Plant auditing – a new methodology for optimizing asset management

Plant auditing is a new methodology which makes the operating conditions in industrial plants easier to interpret and supervise. Its new presentation technique displays quality aspects that allow information normally hidden in time-based trend curves to be observed. In addition, a fuzzy-based knowledge system gives early warning of plant conditions that could cause loss of performance. Plant auditing integrates fully automated handling, including report generation, in a global engineering tool that supports regulatory control as well as maintenance work. Since it makes use of existing field equipment, plant auditing can be applied directly in any industrial sector.

Plant maintenance and supervision have traditionally relied on performance monitoring based on conventional trend curves generated with data from field instruments. As a result, they have looked basically the same since the time of line recorders. Also largely unchanged is the way the information is handled, reprocessing of logged data by means of advanced signal analysis being the exception rather than the rule.

Plant auditing is a new methodology which supplies production engineers and management with direct information about plant operating conditions in an easily understood form. Despite being new, it makes use of existing measuring devices and mechanical apparatus, such as valves and pumps. Since no new equipment is needed, plant auditing can be applied directly in any industrial sector.

Supervision of plant operating conditions by means of plant auditing is superior to any other known technology. Among the user benefits it offers are:

- Extended equipment lifetime
- Higher plant production capacity and reduced downtime
- Higher and more consistent product quality
- Much greater awareness of different plant operating conditions
- Automatic auditing reports
- Advisory information from a fuzzy-based knowledge system

Plant auditing addresses the core asset management goals of optimum performance and maximum return on investment **1**. Audited plants secure the stable and robust conditions necessary for the higher-level optimization functions offered by, eg, model-based predictive multi-variable controllers and/or true plant optimizers. Without auditing, use is not made of the full capability offered by higher-level optimization. Also, without auditing it would take much longer to get production plant up and running and require more work to keep it running correctly.

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The role of plant auditing

General

The aim of plant auditing is to increase the possibilities for plant supervision based on normal field measurements, ie to make operating personnel more aware of

Plant auditing – background

Global competition is forcing industrial plant operators to continuously improve product quality and reduce costs. At the same time, operation and maintenance managers have a common goal that is defined indirectly by the financial climate, ie the need to maximize return on investment. One way of reducing costs is to increase performance. Combining higher, more consistent product quality with a larger production volume, however, makes special demands on asset management.

'Intelligent' equipment is being used increasingly today to provide the information needed to achieve these goals. The cost of this equipment is usually high, making it necessary to install a new supervisory system to gain the promised advantage. It is difficult to justify this investment for normal production facilities unless very high value units are being produced.

Plant auditing is a new methodology which overcomes this limitation on the use of intelligent IT equipment. It combines advanced signal analysis, knowledge-based technology, automatically generated reports and a new presentation technique. The new technology has advantages for all branches of industry, including the pulp and paper, metals, pharmaceutical, food and petrochemical sectors.

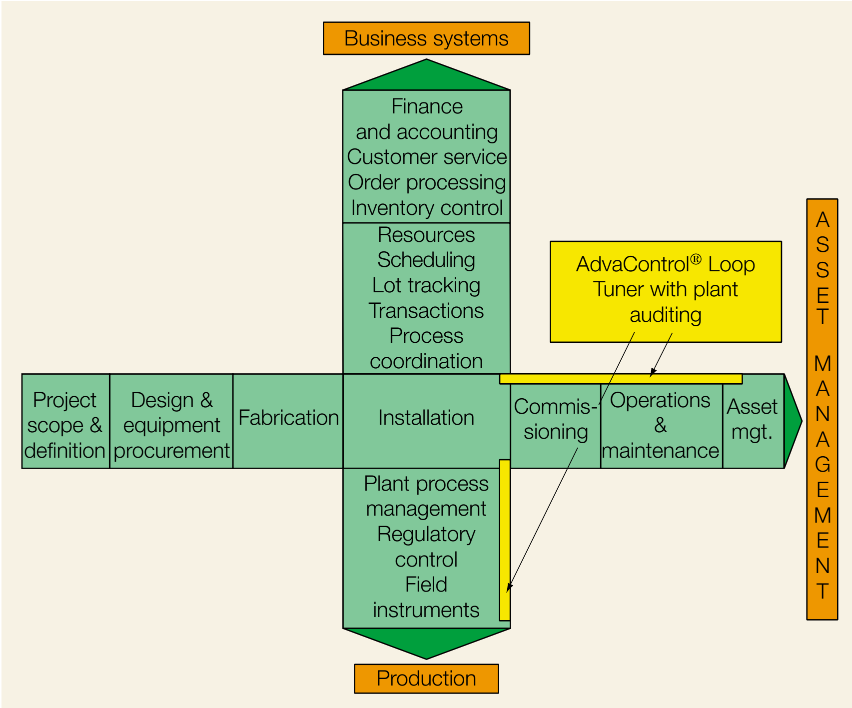
changes in plant operation. Instead of requiring the installation of complex equipment for special measurements, plant auditing allows supervision to be based on normal measuring devices which are also used for other purposes. Installation costs can be kept lower as a result, while the added number of uses for the field devices makes their installation easier to justify.

The overall goal is for the system to run without intervention by the plant instrumentation or the operating personnel, and to automatically supply plant audit reports. Experience has shown that plant auditing needs to be closely integrated with a powerful control engineering tool, eg ABB's AdvaControl® Loop Tuner Package **2**.

The advisory information received from the knowledge system becomes available long before a human being can detect any degradation in plant performance. Based on this early warning, plant maintenance can be scheduled and the corrective action can be integrated into normal plant management activities. Thus, costly interruption-driven service can be reduced to a minimum.

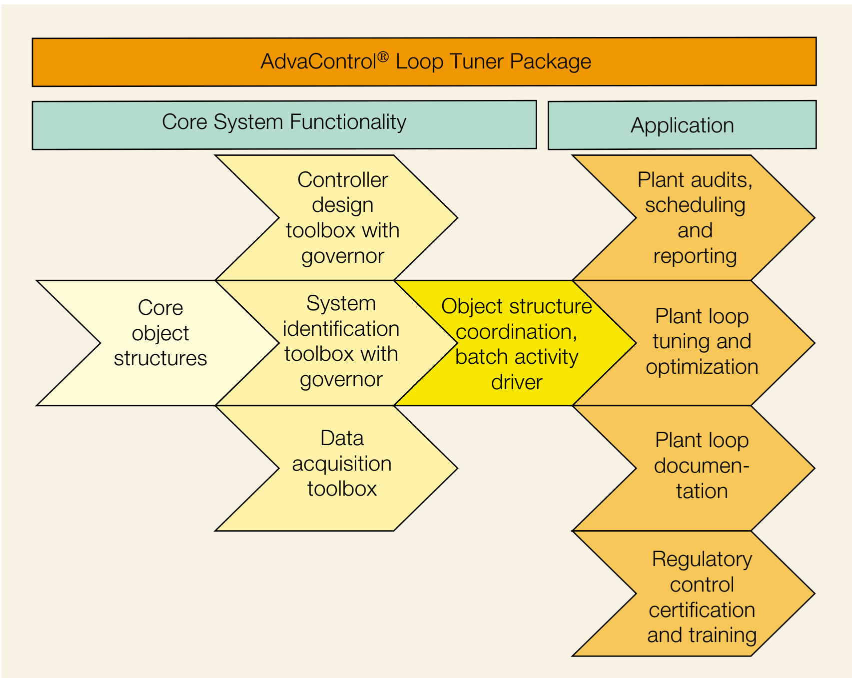
Operating personnel require advice on when to carry out maintenance, etc, and need to be told why. The question 'why' is seldom given the attention it deserves because answering it is time-consuming. The decision when and if re-tuning is to be carried out is based simply on the current loop performance. This means that the loop history is often forgotten (eg, why the particular parameters were chosen, what the loop performance quality was before, and the operating level at which re-tuning took place). Today, pushbutton autotuners have led to plants being 'downtuned', with re-tuning replacing plant maintenance. A more global overview of the plant operating conditions is needed for a better understanding of the total process. This is important as new tuning parameters can create severe problems at other production levels or when working on other products.

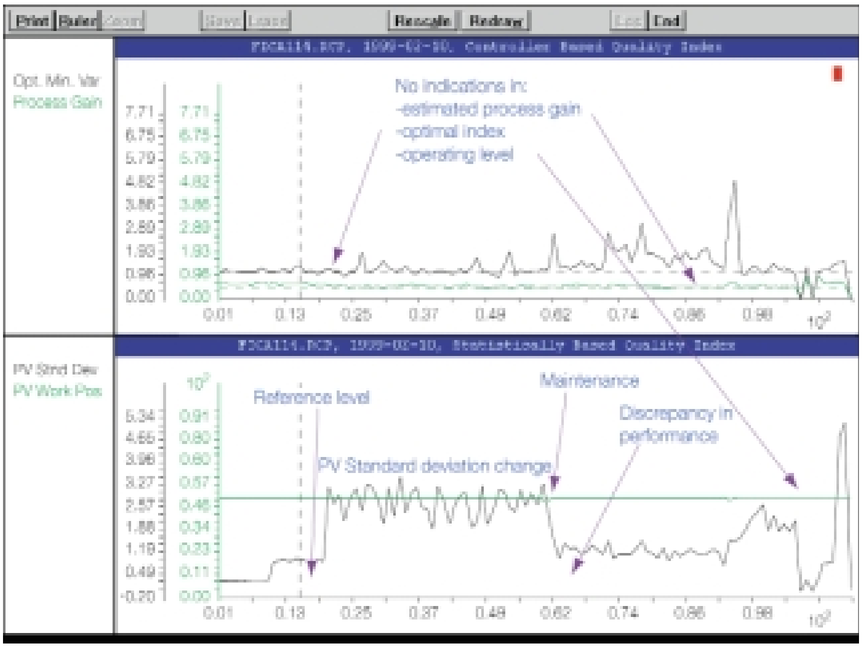
Through plant auditing different aspects of plant supervision can be made accessible to the user. The first and most



Asset management by means of the AdvaControl® Loop Tuner. Plant auditing allows full use of the capability offered by higher-level optimization. **1**

Functionality spectrum of the AdvaControl® Loop Tuner **2**





Quality aspect trend curves heighten awareness of changes in plant performance and allow the effects of maintenance, etc, to be studied. **3**

PV *Process variable*

critical issue is, of course, awareness of the condition of the mechanical equipment needing maintenance or service. Next come the aspects that improve plant performance by offering different ways of counteracting changes in dynamics caused by changed production parameters. By making these changes more observable, regulatory control can be used more effectively to counteract the factors influencing the dynamics.

One essential goal of plant operators is to keep production running at the highest possible level for the longest possible time. Comparison of production quality factors before and after service or maintenance is not an option at the present time since normal historical data logging makes only one aspect of production visible and does not include quality comparisons as a key feature. Plant auditing has made this type of comparison its primary goal, and it is built into the supervisory process from the beginning.

Plant managers know from experience that to maintain a high level of performance the documentation has to be generated automatically and integrated in the management process. In addition, it has to cover many aspects of plant operation (eg, plant auditing, service and maintenance, tuning and plant dynamic models) and facilitate plant analysis by means of advanced methodologies.

If all the above issues are addressed by the same tool, handling and training are made easier and less complex. This is also one of the reasons for the plant auditing and regulatory engineering tools being closely integrated.

The advisory system, in the form of a built-in fuzzy-based knowledge system, makes sure that the automatically generated reports directly inform the user of any indications determined from the different quality aspects. (Normal operation, ie operation during which there is no observed deviation, is also indicated by the advisory system as a plant operating condition.) The fact that the feedback-oriented auditing system and the regulatory engineering tool are closely integrated allows the performance of each loop to be optimized.

Awareness based on quality aspects

Another key issue is the awareness factor, ie the ability to observe changes in the quality of a plant's performance. Different plant operating conditions must be made visible, and this requires different methodologies and signal processing techniques. A basic failure is to believe that one parameter can supply enough information for a reliable statistical appraisal. On the other hand, too much information wrongly handled could mislead operators. A good solution combines knowledge of quality aspects, practice in the field and long-term experience.

Plant production data normally contain a lot of information for the operator which is hidden in the time-based presentation offered by conventional trend curves. Advanced predictions, in combination with selected statistical information, can make the hidden information available to even an inexperienced user. The aim is to make it so observable that it cannot be overlooked. Also, corrective action is possible when feedback is provided. Quality aspects **3** allow engineers to study more closely the effects of action taken in the plant (eg, maintenance and service).

In normal maintenance, an item of equipment (eg, a valve) is serviced and then returned to the production unit without any provision being made for checking to see if it performs correctly afterwards. The operator only sees that it no longer causes the problems it did before. Plant auditing allows it to be checked directly whether or not performance is back at the required level. If it is not, this fact will be clearly shown in the plant auditing reports and corrective action can be taken. This kind of feedback practically excludes the likelihood of operation not being optimized. The results of service and maintenance are fed back via quality aspects.

Quality aspects

As already mentioned, plant auditing and supervision are based on normal production data supplied by conventional field devices. The installed instruments allow the plant to be controlled by means of valves, pumps, motors, etc. This control, plus the tuning parameters for the regulatory control units belonging to the instrument system, has the overall objective of maximizing plant performance. It is clear from the above that accurate analysis of the mechanical equipment is just as important as proper tuning and documentation of the regulatory control units, which must also be able to handle the full range of operating conditions if performance is to be optimized. The close interaction between tuning and performance is a very significant factor as the regulatory unit makes use of the mechanical equipment to perform its functions. In end effect, the overall performance is only as good as the performance of the weakest interactive component. The 'before and after' analysis made possible by plant auditing also has to be considered for the plant loop tuning. This needs to be closely integrated with the regulatory control tool since much of the action that is needed will be executed and validated via its built-in functions.

Since plant performance and functionality revolve around the functions provided by the regulatory control loop, it is quite natural to adopt the same methodology when using the plant auditing system to investigate performance. A regulatory control loop is made up of four main components: a mechanical item (eg, a heat-exchanger), a field measuring device, a regulatory controller (part of the instrument system), and a mechanical device (eg, valve, pump, fan, motor, etc). This means that plant auditing basically supervises all components in the loop **4**. Each of the components is responsible in some way for the characteristic behaviour of the different quality aspects used by the fuzzy-based knowledge system. Plant auditing monitors the influence on performance and the function that should be performed, and not just the individual components. What is important is the way everything functions together, ie the overall impact on performance. The fuzzy-based advisory system allows a detected change in performance to be easily identified.

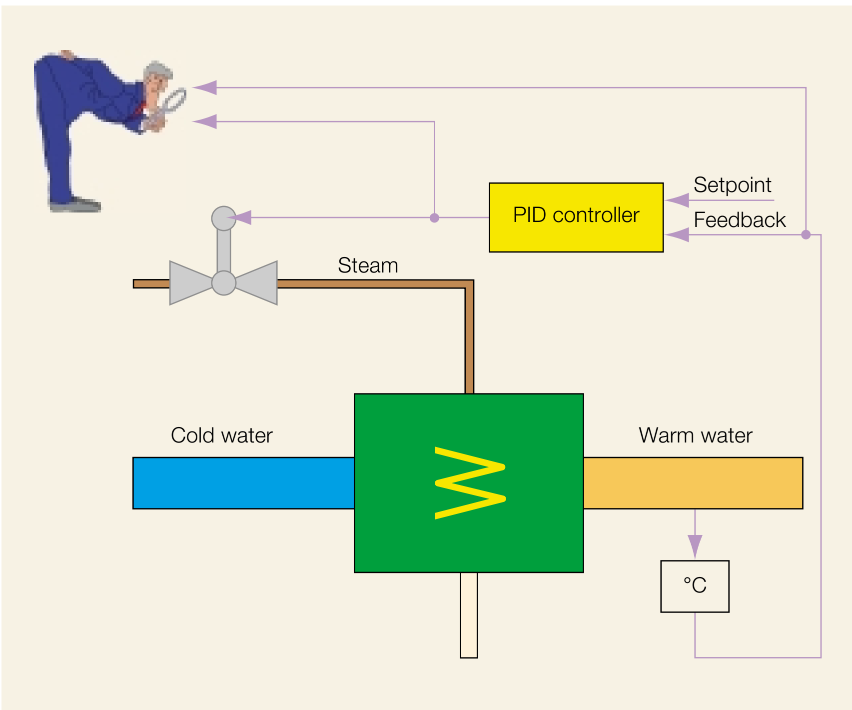
The generic configuration of the advisory plant auditing function means that the same technique can be used for all types of plant, irrespective of the application or production process. Thus, it is equally well suited for all branches of industry, including the pharmaceutical, chemical, metals, food, beverage, pulp and paper, power and petrochemical sectors.

Advisory plant auditing technique

Statistical, multi-variable systems used to investigate steady-state correlation try to position each of the signals used in a two-dimensional, orthogonal system/world. The methodologies used are called *principal component analysis and partial least squares*. The advisory plant auditing function uses a similar technique, but instead of setting up two orthogonal dimensions it tries to determine as many orthogonal dimensions (ie, aspects) as possible from the signals in the loop. Each of the aspects thereby describes a different characteristic in the individual signals or their combined effects.

Quality aspect supervision can also be called Loop Performance Assessment (LPA). LPA enables a solution to be found for a loop problem via the quality indices. The engineering tool therefore has to help

Plant auditing supervises all components in the control loop **4**



the engineer verify the recommended solution. Utilizing just one index for the evaluation will be too restrictive. Providing they cover different aspects, a set of LPA quality indices can be combined with a knowledge system to assist in the evaluation. The LPA quality indices can be divided into two categories:

- Controller-based indices
- Statistically based indices

Where possible, most of the indices have been normalized. It should also be noted that all the estimated values are based on normal production data, ie no excitation is generated and production continues as normal. All the evaluations are based on the calculated aspects of data acquired under these conditions.

Controller-based indices

The LPA quality indices are as follows **5**:

- The *Optimal Loop Quality Index* (OLQI) is based on the minimum variance controller theory. The only drawback with this method is that the process dead-time has to be known. Various papers have suggested different acceptable OLQI levels, but they probably depend to a large degree on the tested application loop. High levels are considered to be values that frequently rise above 3.0; however, the OLQI index is normally in the range of 1.20 to 1.80. The OLQI in the AdvaControl® Loop Tuner has been modified to support less stringent knowledge of the dead-time. The index could therefore be referred to as a 'modified OLQI'. This index is not sensitive to noise and disturbance, but it is useful for the detection of changed process dynamics, hysteresis, etc.
- The *Estimated Process Gain Index* provides an exact estimate of the process gain based on normalized measurements, ie measurements which are percentage-based. This index therefore indicates directly oversized or undersized mechanical components (eg, valves, pumps).
- The *Correlation Shift Index* determines the correlation shift between a process feedback signal and the controller action. This very new index is able to detect if the oscillation is internal or external. When internal, the control object could be the source of the problem (ie, hysteresis or stiction). However, if it is external, the problem is created by the connecting loops. This index gives no indication of whether or not the normalized oscillation index is too low (ie, below 0.2). The different levels – ie, internal or external – are based on the degree of correlation.
- The *Normalized Oscillation Index* indicates the degree of steady oscillation in the signals. The operating range is 0.00 to 1.50. The high end of the operating range indicates a very stable and steady oscillation, while low values indicate either that there is no oscillation at all or the data was not useful.

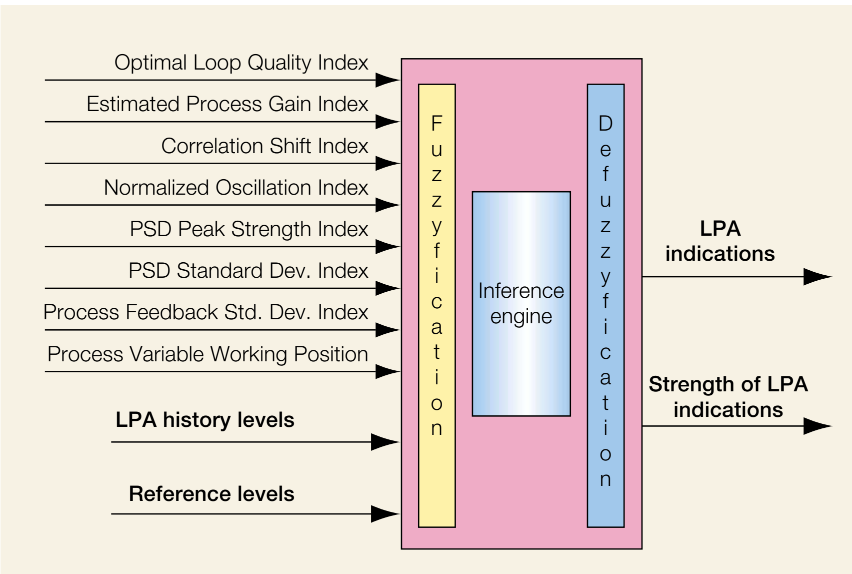
Statistically based indices

There are four of these:

- The *Power Spectrum Density Peak Strength* (PSDPS) is calculated as the peak-to-peak value of the power spectrum density (PSD), normalized by the mean of the PSD. More exactly, the PSDPS is normalized by the mean of the high-frequency range of the PSD. This increases the sensitivity. The peak value is similarly compensated when multiple peaks appear in the spectrum. The normal operating range could be from 1 to 100, whereas values above 400 are considered unacceptable, especially if they appear too frequently. This index indicates the difference in energy content and is very effective for detecting problems that typically create excitation with a persistent frequency range (hysteresis, stiction, etc).
- The *PSD Standard Deviation Index* is calculated as a normal standard deviation but normalized for the high-frequency range of the PSD. Better numerical

Fuzzy-based advisory system for evaluating the quality aspects. Experience is used in formulating the rules of the fuzzy evaluation system (inference engine). **5**

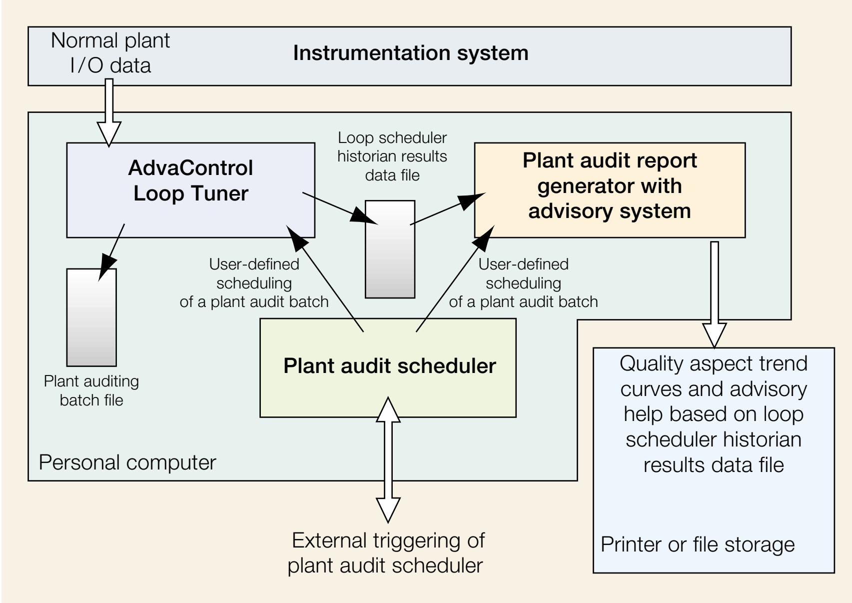
LPA *Loop performance assessment*



stability, and therefore a more robust index, is achieved in this way. This index indicates a different degree of energy concentration than that indicated by the PSD peak-to-peak. This is another powerful index for observing changed loop performance characteristics.

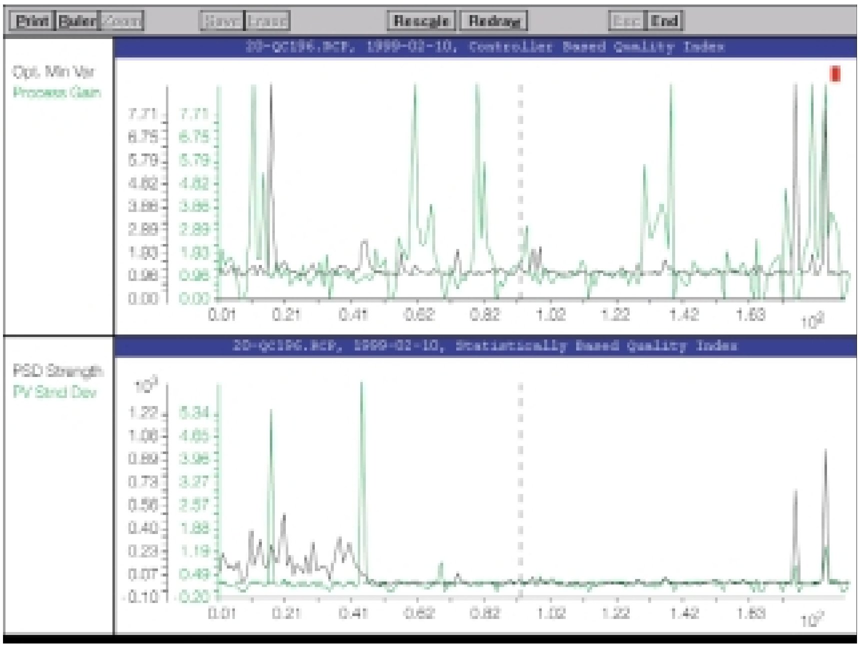
- *Process Feedback Standard Index:* The standard deviation of a process variable, ie the feedback signal, is calculated as described for standard deviations in the textbooks. The process variable is, of course, normalized and the signal processed before calculation. This variable, together with the other variables, supplies essential information about whether or not the loop has the correct structure and the tuning parameters have been set properly.
- The *Process Variable Working Position* is a strong indicator of whether the changed characteristics are due to a change in operating level. If so, a changed loop structure and/or changed tuning parameters could very well solve the problem. This also depends on how the other indices characterize the overall information.

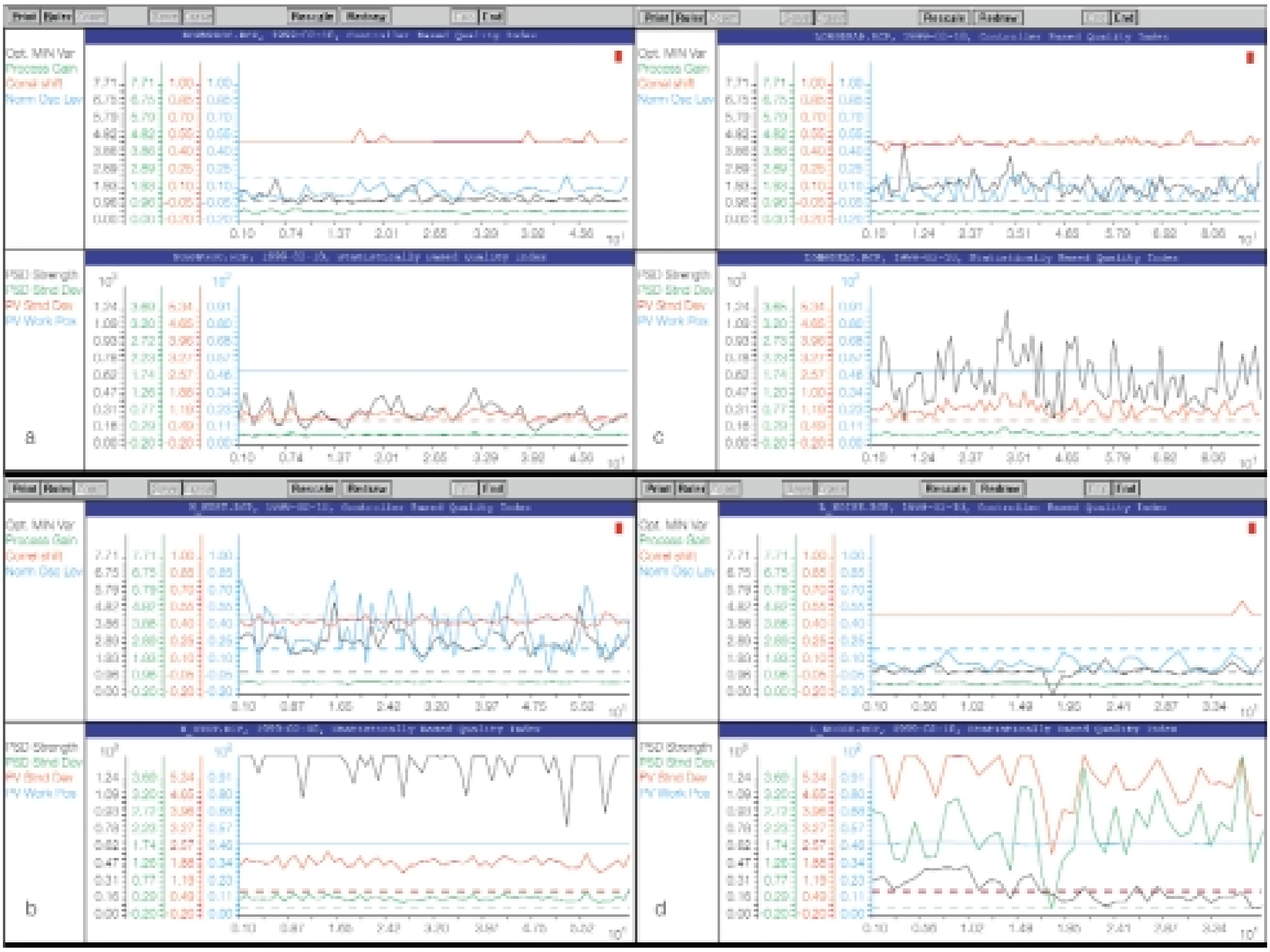
The 'standard deviation' is a multi-purpose statistical index. Nevertheless, it is sometimes used without proper consideration being given to its statistical significance. The standard deviation is also called the one-sigma level. (The 3-sigma level – also called the 6-sigma level as it spans ±3-sigma – normally indicates an acceptance range within which changes can be accepted as long as they occur only occasionally. If they occur frequently, this is assumed to indicate a changed situation and should initiate a more detailed investigation of the source of the change in behaviour.) The advisory system integrates the necessary factors and ensures that such issues are covered by the evaluation of the different quality aspects. This also means that the initial step taken when utilizing any kind of LPA activity is to define the reference levels for the quality aspects, which are then shown in the generated plant audit report. The reference levels are estimated by the plant audit program on request. Although the different application loops can have different reference levels, the latter indicate the targets for the quality aspects in much the same way that setpoints are the targets for (typically PID-type) controllers.



Plant auditing program layout for continuous supervision of control loop performance **6**

Curves showing controller-based and statistically based quality indices for a consistency loop in the paper industry **7**





Examples of quality index displays. By considering the relative strengths of the indications, engineers can decide where the loop investigation should begin. **8**

a *Normal operation*
b *Hysteresis in valve*
c *Long dead-time*
d *Disturbances originating in connected loop*

Plant audit system layout

The layout for continuous supervision of plant loop performance is shown in **6**. The AdvaControl® Loop Tuner has been extended to include the loop performance assessments calculation and an automatic batch handling system. This engineering tool is activated by the plant audit scheduler, which also gives instructions as to which loops are to be analyzed (these are found in the batch file). Experience shows that user-defined scheduling is performed three times a day. The result of each analysis is appended to the associated loop scheduler historian file. The plant audit scheduler program activates the plant audit report generator at intervals defined by the user.

As an alternative to being printed out, automatically generated reports can be filed using the generic bit map file format. The use of a word processor for generating a more customer/application-oriented type of report enables links to the bit map files to be used instead of having to directly import the file information. This automatically updates the word processor document with the latest bit map information the next time it is opened, when it will show the latest reports from the plant audit report generator. For example, the plant audit scheduler could start generating reports at 6 am each Monday morning. The production staff arriving at 7 am could then start the word processor and print out the fully updated internal report document.

As another option, the plant audit scheduler can be triggered externally by other programs. Thus, different LPA batch specification files can be used and the auditing session can be based on plant-specific conditions. This is typically used for sites involving batch-type processes, eg in the pharmaceutical and chemical industries.

Trend curves based on quality aspects

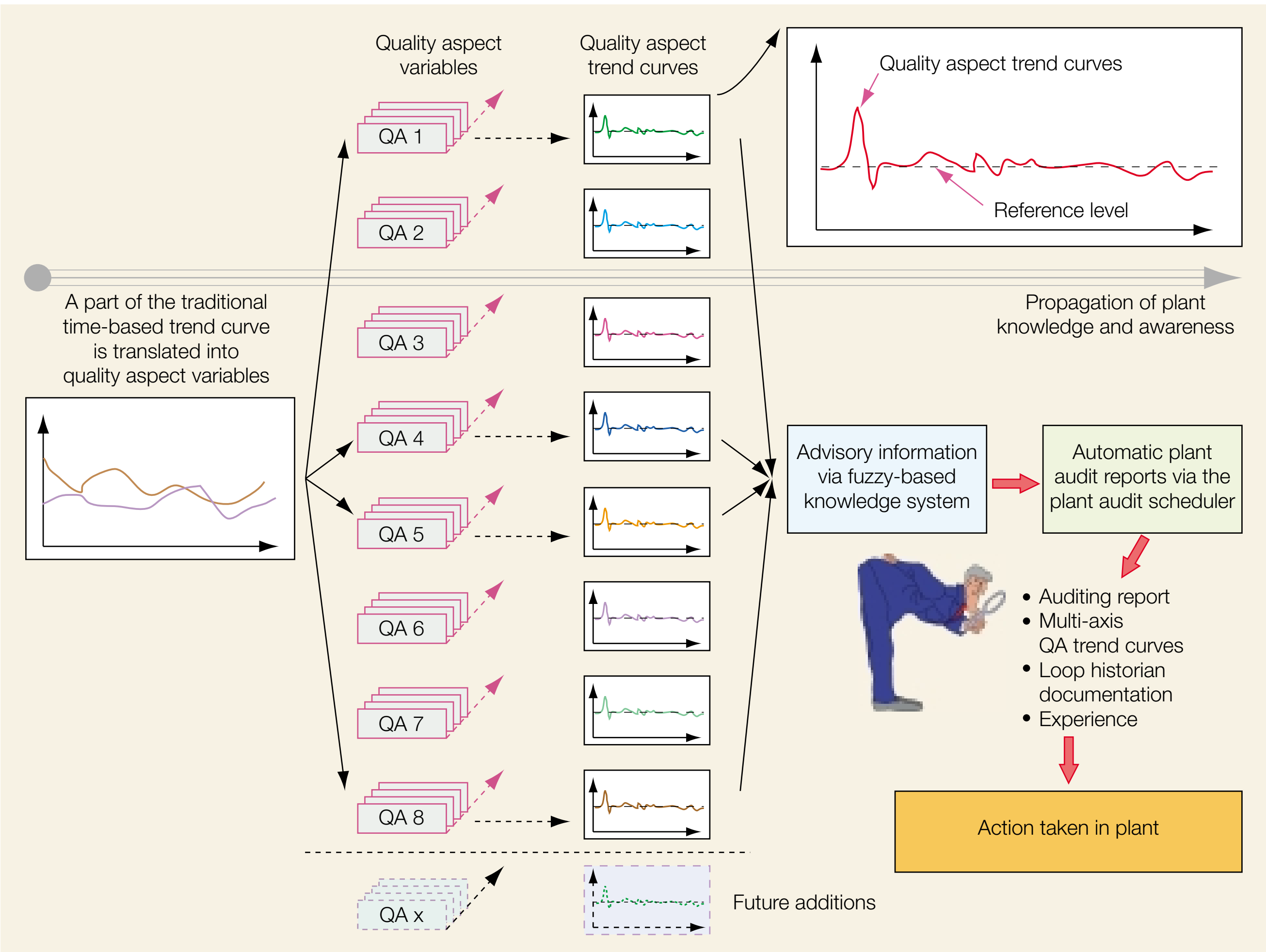
Conventional plant supervision features long-time data storage and direct presentation by means of time-based trend curves. In plant auditing the calculated quality indices are stored in the loop scheduler historian and displayed in trend curves. Thus, calculated results replace raw data. One month of production data represents 100 sets of quality indices – a very compact and easy-to-interpret presentation for detecting changing operating conditions.

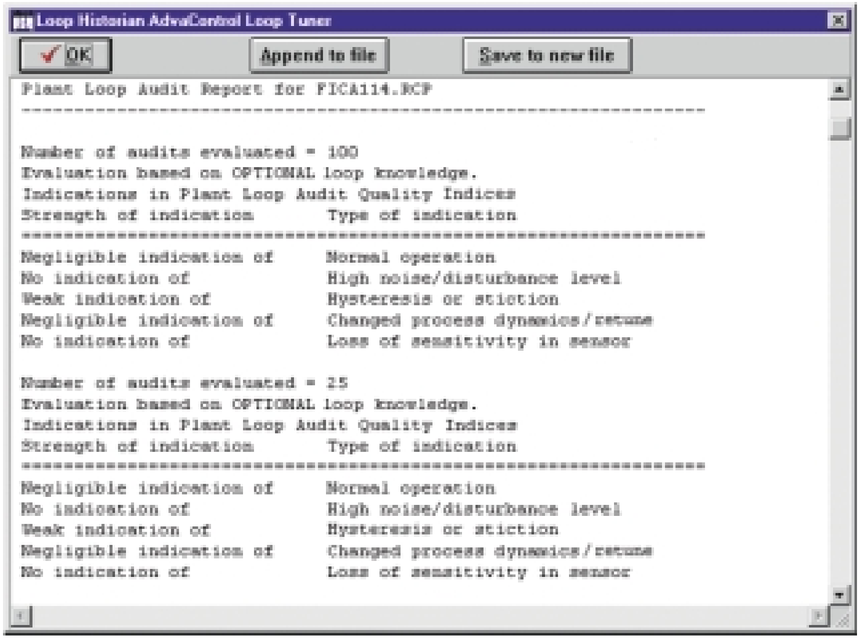
This substantially improves the way the user is made aware of changing characteristics in the loop or supervised object. The quality index trend curves allow the user to directly observe the performance over a very long period. In total, 200 sets of audit sessions can be displayed in the quality aspect trend curves **7**. The last month (ie, 100 sets of auditing sessions) is always displayed without the quality aspect values being condensed, whereas the 100 sets for the previous period are compressed. This means that one year's production data (or, alternatively, three months of performance history) can easily be displayed. The length of the displayed history depends on the amount of information in the associated loop scheduler historian file for the loop under investigation. The dashed vertical line indicates the point at which data compression ends and the individual quality aspect values for each session start. All that is missing is an indication of what causes the characteristics to change. While the advisory system also provides some assistance, the quality aspect trend curves supply the guidance the engineer requires. The information provided by the advisory system further accelerates the optimization of the plant performance.

Fuzzy-based advisory information

As the characteristics of the available LPA quality indices are evaluated by means of a fuzzy-based knowledge system, experience is used to formulate the pre-specified rules for the fuzzy evaluation system **5**, ie the inference engine.

Principle of knowledge propagation through the use of quality aspects **9**





Main advisory window used to evaluate quality aspects **10**

The advisory system supports the evaluation with suggestions. The quality aspect trend curves provide the engineer with the environment he requires to better understand hidden relationships (ie, those not directly observable before) in the plant. This new 'visibility' could also be employed to change the loop structures or for gain scheduling, etc.

Indications

The influence of changed plant conditions can be observed in the quality indices **8**. Reasons for the changes are shown clearly by the evaluation, which also indicates other options. By considering the relative strengths of the indications the engineer can differentiate between them and decide where the loop investigation should start. In time, the engineer learns to quickly recognize typical site problems for each type of loop by directly observing the quality index and curves. There may also be cases where the advisory system is more suitable for the evaluation **9**.

The advisory system displays the evaluation of the quality indices with two time horizons, one showing the previous month and the other showing the previous week **10**.

'Return on action'

Increased awareness of a change in the operating conditions – ie, early warning – allows action to be taken before problems, such as lost production quality, can occur. Also, by making the supervision feedback-oriented, the user is kept informed about the results of his actions. Plant auditing enables the production staff and instrumentation engineers to talk about a 'return on action' (ROA), echoing the 'return on investment' heard so often in the financial world. With the new methodology it is almost impossible not to reach the reference levels indicated in the quality aspect trend curves after taking corrective action following a failure.

Integration of the plant auditing functions in an engineering tool has also made preventive maintenance and further plant optimization easier.

The results show that the basic indications are correct and point to a probable direction in which to search for reasons for changes in the quality characteristics. Plant auditing provides the operation and maintenance personnel with a means of improving overall plant performance after only a short introductory period.

Areas in which AdvaControl® Loop Tuners are currently being used include pulp & paper (AssiDomän and StoraEnso, and Korsnäs and StoraEnso), the pharmaceutical industry (Bayer, Germany), minerals and mining (Boliden, Sweden), and petrochemicals (Shell and Statoil, Norway).

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