Auditing of Batch Processes

G. Janssens-Maenhout[1], L. Dechamp, J. B. Thevenon[2], P. Dransart[2]
Institute for the Protection and the Security of the Citizen, Nuclear Safeguards Unit
Joint Research Centre Ispra, Via E. Fermi 1, TP 421, I-21020 ISPRA (VA), Italy;
tel: +39 0332 78 5831; +39 0332 78 5076; fax: +39 0332 78 9216; e-mail: greet.maenhout@jrc.it; luc.dechamp@jrc.it
[1]docent University Ghent, Engineering Faculty, Electrical Energy Systems and Automation
[2]Euriware, West Region, AREVA group, 25 av de Tourville, 50120 Equeurdreville, France;
tel: +33 6 83 44 45 42; +33 6 83 44 56 13; email: jbtheven@euriware.fr; pdransa@euriware.fr

Abstract

A software tool for auditing the successive batch process steps at the La Hague reprocessing plant is developed in a support to Euratom inspectors. This tool compares the observed data of a batch with a description of the process cycle in order to analyse and to interpret the data of the batch cycle.

The "Data Analysis and Interpretation" monitoring software "DAI" detects important events in the process cycle by means of the start/exit of functional behaviours. Comparison of the observed data with the process model means that deviations from expected behaviour can be detected. The DAI software verifies (1) incoherency with the prescribed goals by checking the required complementarity between linked signals, and (2) the conformity with the predefined design by checking the completeness in the succession of functional behaviours.

The system applied at the reprocessing plant especially allows monitoring of the solution flow through the process by analysing the required coherence in complementary data of communicating tanks. This example demonstrates the usefulness of a simplified syntactical pattern recognition methodology to follow-up the complete transfer of different material flows. This software may be applied for the follow-up of other processes, like in the petrochemical or food industry.

1. Introduction

The need for a monitoring tool, which manages the material flow, is subject to a norm under development of the American Instrumentation Society (ISA), as announced by Vieille (2002).

The software tool, which is described in this paper, is meant for auditing the successive production process steps of a batch of liquor on two levels:

- The batch is submitted to general constraints such as the density, the temperature-dependency, the absence of remarkable mass loss and impurities, which have to be *monitored globally*.
- At each production step there exist also specific constraints such as pressure, temperature and level limits or selective transfers between communicating tanks, which need a *local monitoring*.

It especially allows a near-real time follow-up, as addressed by Janssens-Maenhout et al (2004) and an overview of a batch process under the specified constraints. The specific constraints can be of different types:

- the authorised transfers between tanks,
- the allowed transfer time,
- the physico-chemical relations of the liquid, and
- the exploitation constraints

Each liquor production process is characterized by well-instrumented tanks for the liquor control and inventory tanks for the process control. The process is for each batch repeated and each process cycle is characterized with a set of prescriptions. The liquid has to be traced through the all process steps in quantity (mass) and in quality (density and chemical composition).

Automated supervision and process control is abundantly described in the literature by, for example, Amaral et al. (1992) or more recently Lee et al. (2001). However, this tool only compares the observed data of a batch with a description of the process cycle in order to analyse and to interpret the data of the batch cycle. The intelligent process monitoring system can be defined as a system, which neither supervises nor controls but analyses the measured data points and interprets the required coherency with the prescriptions without intervening in the process by a feedback function.

2. Overview of the process monitoring system

The software tool bases:

- on a data historian for data acquisition with compression and
- on an analyzing kernel for interpreting the data, which is called “Data Analysis and Interpretation” or “DAI” software.

Various data historians are available on the market for the efficient data acquisition and compression. Commonly the PI data historian is still selected in chemical process plants as well-validated data acquisition and compression software tool according to Harrold (2004). This paper does not focus on this part as it is already well resolved by the industry but it focus on the analyzing kernel, for which no standard well-validated industrial software tools are available.

The central task of the analyzing kernel DAI is the recognition of exploited process cycles. Information is collected from the actuators and sensors for direct control and supervision and is analyzed with the following objectives:

- to survey in real time the correct operation of the production process
- to diagnose abnormal situations
- to evaluate the process performance indicators and inventory balances of the batch cycles in real time

2.1. Recognition of batch cycles

Various techniques exist to recognise a pattern:

- the template matching,
- the statistical approach and
- the syntactical approach.

Industrial processes with high production availability are commonly characterized by signals with a certain repetitive form but not mathematically periodical. Therefore the syntactic approach was chosen to analyse the signals' repetition with a given set of predefined functional behaviours.

The DAI software detects important events in the process cycle by means of the start/exit of functional behaviours. Comparison of the observed data with the process model means that deviations from expected behaviour can be detected. The DAI software verifies (1) flow incoherency with the prescribed goals by checking the required complementarity between linked signals, and (2) the conformity with the predefined design by checking the completeness in the succession of functional behaviours. The syntactical pattern recognition is based on expertise analysis, encoded with local functional behaviours of the signal

2.2. Local monitoring by detection of predefined functional behaviours

The DAI software analyzes efficiently the data with all underlaying information and yields continuously updated synthesis of so-called events, which represent the entering / exiting of a functional behaviour. To detect the event in time, an observation window moves from one data point to the next and calculates the average of the variation in data point value. This characterizes each data point with a mean slope. Experience with the online process monitoring has indicated that an algorithm of first order with an observation window of fixed time and with a predefined cone of allowed mean slope variation are fast and sufficiently precise for the recognition and confirmation of an event.

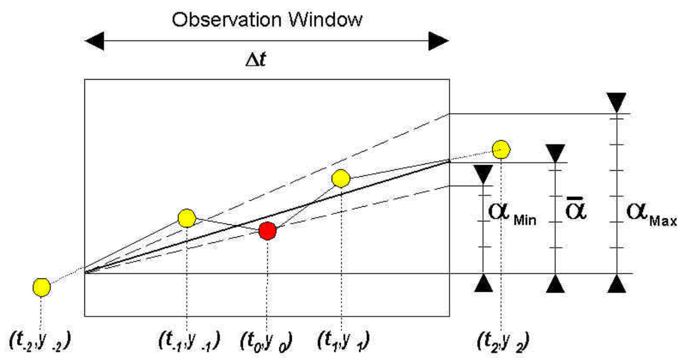

Fig. 1: Slope calculation for the detection of a functional filling behaviour

Each functional behaviour is characterized by the mean slope value and the predefined cone of allowed slope variation. The larger the cone, the more noisy the signal, however the exit time identified is less accurate. The observation window with fixed time width for the whole process monitoring slides normally its center to each data point, as shown in Fig. 1. To detect the starting point of a new functional behaviour the slope evaluation is repeated for a certain number of previous points with the left border of the observation window positioned at each of the previous points. Analogously to detect the exit point of a functional behaviour the slope evaluation is repeated with the right border of the observation window positioned at the points. More information can be found in the paper by Thevenon et al. (2003)

Experience with those algorithms in the online monitoring of a process has revealed the following weaknesses:

- the recognition of a functional behaviour is sensitive tot the parameters defining the cone of allowed slope variation
- the recognition of the main functions in a process cycle on a tank may be complicated by superposed oscillations due to liquid agitation
- the identification of the start and end points of a functional behaviour is very important as these dates and times determine the total duration of the functional behaviour and the total mass transfer

For the example of a solution tank cycle the principal functional behaviours include filling/emptying at know or unknown flow, plateau at known or unknown level and steps at known amplitude or known limit. The monitoring tool allows visualisation of the nuclear material flow through the plant by means of two couple layers: a fixed design work sheet and a real-time updated process signal sheet.

2.3. Global monitoring of a complete batch cycle

On the design work sheet of a plant, all process cycles are modeled with the involved functional behaviours. An example of a tank cycle with filling - mixing - emptying - is shown in Fig. 2. Not only the signal profile of a tank in operation in a process cycle can be identified, which is referred to as signal auto-correlation, but also the total material transfer between tanks can be traced, which is referred to as signal cross-correlation. Moreover the design work sheet guides the detection of functional behaviours and is therefore also a diagnostic aid in the case of abnormal exit of a cycle.

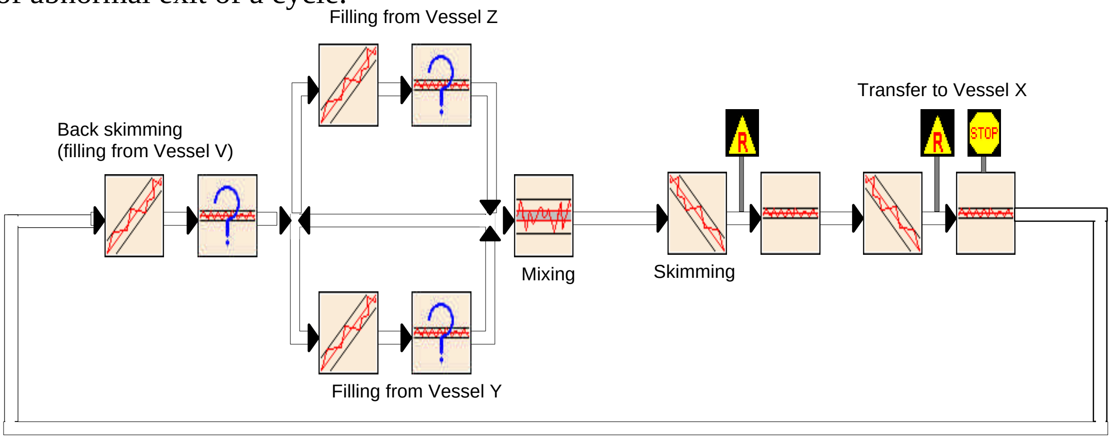

Fig. 2: Design work sheet of a prototype cycle for an inventory tank. The sequence of expected level slopes is described in detail with three different possibilities: (i) filling in 2 steps, (ii) filling in one single step, (iii) filling in three steps.

Each design work sheet connects to a process signal sheet, which visualises in real-time all recorded signals for the selected process cycle. On this process signal sheet all important events are displayed and the coherency in material flow is verified. Fig. 3 shows an example of the level signal in red and volume signal in green for four tank cycles with filling – mixing – sampling – skimming - emptying. The events (starting points and end points of the functional behaviour are indicated in red and are utilized to calculate the total material transfer and to verify coherency between transferred material. Once all functional behaviours as defined in the design work sheet of the plant are encountered, the conformity with a complete cycle is confirmed and a new cycle is initiated.

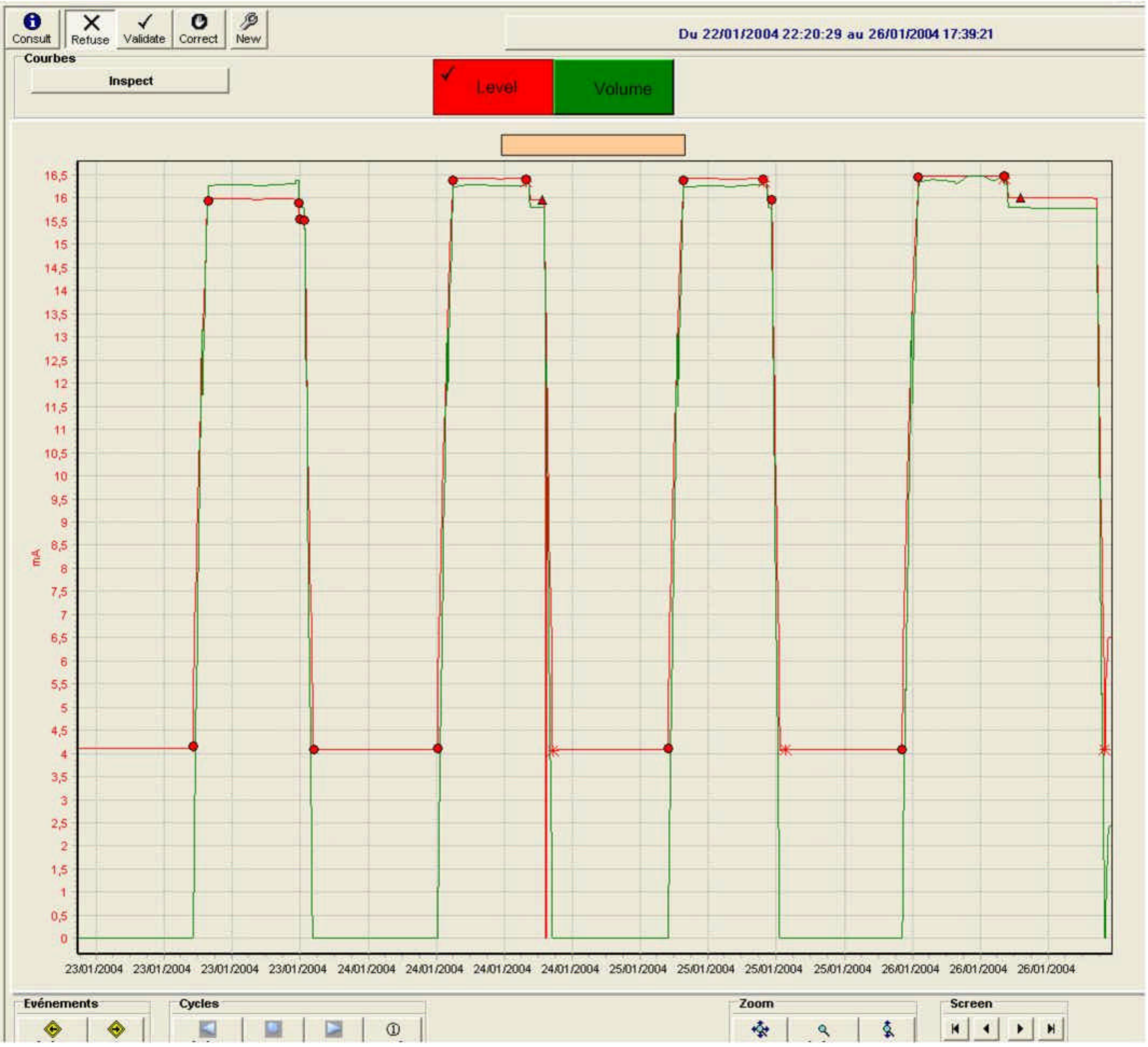

Fig. 3: Process signal sheet with real-time representation of the level (red) and volume (green) signal for four tank cycles.

2.3. Verification method for the transition between successive functional behaviours

To facilitate the verification of incoherence in data from communicating tanks and of conformity in procedure, the monitoring system applies a formalism, which allocates to each functional behaviour one of the five distinct modes: Passive, Ready, Active, Checking and Completed.

At the initialization all functional behaviours are in passive mode. Their mode can be transformed to ready if the prescribed model considers them as one of the possible functional behaviours in the following time steps. In case the functional behaviour can be immediately recognized the ready mode passes to active, and after reaching its exit point, the mode finally passes to completed. In case the functional behaviour is not immediately detectable, the ready mode is first submitted to a checking mode before passing to active and completed.

3. Application on an inventory tank in a reprocessing plant

A solution monitoring tool with a modular structure and an analyzing kernel in C# is realized, which runs under an XP environment and which is validated for the UP2 reprocessing facility at the La Hague site. The solution monitoring tool has similar features to the one described by Howell and Scothern (1997) but operates in a more pragmatic way on a larger scale.

No real data from the UP2 in La Hague could be shown here, because they are strictly proprietary information. Instead a fictitious but representative example of the most important inventory tank of a reprocessing plant, the input accountancy tank is presented in Fig. 4. In the example the accountancy tank (AT) is connected to three similar feeding tanks (FT) and to one succeeding process tank (PT). The accountancy tank knows a filling in three parts corresponding to each of the three upstream tanks with a simple emptying. The filling functional behaviour of the AT is correlated with the emptying functional behaviours of the three FT, which are successively assigned the active status.

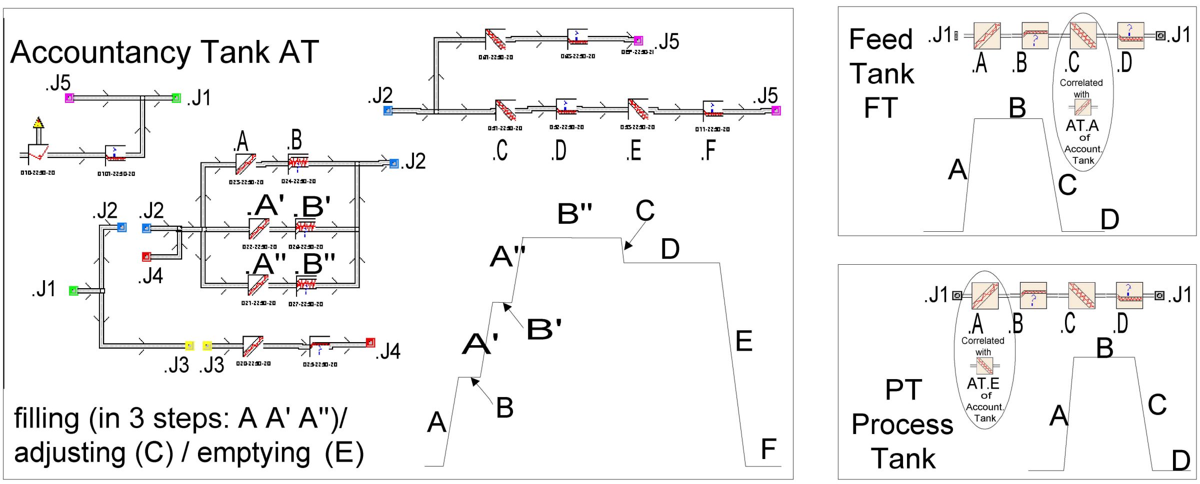

Fig 4: Example of the modeling of an accountancy tank with three feeding tanks and one successive process tank.

The inspector follows in real-time the collected measurement data on the process signal sheet. In case an anomaly is noticed, the subsequent events are marked on the signal profile with a symbol, which indicates the type of error. Additionally an alarm is generated and the monitoring may be interrupted. The monitoring is automatically reinitiated with the synchronisation point modeled in the design work sheet.

4. Conclusion

A stand-alone software tool DAI (for Data Analysis and Interpretation) has been realized, which monitors the liquid in a reprocessing plant according to the described algorithms and formalism. The system applied at the reprocessing plant especially allows monitoring of the solution flow through the process by analysing the required coherence in complementary data of communicating tanks and the required conformity with the process procedure and cycle completeness. The signals from a central accountancy tank are not only interpreted with identification of all functional behaviours but also evaluated carefully in order to asses the integrity of the material flow from and to the connected tanks.

The inspectors are satisfied with this tool, which serves for the verification of all cyclic functional behaviours as prescribed in the design. At each point where a non-conformity is detected, the cycle is interrupted and an alarm for the inspector is switched on. The tool then lists all possible procedural errors or constraint violations. It is left to the inspector to decide on the real case, consistent with their defined responsibility in the follow-up of the process.

This example demonstrates the usefulness of a simplified approach to follow-up the complete transfer of different material flows. The syntactical pattern recognition based on expertise analysis appeared to be a very appropriate methodology to follow batch processes. This methodology and to some extend also this software may be applied in other process facilities, such as petrochemical plants, milk or sugar production facilities.

References

J. Vieille (2000), Repères Batch : Regard S88 / S95 sur le(s) cycle(s) de vie du système de production, ***Applicatif J'automatise,*** No. 9, April 2000, p. 82-90

Janssens-Maenhout G. and Dechamp, L. (2004), Process Monitoring Appropriate for Near Real Time Accountancy***, J. Nuclear Material Management***, Vol **32**, No. 3, Spring issue 2004

Amaral W., Arruda L. and Bueno S. (1992), CAD package for industrial process identification***, J. Process Control,*** Vol. **2**, No. 3, p. 155-161

Lee J., Natarajan S. and Lee K. (2001), A model-based predictive control approach to repetitive control of continuous processes with periodic operations, ***J. Process Control***, Vol. **11**, No. 2, p. 195-207

Harrold, D. (2004), Historian holds key to performance, ***Control Engineering,*** January 2004

Thevenon J.-B., Janssens-Maenhout G., Dransart P. and Dechamp L. (2003), Une approche du monitoring d'installation industrielle, ***Proc. Optimation Automation Congress***, Paris, October 2003

Scothern S.J. and Howell J. (1997), A physical-model-based diagnostic aid for safeguarding nuclear material in a liquor storage facility, ***J. Nuclear Materials Management,*** Vol. **25**, No.4