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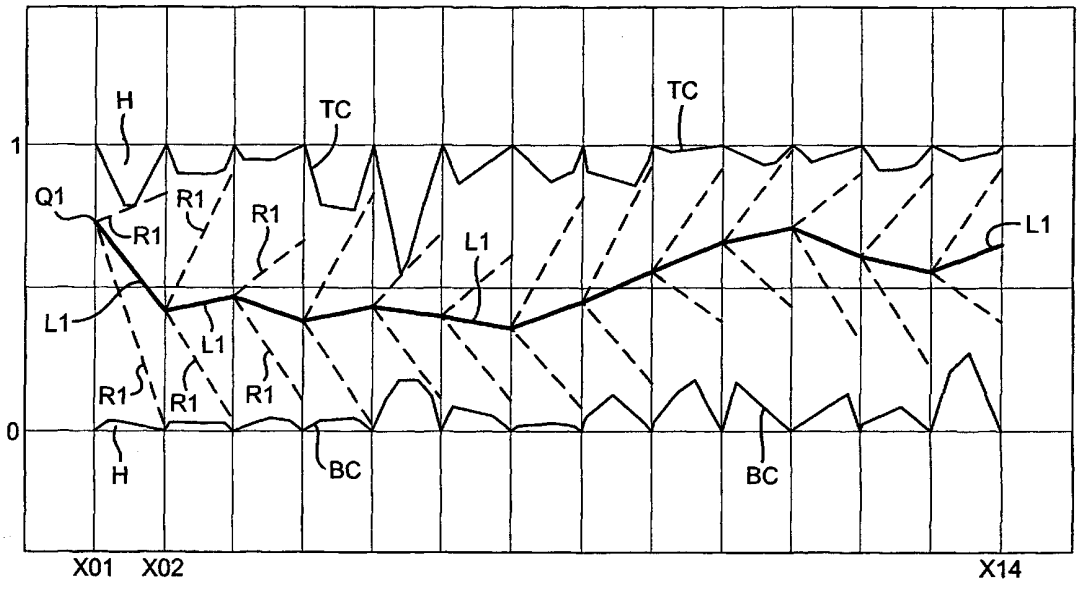
(54) Title: MULTI-VARIABLE PROCESSES



(57) Abstract: Control and output-quality variables of a process plant (1) are plotted against parallel axes in a display unit (7). Convex hulls between pairs of variables are calculated from sets of the variable-values accumulated historically in stores (7, 9) during successive runs of the process, and hulls (H; TC, BC) between successive axis-pairs are displayed. New variable-values for process optimisation are fixed for the variables taken in turn, each selection being made within displayed ranges (Rn-Rn) derived from the hulls effective between the respective variable and the variables already fixed. A display unit (13) provides on-line parallel-axis display of variable-values from the plant (1) showing alarm carets (DC, UC) where values violate limits (UL, LL) determined by the convex hulls, and allowing variation in the displayed-value for observing the resultant effect in avoiding alarm situation and towards optimisation.

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Multi-Variable Processes

This invention relates to multi-variable processes.

The invention is particularly concerned with methods and systems for displaying variables of multi-variable processes.

According to one aspect of the present invention a method for displaying variables of a multi-variable process, comprises deriving a multi-dimensional display representation in parallel coordinates of a feasible region of the process-variables, the representation being derived from sets of values for the process-variables accumulated respectively from multiple operations of the process, deriving a further set of values for said variables within said region and displaying them within said representation, and defining within the display representation available ranges for the variables according to the values of other variables within said further set.

According to another aspect of the present invention a system for displaying variables of a multi-variable process, comprises means for providing a multi-dimensional display representation in parallel coordinates of a feasible region of the process-variables, the representation being derived from sets of values for the process-variables accumulated respectively from multiple operations of the process, means for deriving a further set of values for said variables within said region and displaying them within said representation, and means for defining within the display representation available ranges for the variables according to the values of other variables within said further set.

The definition of available ranges of the process-variables in the method and system of the invention may be carried out by reference to convex hulls calculated for each pair of variables from the accumulated sets of values. A convex hull in orthogonal coordinates is a closed polygon that encloses all relevant data points of the two-dimensional space, whereas in parallel coordinates it is a pair of spaced linear curves that as between corresponding parallel axes, bound the region occupied by the lines that represent (in the parallel-coordinate space) those data points. A feature of convex hulls used in the present invention is that when the value of one variable is fixed a range of values from maximum to minimum of the other can be derived.

The invention may be applied to monitoring and optimisation of multi-variable processes. More especially, the invention is applicable to ensuring safe and efficient on-line operation of multi-variable processes, in particular by providing a display representation including warning alarm limits on some or all of the variables where these limits are continuously re-calculated in accordance with current operating conditions. Furthermore, the invention is applicable to assist selection of values for the variables of the process and to systems for providing display representations for use in such selection.

According to a feature of the present invention a method for selection of values for variables of a multi-variable process, comprises a first step of deriving a multi-dimensional display representation in parallel coordinates of a feasible region of the variables, the representation being derived from sets of values for the process-variables accumulated respectively from multiple operations of the process, a second step of selecting, so as to fix, a value within said region for one of said

variables and defining available ranges for the other variables in accordance with the selection made, and a third step of selecting, so as to fix, a value within the available range defined for one of the remaining unfixed-value variables and re-defining the available ranges for the other unfixed-value variables in accordance with the selections so far made, this third step being repeated until values for all unfixed-value variables have been fixed by the selections made.

According to another feature of the invention a system for providing a display representation for use in selection of values for variables of a multi-variable process, comprises means storing sets of values for the process-variables accumulated respectively from multiple operations of the process, display means providing a multi-dimensional display representation in parallel coordinates, the representation including in accordance with the stored sets of values, display of a feasible region of the variables, and selection means that is operable successively to select, so as to fix, values within said region for all said variables in turn, said display means being operative upon each operation of the selection means to define available ranges for such of the other variables that remain of un-fixed value.

A method and system according to the present invention will now be described, by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a schematic representation of a system according to the invention in the context of collection and utilisation of data derived from operation of a multi-variable processing plant;

Figure 2 is illustrative of a plot in multi-dimensional space defined by parallel coordinate axes, of operation of the multi-variable processing plant of Figure 1;

Figure 3 shows in part a multiplicity of plots corresponding to that of Figure 2 resulting from variation of operation of the multi-variable process;

Figures 4 to 6 are illustrative of displays provided during successive stages of the method according to the invention, for assisting with selection of values for the variables of operation of the processing plant of Figure 1;

Figures 7 to 10 are illustrative of further displays provided according to the invention to assist further in selection of values for variables of operation of the processing plant of Figure 1; and

Figures 11 to 13 are illustrative of displays derived in varying circumstances during on-line monitoring of operation of the processing plant of Figure 1.

The example of method and system to be described is related to the operation of a multi-variable process carried out by a simple, notional processing plant. Details of the plant and its purpose are not of consequence, and indeed the method and system of the invention are related more specifically to operation of the plant as an example of a multi-variable process rather than to the purpose of the process performed, being applicable in the generality to any situation involving a multi-variable process. In the context of description of the present specific example, however, there are fourteen variables involved in plant-operation, and of these, eleven are control variables to the extent that their values determine the outcome of the process.

The remaining three variables are quality variables in the sense that their values define, or more especially are defined by, that outcome.

Referring to Figure 1, the plant 1 has an input 2 and an output 3 between which there are a multiplicity of processing stages 4. The processing within each stage 4 is carried out in accordance with one or more variables that, in this example, are regulated by eleven controllers 5. The values of these variables for each operation or 'run' of the process are communicated to a data collection unit 6 to be accumulated in a store 7. The term 'run' in this context may refer to a discrete operation of the process, but it may also refer to what applies at a discrete point in time within continuous operation.

The outcome at the output 3 of each run of the process, is submitted to a unit 8 for analysis in respect of its quality as determined according to three variables. The values of these three quality variables are accumulated in a store 9, so that each run of the process and its outcome is defined by an accumulated set of fourteen values, eleven in the store 7 and three in the store 9, for the fourteen variables respectively.

As the process is run again and again, a multiplicity of different sets of fourteen values are accumulated to provide a historical record in the stores 7 and 9 of the successive runs. This record is used in the method of the present invention to assist selection of the values of the various variables appropriate to achieving a particular outcome. More especially, the fourteen values of each individual set, eleven in the store 7 and three in the store 9, are brought together in a merge unit 10 and each scaled to the range 0 to 1. The scaled values are then processed in a unit 11 according to a convex-

hull model to plot them in an electronic display unit 12. The scaled values of each set are plotted in fourteen-dimensional space using a system of parallel coordinates as illustrated in Figure 2.

Referring to Figure 2, the fourteen values are plotted on fourteen equally-spaced, parallel axes X01-X14 representing the fourteen variables respectively. The first three axes, X01-X03, are used for the quality variables, and the plots are joined up to form a polygonal line L that is representative of the single fourteen-value operating point of the process. The other sets of process-values are each correspondingly plotted against the same axes X01-X14 resulting in a multiplicity of polygonal lines corresponding to the line L; this is illustrated in part in Figure 3. Each polygonal line is representative of an individual operating point or run of the process from the historical record.

Referring further to Figure 3, convex hulls H for all pairs of adjacent variables of the parallel-axis system, are calculated in the unit 11 and displayed. Between each pair of adjacent axes X01-X14 there will be an upper and lower hull H defining upper and lower limiting boundaries between those two axes, of the operating-point lines. The upper and lower hulls H of the successive pairs of adjacent axes join together to define top and bottom boundaries or chains TC and BC respectively. Calculation of the convex hulls applicable to all the other pairings of variables is also made, but are not displayed in display unit 12.

Once the calculation of all the convex hulls has been completed, a display as shown in Figure 4 is provided in which the upper and lower hulls H are restricted for simplicity to those parts lying within the range 0 and 1. In this way, the upper and lower hulls H are seen more

clearly as joining up together as top and bottom chains TC and BC respectively, defining (for example, in colour red) the upper and lower boundaries of a region within which feasible operation of the process can take place. Clearly, the larger the number of historical sets of operational data used, with as wide as possible range of values for the individual variables, the more accurately will this region be defined.

It is optional whether representation in the form of Figure 3 is provided by the display unit 12, but representation in the form of Figure 4 is displayed and utilised for the selection of the process-variables to be used in optimum, or otherwise, operation of the process. The steps of selection begin with fixing the first variable, that is to say, the variable of axis X01. This is a quality variable and the selection made establishes the value, Q1, this variable is to have in the outcome of the prospective process-run. The selection may be made by moving a cursor up the axis X01 in the display using a mouse (not shown), and clicking at the appropriate position.

The selection of the value Q1 of the first variable, brings about display of a polygonal line L1 (for example in colour blue) representing the operating point that would result in the event that the other thirteen variables were each fixed at the mid-points of their available ranges. In this regard, a calculation is made for each of these unfixed variables of the restricted range of values which is open for selection in respect of that variable as a consequence of the selection of value Q1 for the first variable. The range is derived in each case by reference to the convex hull between the fixed first variable and the unfixed variable. These ranges are denoted in the display for each unfixed variable by the intersection with its respective axis X02-X14 of two

lines R1 (for example in colour green) that diverge from the immediately preceding axis X01-X13; the lines R1 are tangential to the convex hull between the fixed first variable and the unfixed variable. The lines R1 that intersect the axis X02 of the second variable diverge from the selected value Q1 on the axis X01, whereas in each other case (for the variables of axes X03-X14) they diverge from the mid-point of the available range of the variable of the immediately preceding axis X02-X13. It is this mid-point that is assumed selected for each of the unfixed variables, in the plotting of the line L1.

The next step is the selection of the value Q2 of the variable of the second axis X02. Selection is made by moving the cursor up the axis X02 and clicking the mouse at the appropriate position, and has the effect of changing the display to that shown in Figure 5. A new line L2 is displayed joining the fixed points Q1 and Q2 between axes X01 and X02 and extending from point Q2 through the mid-points of the available ranges of the other twelve, unfixed variables. These available ranges, which are denoted by divergent lines R2 (for example in colour green), are each derived by reference to the overlap with the range previously calculated for the fixed value Q1 and denoted by lines R1. The available range defined for each unfixed variable by the lines R2 is restricted by virtue of the overlap to the range of values of that variable which is available for selection having regard to both selected values Q1 and Q2. The lines R1 and L1 may, as indicated in Figure 5, be retained in the display (but for example now in colour grey) for reference purposes to indicate the range available for each unfixed variable before selection of value Q2, and the previous course of the line L1 from the axis X02.

The selection method now proceeds to the step of selecting in a similar way the value Q3 of the third variable (axis X03), and then on from there through successive steps until the values Q4-Q14 of all the remaining variables have been selected to complete definition of the value-set for the desired operating point. The display changes as the selections are made, and for example appears as in Figure 6 when the values Q1-Q5 of the first five variables have been selected. In this case, lines R5 identify the available ranges for the remaining variables of axes X06-X14, and lines R4 show the ranges available immediately before the value Q5 was selected. The polygonal line L5 interconnects the already-selected values Q1-Q5 and the mid-point values of the available ranges of the remaining unfixed variables, whereas line L4 shows its previous course from axis X05.

As each individual selection is made to fix the value Qn of the next unfixed variable (in the order of the axes X01-X14), so the restricted range due to each already-fixed variable is calculated using the relevant convex hull between those fixed and unfixed variables. The available range is displayed for each unfixed variable using lines Rn. The lines Rn define the available range of each unfixed variable as the portion of the relevant axis X which is common to (overlapped by) the restricted ranges derived for that variable and each of the fixed variables. The polygonal line Ln is established passing through all the values Q selected for the currently-fixed variables and also through the mid-points of the available ranges of the unfixed variables.

The polygonal line Ln connects the fixed values of the fixed variables and the working (or suggested) values of the unfixed variables. To ensure that the line Ln always represents a feasible operating point of the process, the working values of the unfixed variables apart from that

to the immediate right of the last fixed variable, are calculated using a more restricted range than that displayed. In this regard, the range due to the fixed variables is overlapped with the ranges due to the working values of all the unfixed variables to the left of the one whose working value is being calculated to give the working range, and the mid-point of this range is taken as the working value. These working ranges may be optionally displayed in a different colour from the ranges due to the fixed variables.

Throughout the method of the invention as the display progresses step-by-step from that of Figure 4 to that of Figures 5 and 6, and so on until all selections have been made, the operator is presented with information that enables selection of feasible values of the variables consistent with desired objectives of economy, efficiency and outcome of the process. The information is derived without the need to fit a functional model to the historical data and the disadvantages associated with this, and is applicable to adjustment or re-setting of the controllers 5 of the plant 1 for optimisation of plant-operation.

The values of the variables that have been fixed in the display of unit 12 can be changed. This enables the operator to search for sets of values that give the 'best' ranges for the unfixed variables, and in this regard the 'best' range in any particular case may simply be a narrow range about a desired value. The limits within which each fixed variable can be moved while holding the other fixed variables constant, are calculated using the convex hulls between the fixed variables, and are included in the display. This display changes continuously as the fixed variable is changed.

These characteristics of the display may be used with particular advantage if the controllable variables are fixed and arranged to the left of all the quality variables. The controllable variables can then be moved until satisfactory values of the quality variables are obtained.

The latter functionality of the display is illustrated in the example of Figures 7 to 10. In this example, variables p11, p12, p13 and p14 are considered to be 'process' variables which can be manipulated, and variables q7 and q8 are considered to be 'quality' variables which depend on the process variables.

In Figure 7, point Fp11 is the value to which the variable p11 has been set, and points Wp12 to Wp14 and Wq7 and Wq8 are the working values of variables p12 to p14 and q7 and q8 respectively. These points are joined by a polygonal line L1, and line-pairs RF1 to RF5 display the ranges of the respective variables p12 to p14 and q7 and q8, that are due to variable p11 having the value Fp11. The range in each case is shown by the intercept the line-pair makes with the axis of the relevant variable.

A line-pair RW2 (the upper line of which is co-linear with the upper line of the line-pair RF2) show by their intercepts on the axis p13 the range of variable p13 that is due to variable p11 having the value Fp11 and the variable p12 having the value Wp12. The value Wp13 is the mid-point of this range. Similarly, a line-pair RW3 displays the range of variable p14 that is due to variables p11, p12 and p13 having the values Fp11, Wp12 and Wp13 respectively, and value Wp14 is the mid-point of this range. Line-pairs RW4 and RW5 correspondingly display ranges, with mid-points Wq7 and Wq8, of the variables q7 and q8 that are due respectively to the

values set for the four variables p11 to p14, and the five variables p11 to p14 and q7.

Figure 8, illustrates the display that results from now setting the variables p11 to p14 to the values Fp11 to Fp14 respectively. Carets at Up11 and Lp11 indicate the calculated limits (as referred to above) between which the value of variable p11 may be moved while holding variables p12, p13 and p14 at values Wp12, Wp13 and Wp14 respectively. Similarly, carets at Up12 and Lp12 indicate the limits between which the variable p12 may be moved while holding variable p11 at value Fp11, variable p13 at value Fp13, and variable p14 at value Fp14. Carets Up13 and UL13 and Up14 and Lp14 are correspondingly provided for the variables p13 and p14, and the upper carets Up11 to Up14 are joined by polygonal line UC and the lower carets Lp11 to Lp14 by polygonal line LC.

Figure 9 illustrates the effect of moving the point Fp13 to the current lower limit represented by caret Lp13. The limits represented by the other carets have in general changed, and so too have the ranges of variables q7 and q8 represented by the line-pairs RF4 and RF5. In particular, the upper limit of variable p14 represented by caret Up14, has moved down to the current value Fp14, indicating that the convex hull between axes p13 and p14 is setting the most restrictive lower limit on variable p13.

Figure 10 illustrates the situation when the user, by experimenting with the values of variables p11 to p14, has discovered settings for these variables which keep the value of variable q8 within a narrow range near the value 0.5, as evidenced by the intercepts of both lines RF5 with the axis of variable q8, close to this value.

The display techniques described above may be used to determine appropriate warning alarm levels on plant variables during process operation, and to display those alarm levels and the current values of the corresponding variables to the process operator. This is achieved as illustrated in Figure 1, using a further electronic display unit 13. The display unit 13 is driven from an alarm-algorithm unit 14 in accordance with data from the unit 11 and the values of the process variables in real time, supplied from the unit 6. All the variables are treated as of fixed value.

Whenever a new set of values for the process variables is received from the unit 6, the unit 14 identifies which variables have values lying in the 'best-operating' zone or region defined between the relevant top and bottom chains of convex hulls. Upper and lower limits for all variables are calculated from these values within the best-operating zone using the relevant convex hull as for the display of unit 12. Furthermore, the unit 14 identifies which, if any, of the variables have values that lie outside these limits, and gives warning by indication in the display of unit 13 or otherwise, of the condition. As each new set of values is received, the display changes, and the limits on all the variables are re-calculated and shown in the display of unit 13, exactly as if the point had been moved by the program-user in off-line operation. The quality variables are treated no differently from the control variables in determining the on-line alarm limits.

In this way the display unit 13 provides representation of warning alarm limits for all variables simultaneously. These limits are always calculated using the current values of all the other variables; no model-fitting or statistical assumptions are required.

Displays provided by the unit 13 in three different circumstances are illustrated in Figures 11 to 13, for ten variables plotted against axes Xa-Xj.

Referring to Figure 11, the plotted values Qa to Qj are all within the current best-operating zone defined between top and bottom chains Tc and Bc respectively. Upper and lower current limits calculated for the individual variables and plotted on the respective axes Xa-Xj are joined up to provide polygonal lines UL and LL. The lines UL and LL define the zone within which the values of the variables are to be retained. In this example, all values Qa to Qj are within the zone, but this is not so in the circumstances of the displays illustrated in Figures 12 and 13.

In the circumstances of the display of Figure 12, the value Qc for the variable plotted on the axis Xc is on the upper limit UL, and the values Qb, Qg, Qi and Qj for the variables plotted on axes Xb, Xg, Xi and Xj respectively, are on the lower limit LL. On the other hand, in the circumstances of the display of Figure 13, the values Qc and Qd of the variables plotted on axes Xc and Xd, are the only ones within the best-operating zone between the limit lines UL and LL. In both cases, as illustrated in Figures 12 and 13, a caret (for example of colour red) is included in the display where a variable-value is on the boundary or outside the best-operating zone. More particularly, a downwardly-directed caret DC is displayed on the relevant axis of any variable where the value is on or above the line UL and an upwardly-directed caret UC is correspondingly displayed where the value is on or below the line LL.

The process operator can interact with the display unit 13 to adjust one or more of the fixed values Qa-Qj up or down their respective axes experimentally, to see the

effect this has on the limits of the other variables. When an alarm condition exists, and several variables are on or beyond their limits, adjusting the value Q of even one of them may be found to move the limit lines UL and LL outwardly from one another sufficiently to relieve the alarm condition on the others.

Accordingly, by using the on-line display of unit 13, the operator can not only monitor the current settings and results of the process, but can also be made aware of alarm situations and receive guidance in focussed investigation of the remedial action necessary.

Claims:

1. A method for displaying variables of a multi-variable process, comprising deriving a multi-dimensional display representation in parallel coordinates of a feasible region of the process-variables, the representation being derived from sets of values for the process-variables accumulated respectively from multiple operations of the process, deriving a further set of values for said variables within said region and displaying them within said representation, and defining within the display representation available ranges for the variables according to the values of other variables within said further set.

2. A method according to Claim 1 wherein definition of the available ranges utilises convex hulls that are calculated for each pair of variables from the accumulated sets of values.

3. A method according to Claim 2 wherein the variables are related in ordered sequence to respective axes of a set of parallel coordinate axes of the multi-dimensional representation, and convex hulls for the successive pairs of variables in said ordered sequence are displayed between the axes of those variables in said representation.

4. A method according to any one of Claims 1 to 3 wherein the values of the further set of values are derived selectively and sequentially with one another, and the available ranges are defined and re-defined according to the selections made.

5. A method according to any one of Claims 1 to 3 performed during running of the process, wherein the

values of said further set are the current values of the variables during that run, and alarm indication is provided in respect of any said variable for which the current value is outside the available range for that variable.

6. A method according to Claim 5 wherein said alarm indication includes the display of an alarm marking against the available range violated.

7. A method for selection of values for variables of a multi-variable process, comprising a first step of deriving a multi-dimensional display representation in parallel coordinates of a feasible region of the variables, the representation being derived from sets of values for the process-variables accumulated respectively from multiple operations of the process, a second step of selecting, so as to fix, a value within said region for one of said variables and defining available ranges for the other variables in accordance with the selection made, and a third step of selecting, so as to fix, a value within the available range defined for one of the remaining unfixed-value variables and re-defining the available ranges for the other unfixed-value variables in accordance with the selections so far made, this third step being repeated until values for all unfixed-value variables have been fixed by the selections made.

8. A method according to Claim 7 wherein definition of the available ranges utilises convex hulls that are calculated for each pair of variables from the accumulated sets of values.

9. A method according to Claim 8 wherein the variables are related in ordered sequence to respective axes of a set of parallel coordinate axes of the multi-dimensional representation, and convex hulls for the successive pairs

of variables in said ordered sequence are displayed between the axes of those variables in said representation.

10. A method according to Claim 9 wherein the value of said one variable is selected by selecting a position corresponding to that value along the first axis of the set of axes, and the multi-dimensional representation includes display of a polygonal line that extends from the selected position to intersect each individual axis of the other axes at a position corresponding to the mid-point of a working range that lies within said available range defined for the variable of that axis.

11. A method according to Claim 10 wherein said third step includes the display of a new polygonal line in the multi-dimensional representation as the value of each successive variable is fixed by selection, the new line extending through positions which on the respective axes of the fixed-value variables correspond to the values selected, and which on the respective axes of the unfixed-value variables correspond to the mid-points of working ranges that lie within the said available ranges of those unfixed-value variables.

12. A method according to Claim 11 wherein the available range for each unfixed-value variable is displayed on the axis of that variable by an intercept therewith of divergent lines from the axis of the immediately preceding variable of said ordered sequence.

13. A method according to any one of Claims 8 to 12 wherein the re-definition of available ranges in the third step is effected in dependence upon the convex hulls which are applicable individually between the remaining variables of unfixed value and each of the fixed-value variables.

14. A method according to any one of Claims 7 to 13 wherein the representation includes display in respect of each of a plurality of the fixed-value variables, of a range within which the value of that variable may be changed while holding the others of said plurality of fixed-value variables at their fixed values.

15. A method according to any one of Claims 7 to 14 wherein a further multi-dimensional display representation in parallel coordinates is provided during running of the process, the further representation displaying the values of the variables current during that run and providing alarm indication in respect of any said variable for which the current value is outside limits for that variable that are dependent upon the current values of the other variables and are calculated in accordance with the sets of accumulated values.

16. A method according to Claim 15 wherein said limits are displayed in the display representation, and said alarm indication includes the display of an alarm marking against a limit violated.

17. A system for displaying variables of a multi-variable process, comprising means for providing a multi-dimensional display representation in parallel coordinates of a feasible region of the process-variables, the representation being derived from sets of values for the process-variables accumulated respectively from multiple operations of the process, means for deriving a further set of values for said variables within said region and displaying them within said representation, and means for defining within the display representation available ranges for the variables according to the values of other variables within said further set.

18. A system according to Claim 17 wherein definition of the available ranges utilises convex hulls that are calculated for each pair of variables from the accumulated sets of values.

19. A method according to Claim 18 wherein the variables are related in ordered sequence to respective axes of a set of parallel coordinate axes of the multi-dimensional representation, and convex hulls for the successive pairs of variables in said ordered sequence are displayed between the axes of those variables in said representation.

20. A method according to any one of Claims 17 to 19 wherein the values of the further set of values are derived selectively and sequentially with one another, and the available ranges are defined and re-defined according to the selections made.

21. A method according to any one of Claims 17 to 19 performed during running of the process, wherein the values of said further set are the current values of the variables during that run, and alarm indication is provided in respect of any said variable for which the current value is outside the available range for that variable.

22. A method according to Claim 21 wherein said alarm indication includes the display of an alarm marking against the available range violated.

23. A system for providing a display representation for use in selection of values for variables of a multi-variable process, comprising means for storing sets of values for the process-variables accumulated respectively from multiple operations of the process, display means for providing a multi-dimensional display representation

in parallel coordinates, the representation including in accordance with the stored sets of values, display of a feasible region of the variables, and selection means that is operable successively to select, so as to fix, values within said region for all said variables in turn, said display means being operative upon each operation of the selection means to define available ranges for such of the other variables that remain of un-fixed value.

24. A system according to Claim 23 wherein the display means includes an electronic display unit.

25. A system according to Claim 23 or Claim 24 wherein said display means determines the available ranges from convex hulls calculated for each pair of variables from the accumulated sets of values.

26. A system according to Claim 25 wherein the variables are related in ordered sequence to respective axes of a set of parallel coordinate axes of the multi-dimensional representation, and convex hulls for the successive pairs of variables in said ordered sequence are displayed between the axes of those variables in said representation.

27. A system according to Claim 26 wherein the value of said one variable is selected by selecting a position corresponding to that value along the first axis of the set of axes, and the multi-dimensional representation includes display of a polygonal line that extends from the selected position to intersect each individual axis of the other axes at a position corresponding to the mid-point of the available range defined for the variable of that axis.

28. A system according to Claim 27 wherein said display means is operative to display a new polygonal line in the

multi-dimensional representation as the value of each successive variable is fixed by selection, the new line extending through positions which on the respective axes of the fixed-value variables correspond to the values selected, and which on the respective axes of the unfixed-value variables correspond to the mid-points of the available ranges of those unfixed-value variables.

29. A system according to Claim 28 wherein the available range for each unfixed-value variable is displayed on the axis of that variable by an intercept therewith of divergent lines from the axis of the immediately preceding variable of said ordered sequence.

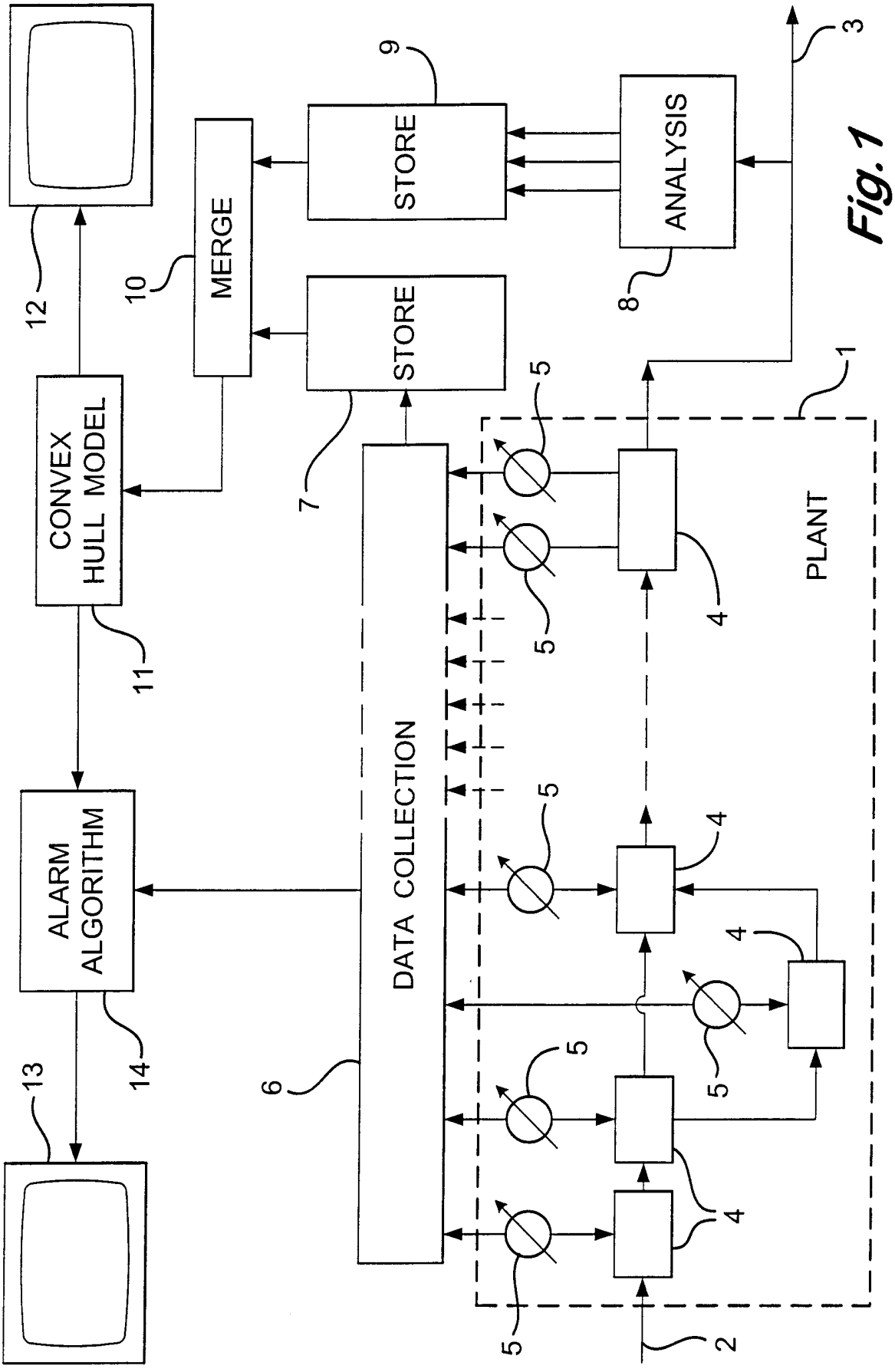
30. A system according to any one of Claims 25 to 29 wherein the definition of available ranges is effected in dependence upon the convex hulls which, for the time being, are applicable individually between such of the variables that remain of unfixed value and each of the fixed-value variables.

31. A system according to any one of Claims 23 to 30 wherein the representation includes display in respect of each of a plurality of the fixed-value variables, of a range within which the value of that variable may be changed while holding the others of said plurality of fixed-value variables at their fixed values.

32. A system according to any one of Claims 23 to 31 including further display means for providing display representation in parallel coordinates during running of the process, the further representation displaying the values of the variables current during that run and providing alarm indication in respect of any said variable for which the current value is outside limits for that variable that are dependent upon the current

values of the other variables and are calculated in accordance with the sets of accumulated values.

33. A system according to Claim 32 wherein said limits are displayed in the display representation, and said alarm indication includes the display of an alarm marking against a limit violated.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14
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STORE
STORE
MERGE
ANALYSIS
CONVEX HULL MODEL
ALARM ALGORITHM

Fig. 1

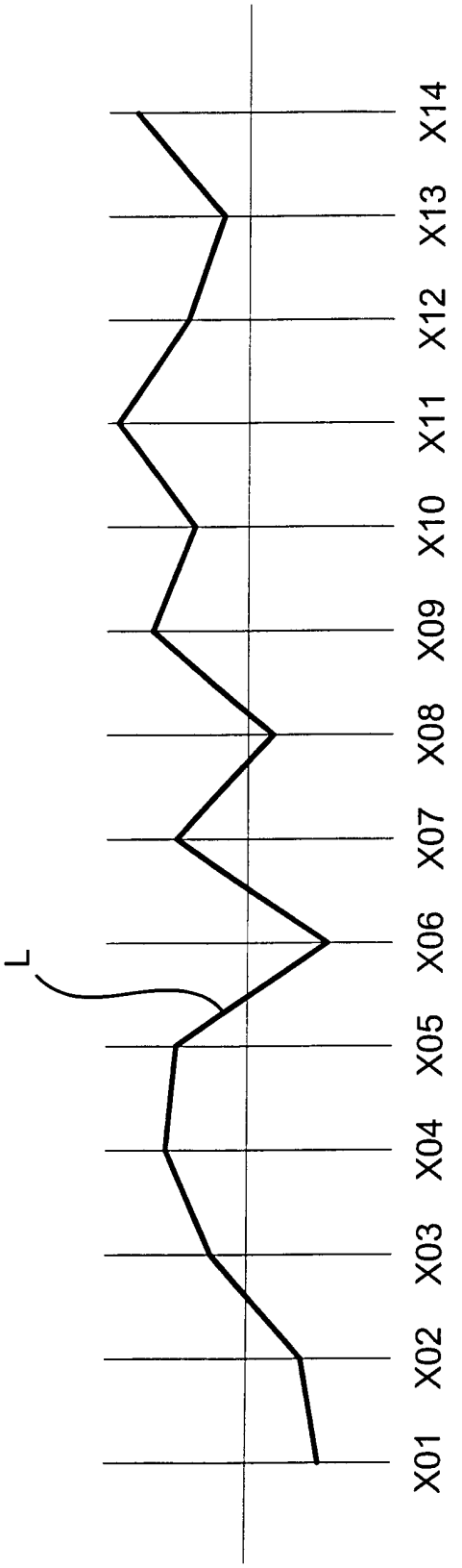


Fig.2

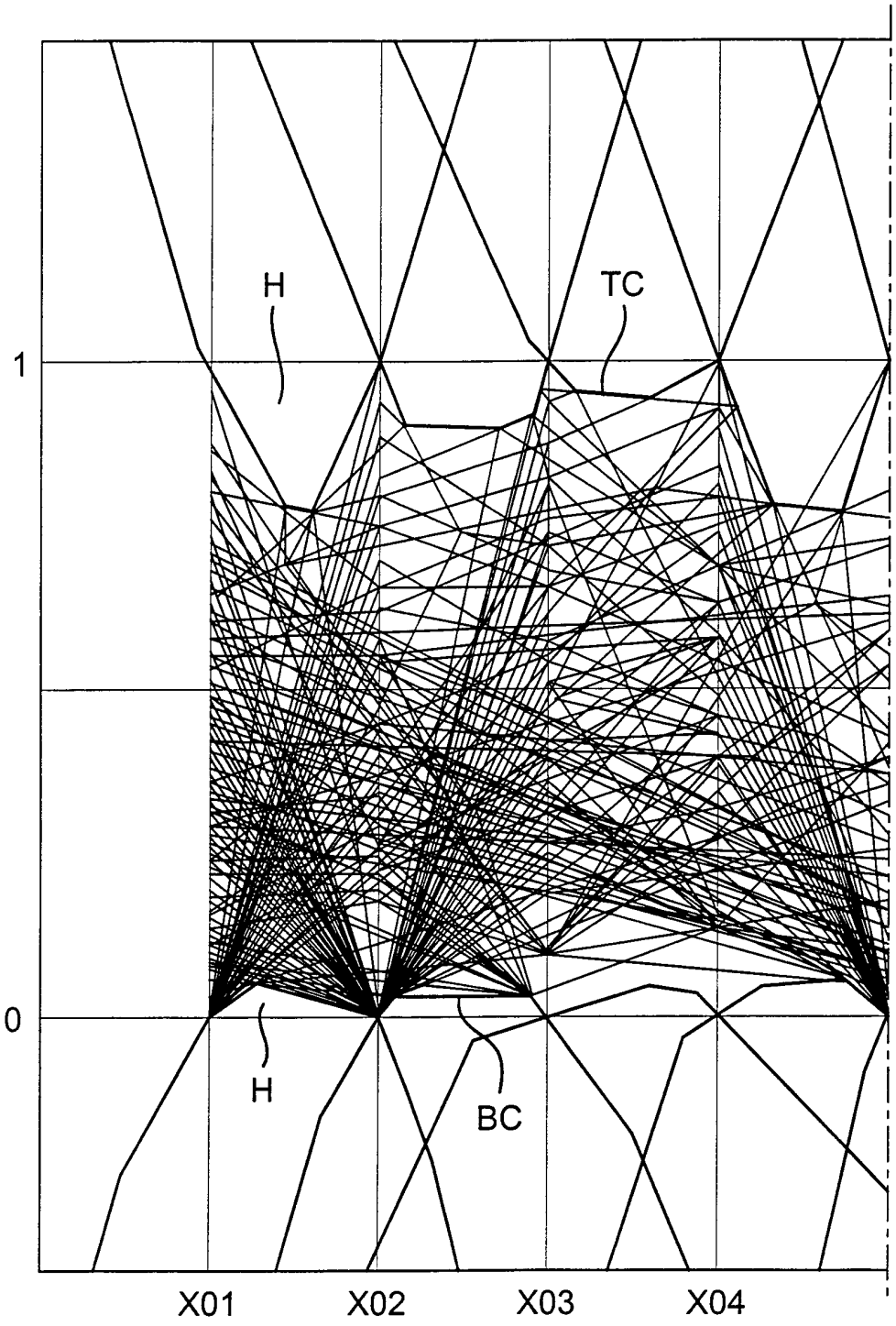


Fig.3

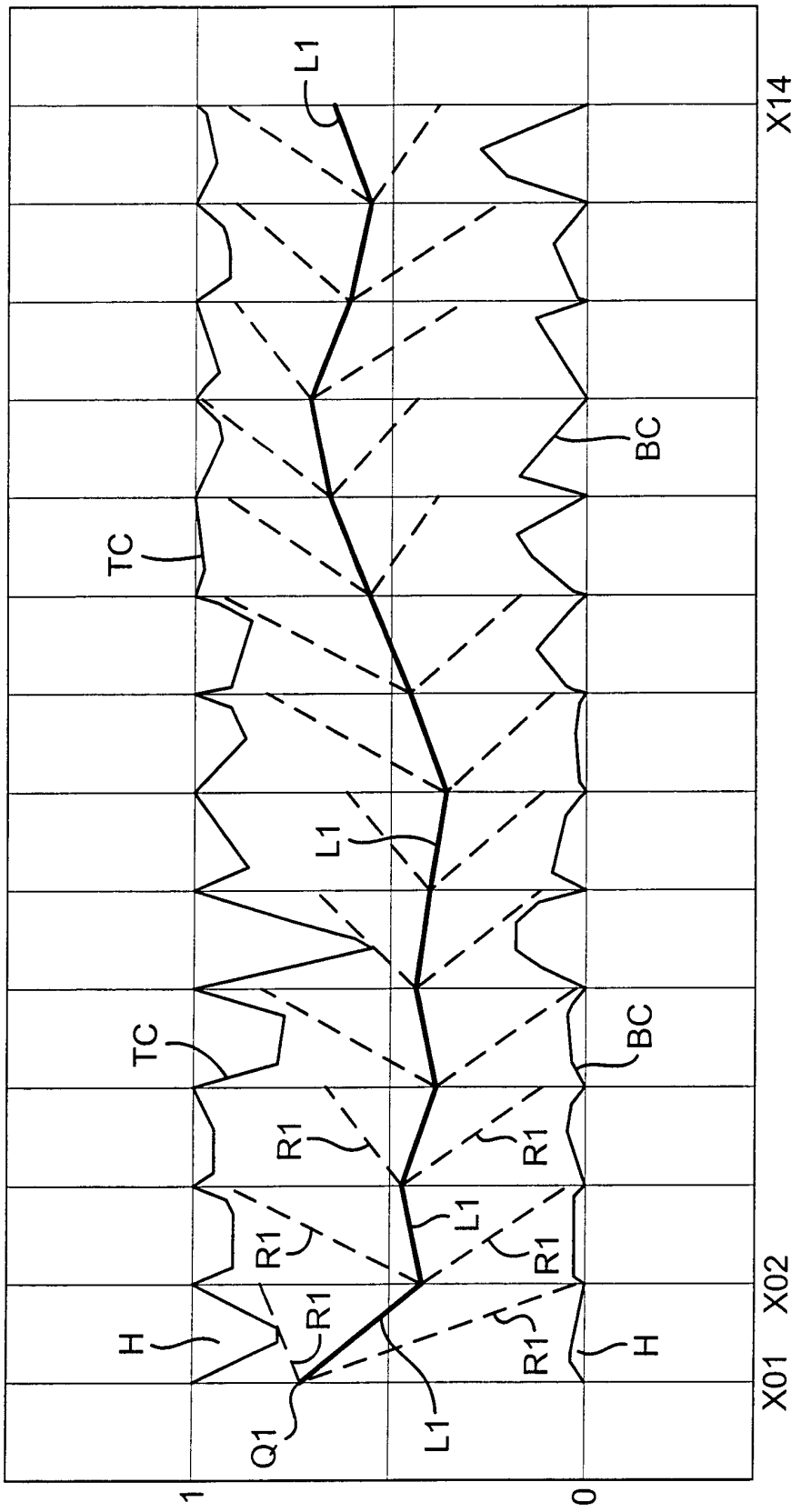


Fig.4

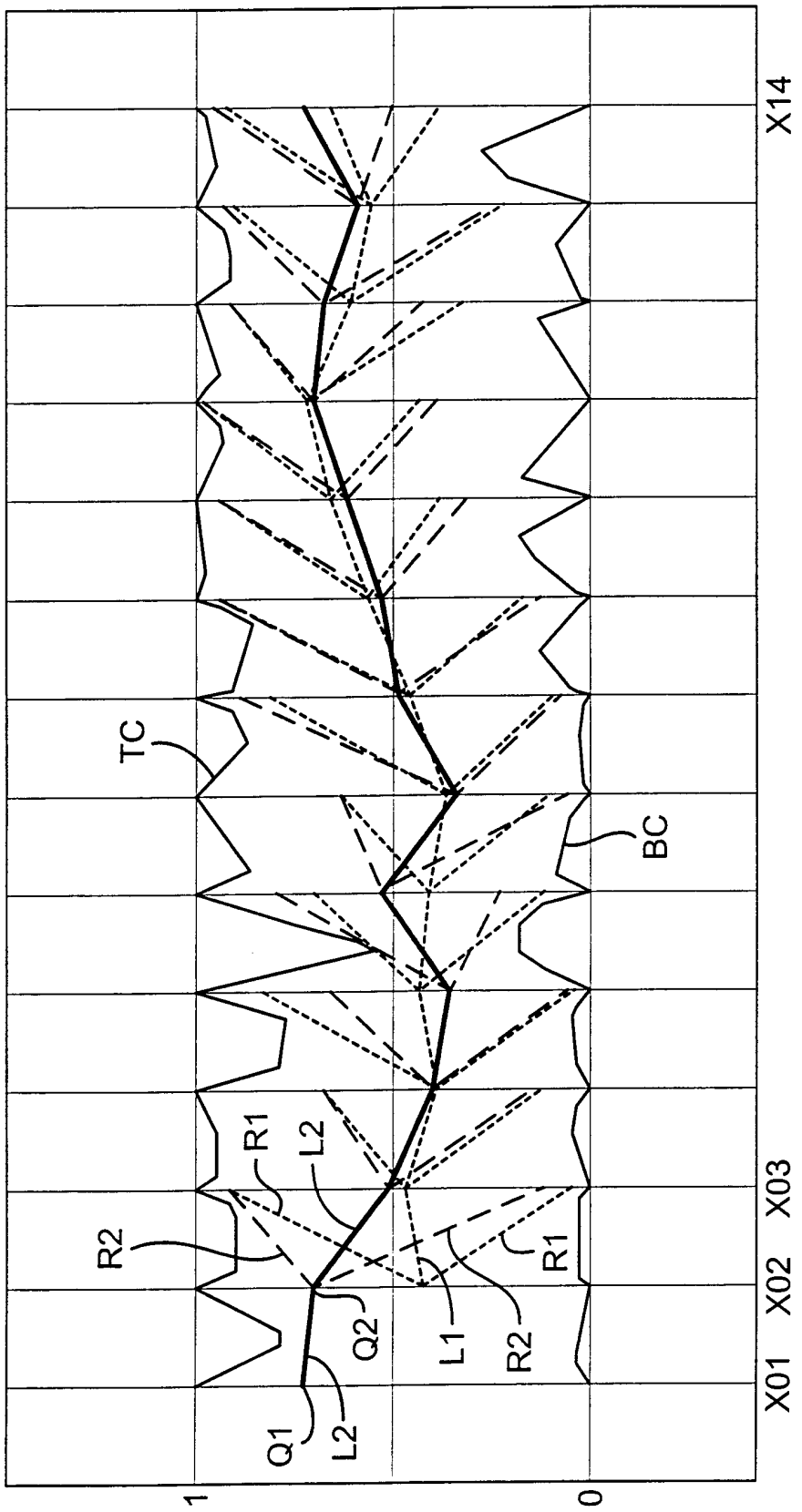
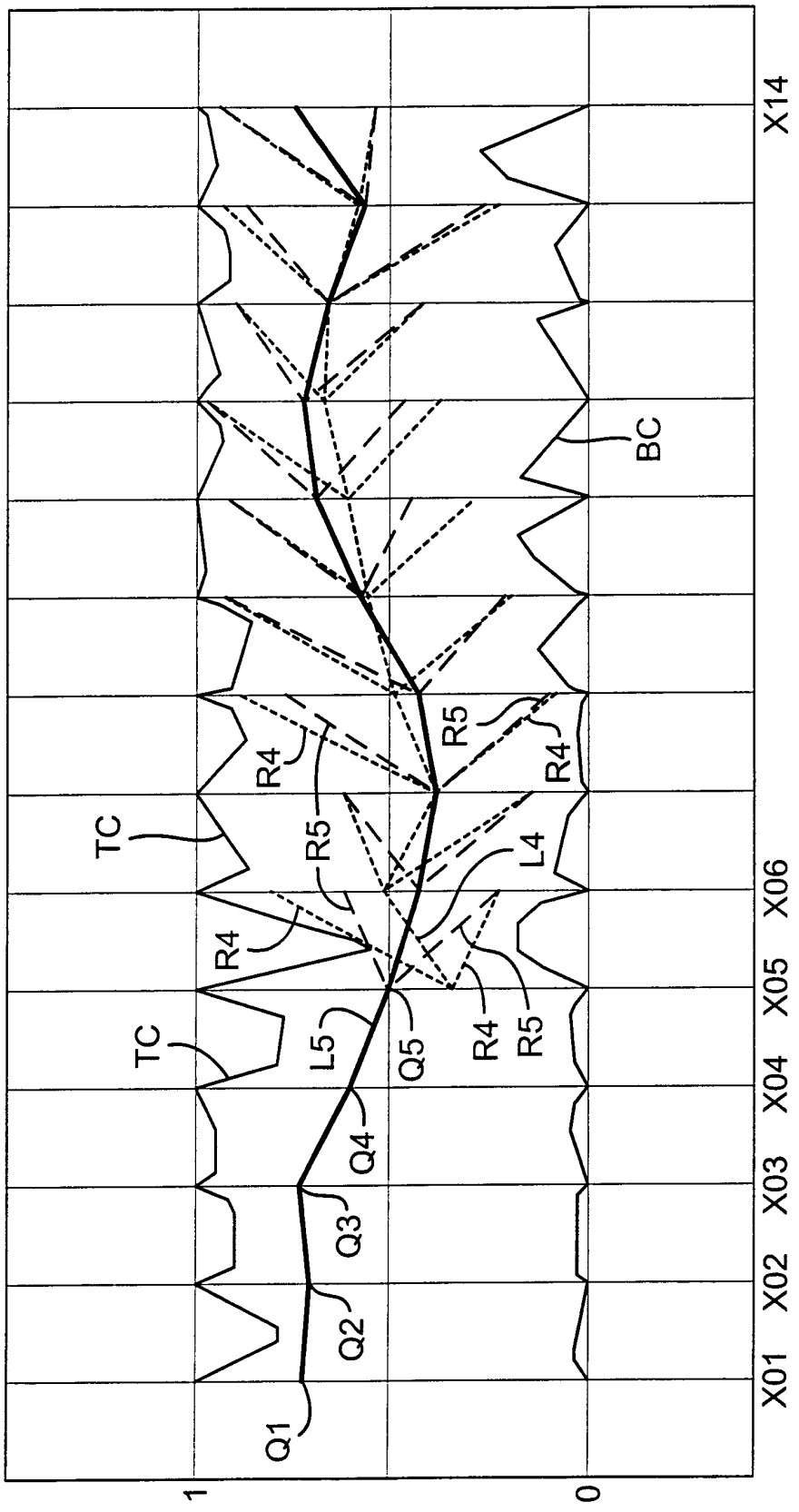


Fig.5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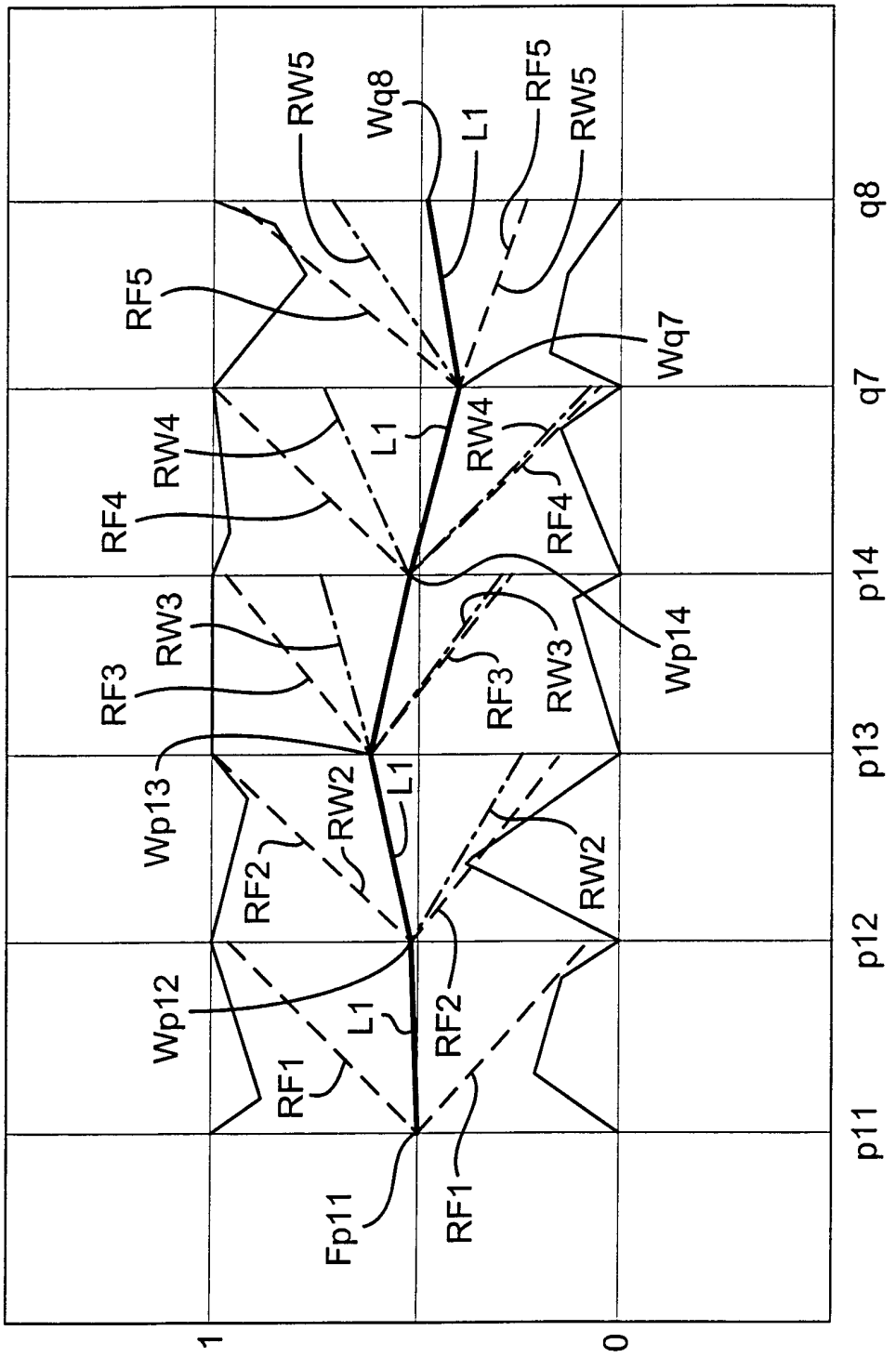
R5
BC

Fig.6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RW2
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p14
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q8

Fig. 7

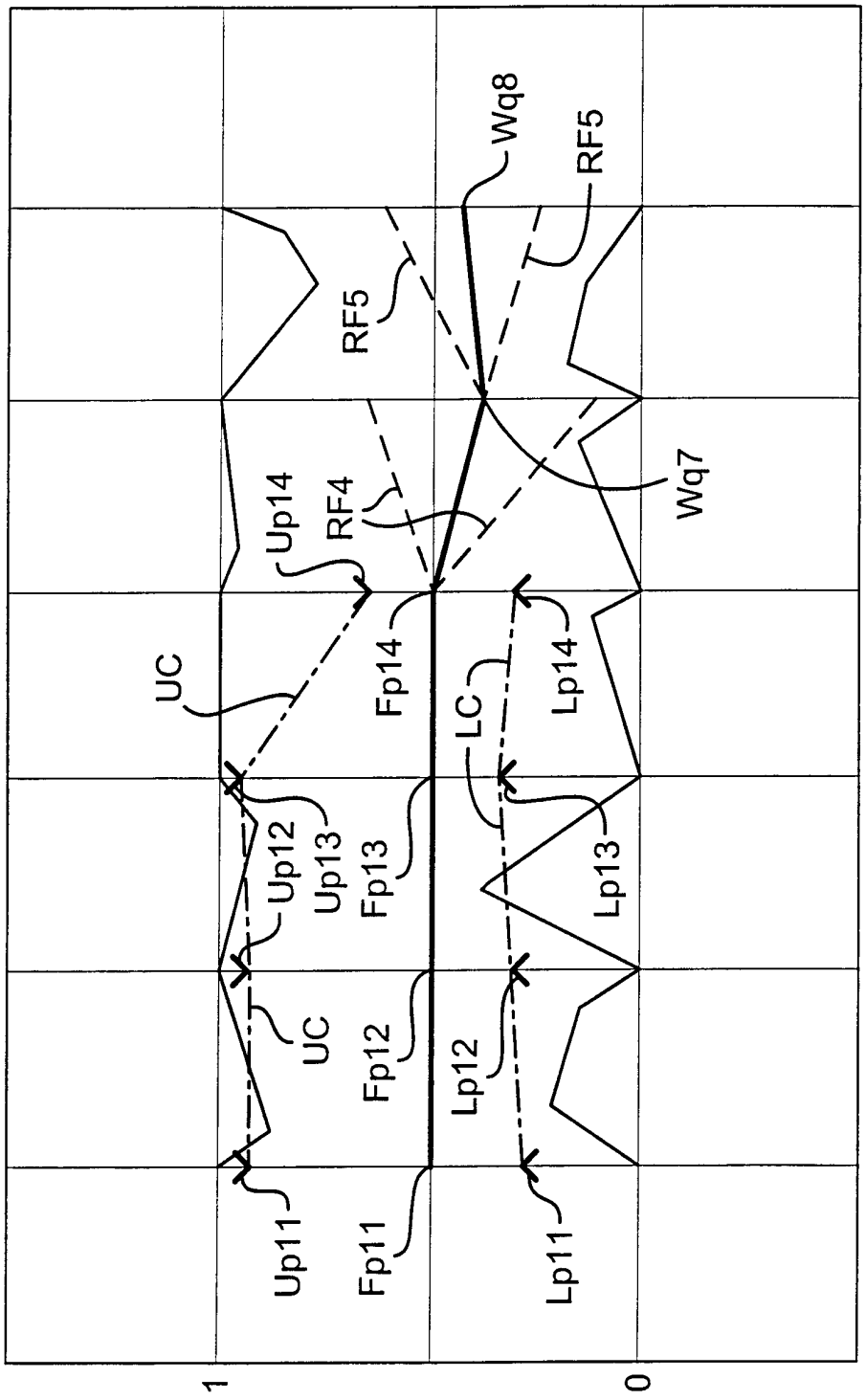
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Fig.8

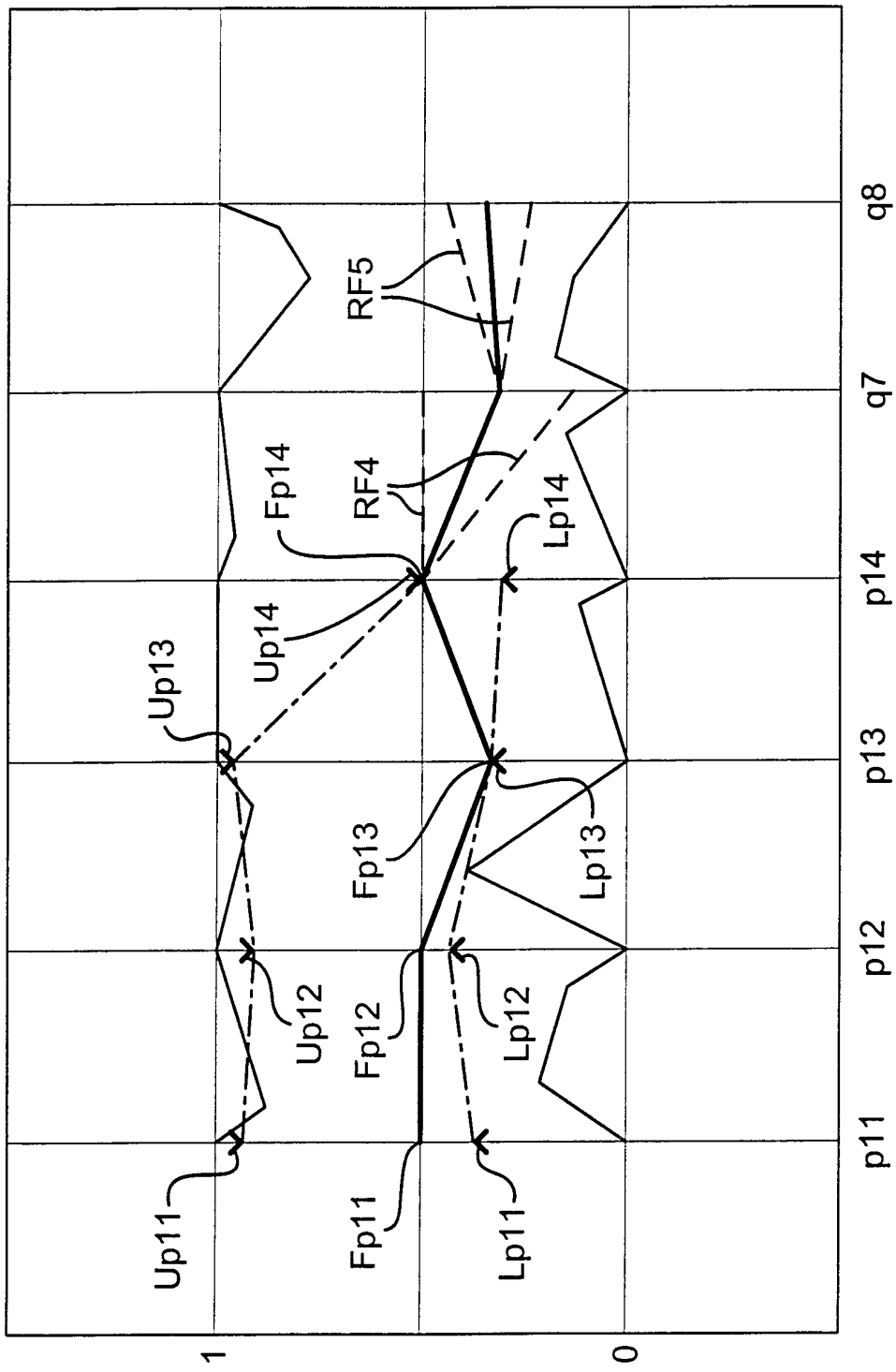
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Fig.9

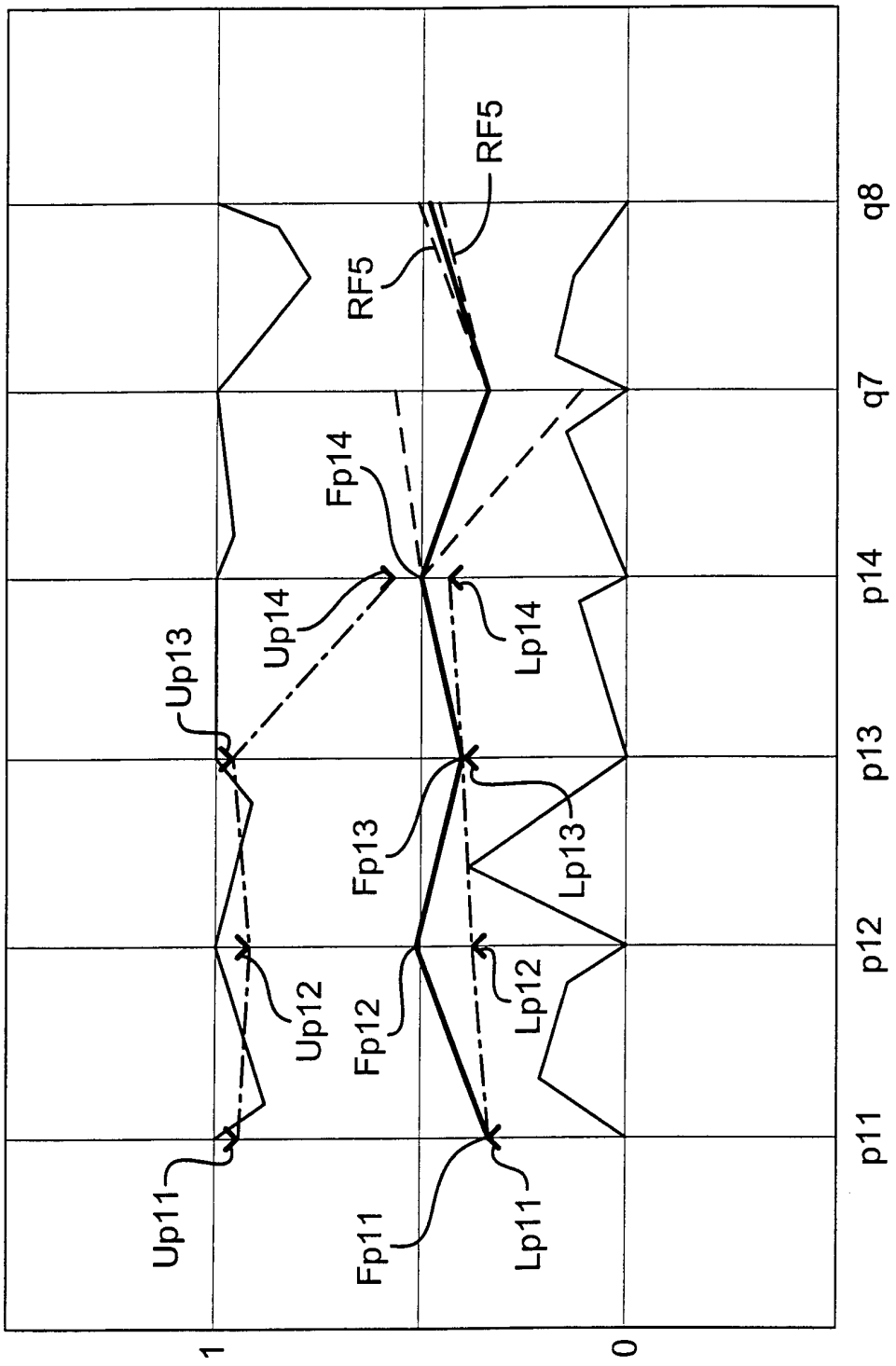
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Fig. 10

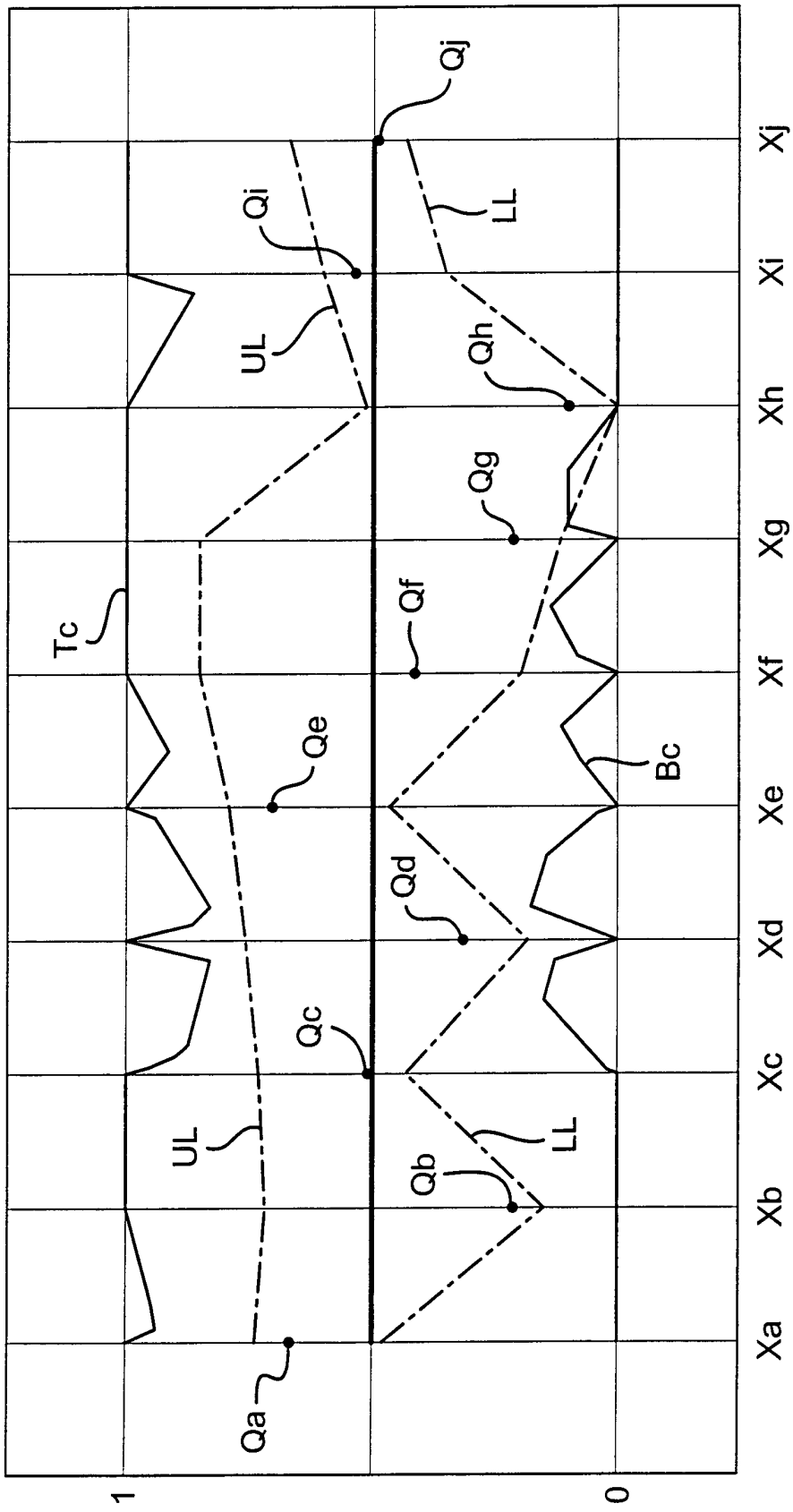
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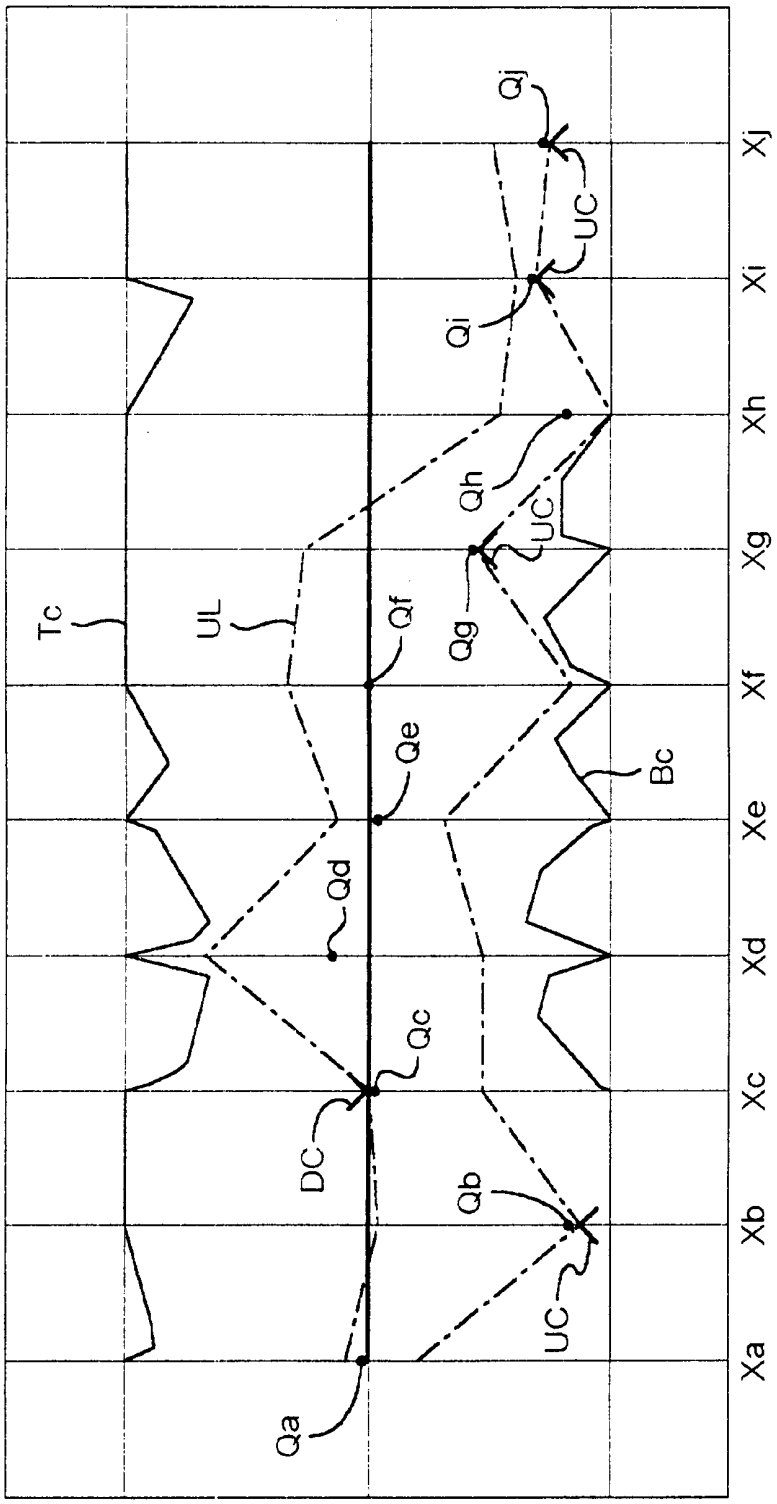
Fig. 11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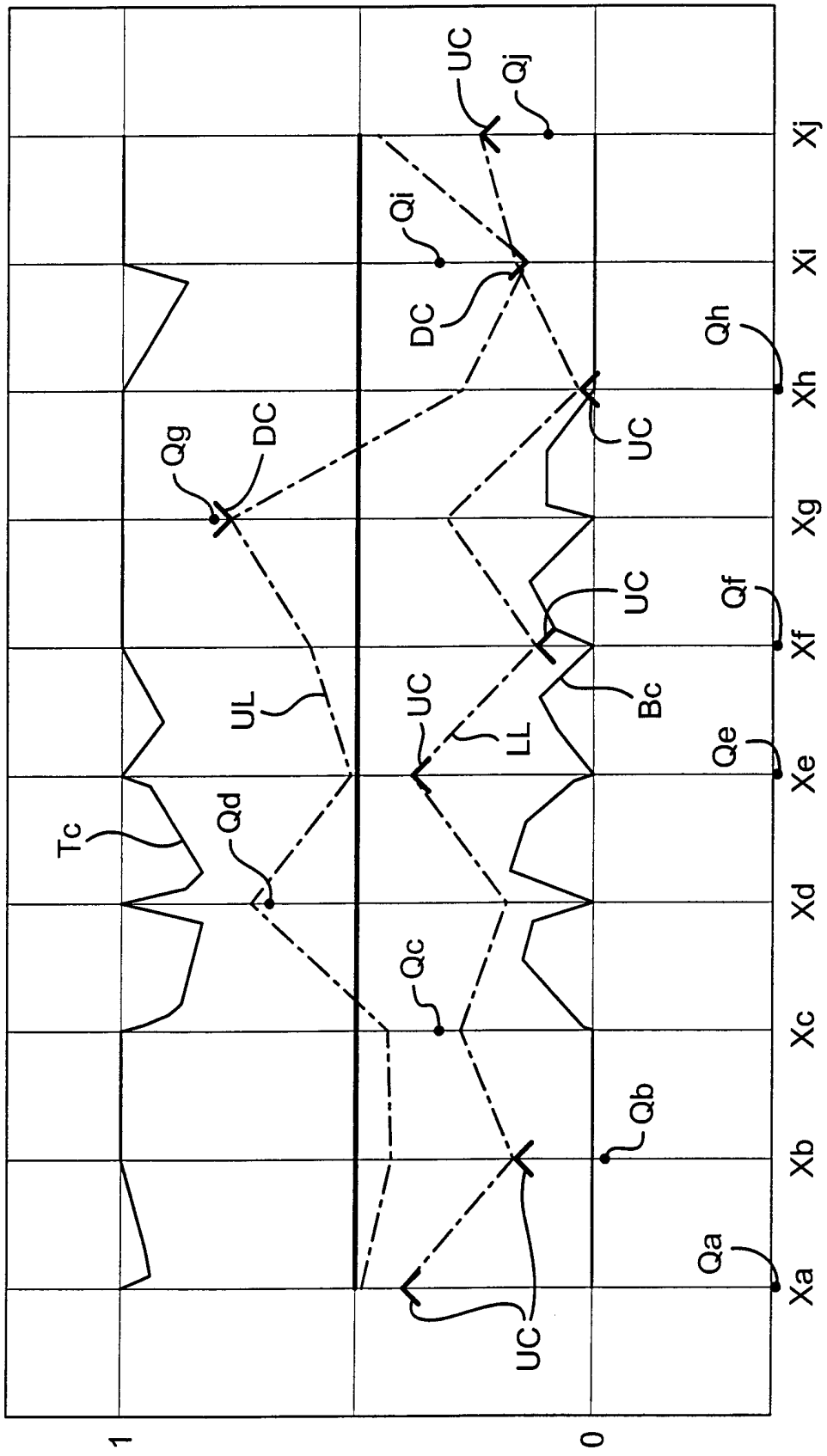
Xj

Fig. 12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Xe
Tc
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Qb
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Xa
UC
1
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Fig. 13

INTERNATIONAL SEARCH REPORT

Internat .l Application No
PCT/GB 00/04506

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01D7/06 G05B23/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01D G05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
WPI Data, PAJ, EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 453 817 A (TEKTRONIX INC) 30 October 1991 (1991-10-30) abstract	1,4-7, 17,20-23
A	ZINSER K: "INTEGRATED MULTI MEDIA AND VISUALISATION TECHNIQUES FOR PROCESS S&C" PROCEEDINGS OF THE INTERNATIONAL CONFERENCE ON SYSTEMS, MAN AND CYBERNETICS,US,NEW YORK, IEEE, vol. -, 17 October 1993 (1993-10-17), pages 367-372, XP000462477 ISBN: 0-7803-0911-1 figures 2,4	1
A	EP 0 753 283 A (HEWLETT PACKARD CO) 15 January 1997 (1997-01-15) abstract	1

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

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"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 April 2001	17/04/2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Lloyd, P

1

Form PCT/ISA/210 (second sheet) (July 1992)

INTERNATIONAL SEARCH REPORT

Information on patent family members

Internat. ..l Application No
PCT/GB 00/04506

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0453817 A	30-10-1991	US 5148230 A	15-09-1992
		DE 69112479 D	05-10-1995
		DE 69112479 T	22-08-1996
		JP 2704323 B	26-01-1998
		JP 5346369 A	27-12-1993
EP 0753283 A	15-01-1997	US 5731998 A	24-03-1998