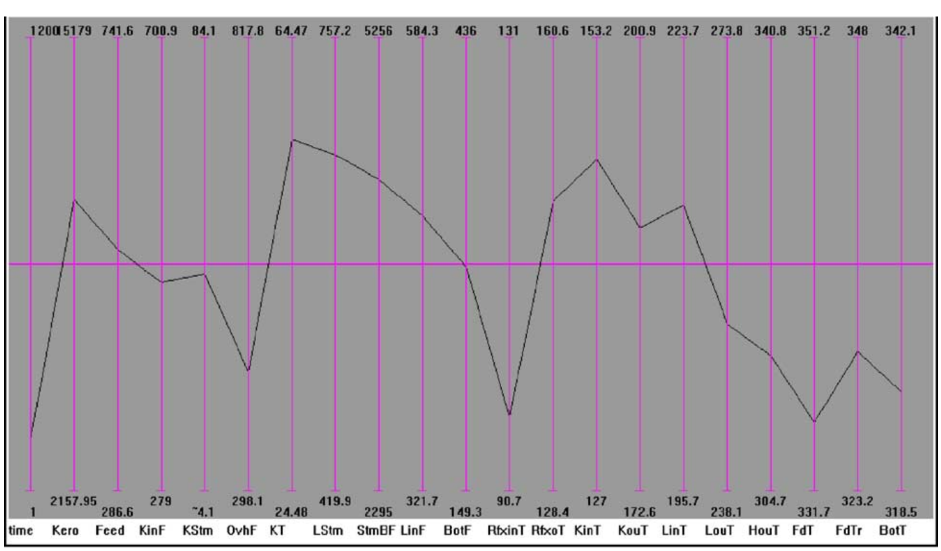

Fig. 2. A 25D graph showing one point.

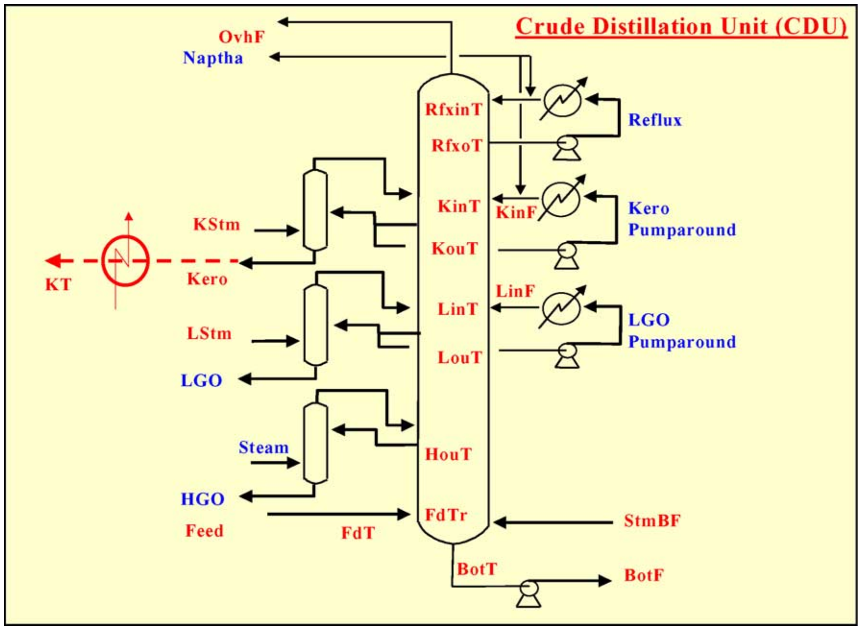

Fig. 3. The crude distillation unit (CDU) showing the location of variables.

tween variables define a non-rectangular operating zone envelope inside and thus of less ‘volume’ than the enclosing hypercube. It is thus necessary to consider what happens between the axes of the parallel coordinate plot in order to understand the actual shape of the non-rectangular operating zone.

Suppose in Fig. 5 the blue (FdT <345 °C) operating zone was chosen. Isolating the blue points gives Fig. 6. We can thus say that it is necessary to stay simultaneously inside all the variable ranges identified by the points in Fig. 6 in order to always meet the objective FdT <345 °C. Alternatively, if we take the envelope of the points in Fig. 6, any operating point has to be an interior point of the envelope in order to meet the objective FdT <345 °C. Geometrical methods can be used to construct the envelope and can also determine whether the current operating point is an interior point or an exterior point. However, as soon as a value is fixed for any one variable the affect is to identify reduced ranges on all the other variables within which values of those variables must lie in order for the point to remain wholly within the envelope.

The result of this construction is shown in Fig. 7 in the way that it is displayed to the process operator. The current process operating point is shown by the set of blue dots connected to form a blue polygonal line. The red outlines are the projections of the envelope of the points from Fig. 6 scaled for maximum resolution. The green values on each variable represent the reduced ranges or available ranges that must be observed around the current operating point in order to be an interior point of the red envelope and thus not in alarm. The points where the red envelope meets the vertical axes are the high–high/low–low alarm levels.

The green envelope changes shape as the process operating point moves and it is the role of process control (whether

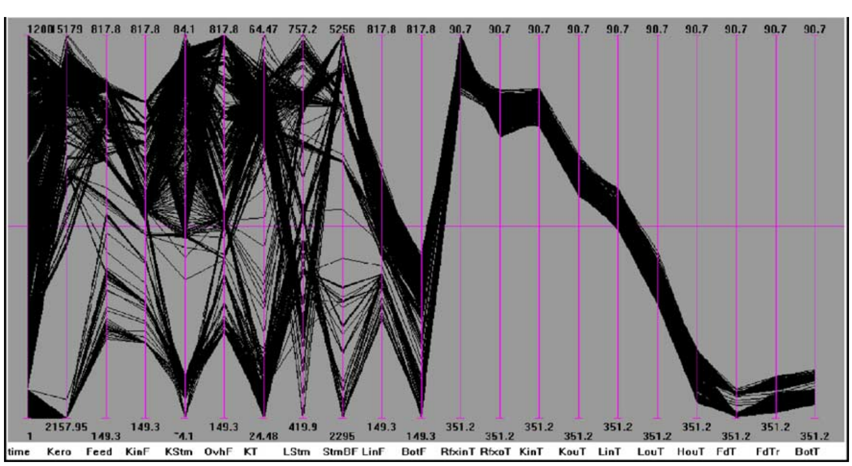

Fig. 4. The same graph with over 1000 points representing 3 months of operation.

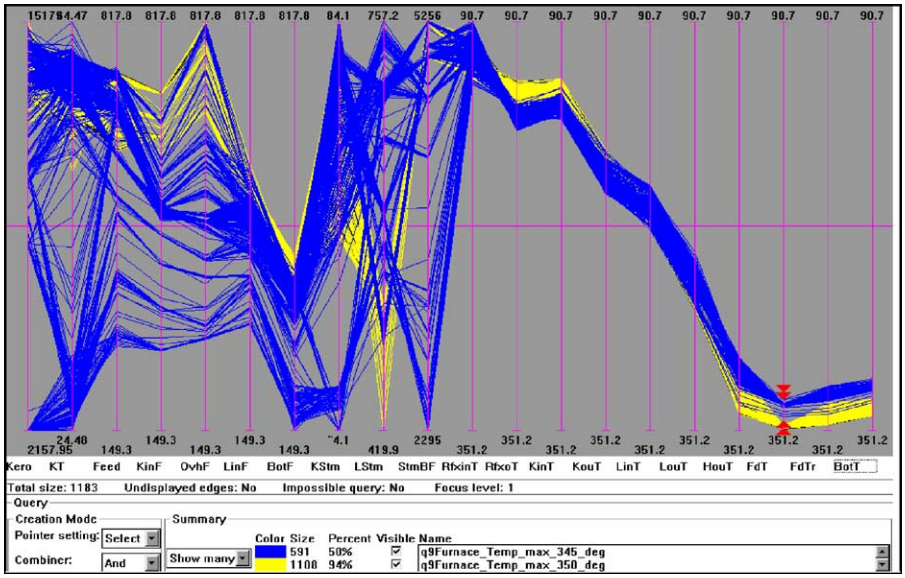

Fig. 5. Two operating regimes.

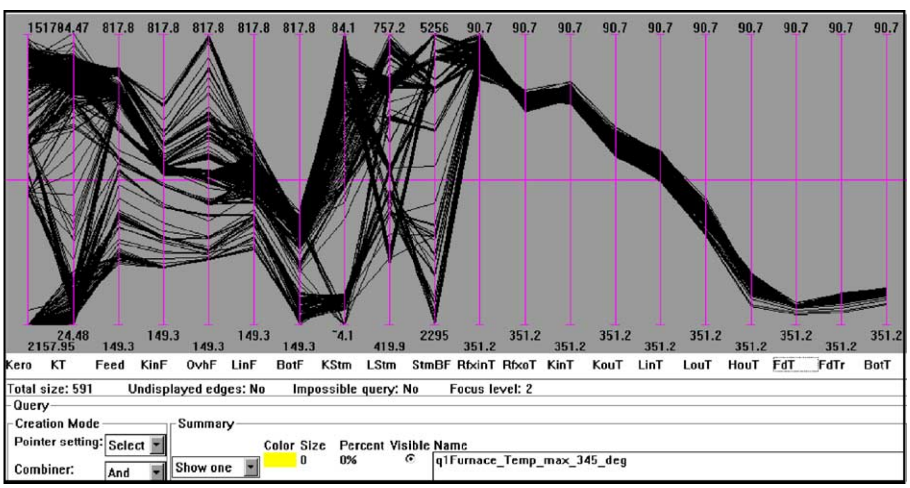

Fig. 6. The points in the max 340 (blue) operating zone.

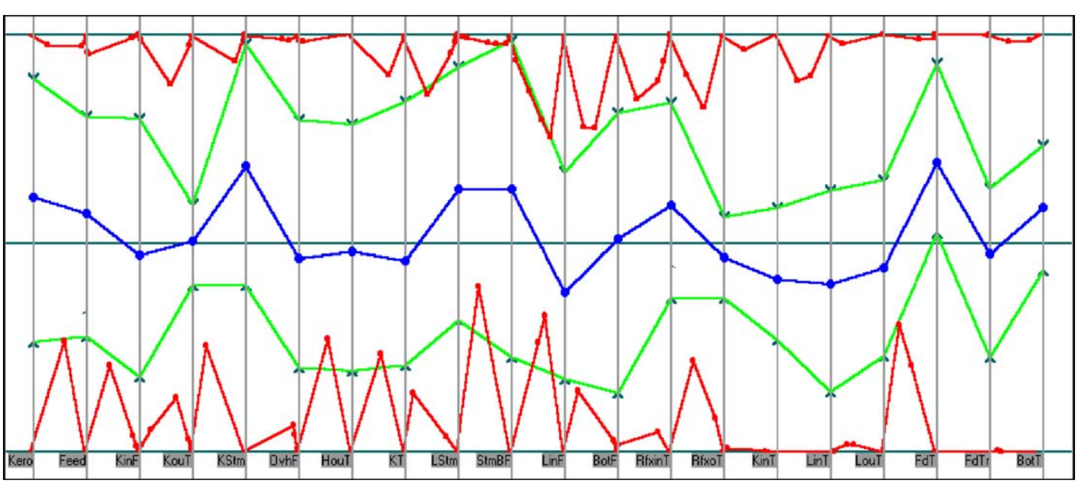

Fig. 7. The operating envelope for FdT <340 °C, an operating point and the resulting currently usable ranges of all variables.

manual control or model-based control) to keep the process inside the green envelope at all times and thus achieve the objective by which the red envelope was chosen. Reversing this, we can see that if any variables value were to be outside the green envelope process control would have failed in the task of which it was previously capable. Thus the green values on each variable represent the earliest value at which one can confidently say that a problem is developing and are where we define and annunciate an alert or high/low alarm. Since the high/low alarm levels are the ends of the available range on each variable due to the values of the other variables in relation to the red envelope, when the process moves the high/low alarm levels (and the green envelope joining them) move.

Industry has been accustomed to leave the high/low alarm limits fixed for want of any way to calculate how to move them. This accounted for the very high proportion of false alarms, which both raised the annunciation rate and devalued all alarms for the operator. This led in many plants to high/low alarms set so wide apart that they almost never annunciated, which is almost the same thing as having no high/low alarms and depending on operator vigilance and high–high/low–low alarms. The advantage of having good high/low alarms is that the operator is asked to intervene when the maximum time is available for him to find a remedy and before the process has developed too much momentum in its movement. Geometric process control puts high/low alarm levels at the heart of process control.

These alarms and alerts are particularly good because of the subtlety of the variable inter-relationships captured by the red envelope. This was evidenced during the IneosChlor Field Trial by a single standing alert on a reactor exit temperature. The value was above the green limit but below the red so was well within what would previously have been considered a normal range. Investigation revealed that reactor coolant level, a variable whose measurement was not connected to the computer, was lower than usual so removing less heat and causing a higher then usual outlet temperature. In other words, the alarm detected was not simply a high value of one variable in isolation but was a deviation from the normal heat balance relationship between several variables. The ability to detect this type of multi-variable alarm without the engineer having had to think of providing for the possibility is extremely powerful and reassuring in terms of additional plant safety.

Once an alarm or alert has occurred geometry can be used again to generate corrective changes to the Manipulable variables. We use the term ‘manipulable variables’ to mean those variables, such as flows (or, in some cases, set points of regulatory controllers), that can be changed directly. A density, for instance, may be measured online but cannot be changed directly. Effectively we find changes to the Manipulable variables that would cause the shape of the green envelope to change such that the maximum number of alerted variable values are included in the re-shaped envelope so minimising the total number of alarms. In practice, it has been found that following the advice given over a few time steps fairly quickly brings the process back to a normal or no-alarms state.

Fig. 8 shows an example of the process operating advice given with the red envelope not displayed at the request of process operators since it does not change and its omission increases the clarity of the display. There is one alert (a high alarm) on variable *KT*, which is not directly manipulable. Increasing the Kero product flow rate, the kerosene return from the stripping column to the main column KinF and the steam flow to the kerosene stripping column KStm will change the shape of the green envelope to that of the blue envelope which is sufficient to clear the alarm on *KT*.

This is very sophisticated advice to be generated by an algorithm. It appears at least comparable to that generated by

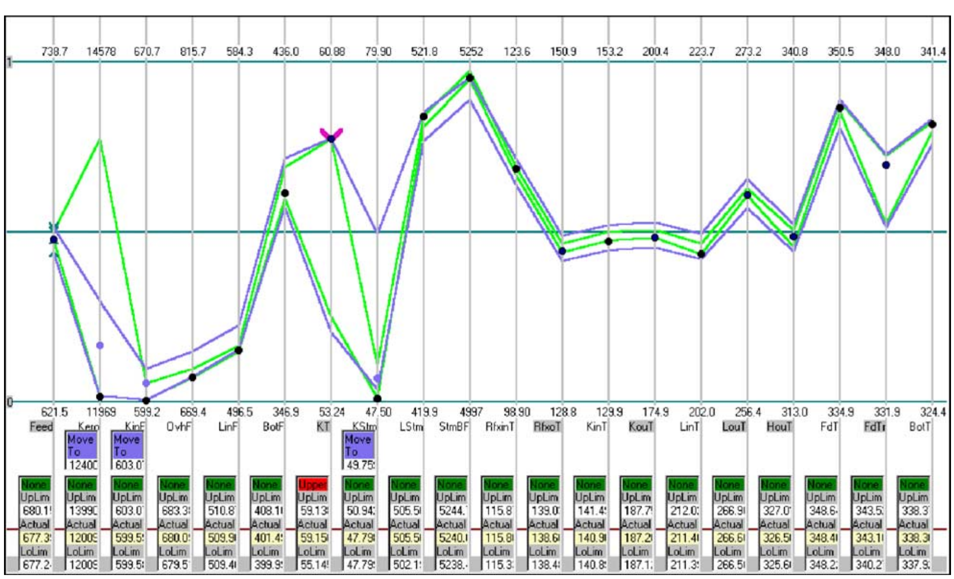

Fig. 8. The geometric algorithm generates sophisticated advice involving moves of three variables to correct one alarm.

rule-based systems in the subject categories of ‘Knowledge Engineering’ and ‘Computational Intelligence’ but without the sometimes considerable cost of building and maintaining a rule-base.

The desire to prove the quality of the alarms and of the advice on a real process was the motivator for the two field trials conducted at Ineos Chlor, Runcorn, UK and Mallinckrodt Chemicals, Staveley, UK. For these early trials it was decided to run in open-loop operator guidance mode. The first trial has completed with considerable success, the results have been publicized [4] and a permanent installation is commissioning now, the second trial is still in progress but results to date are fully supportive of the first trial results.

The results of the first trial included an assessment of alarm quality by comparing alarms generated using alarm limits set using the best experience and knowledge of the plants engineers with alarm limits generated using the methods described in this paper. The objective in both cases was to produce product within specifications as measured by subsequent laboratory analyses. Alarms were retrospectively rated true or false depending on the result of the laboratory analysis when it was received some hours later. Alarms raised with the traditionally set alarm limits were false 49% of the time, whereas those raised by the new method were false only 10% of the time. The 10% has since been further reduced by improved choice of variables in the envelope. Reducing the total number of alarms annunciated by 39% also reduced the annunciation rate, defined as the average number of alarms annunciated per minute, in a similar proportion.

Warning alarms (Hi/Lo Alarms) successfully advised operators where to operate the process. The principle is not only react to alarms when they happen, but to try to keep the process well inside the green envelope with some up and down leeway on each variable.

It is possible when designing alarm systems to overlook the fact that *any alarm system is only as good as the operator’s confidence in it*. An essential feature of GPC is that operators appreciate the rationale of the alarms raised.

The operators were asked to record their acceptance or rejection of the advice generated (through a form on the display). The conclusion was that the operators generally accepted the advice. It was interesting that advice could be generated that made physical sense to those who knew the process without explicitly representing any physical/chemical relationships in the model. It seems that *the geometric model does capture the essential relationships among the variables*.

Acknowledgements

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