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PRACTICAL ASPECTS ON SELF TUNING REGULATORS

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Abstract

Self Tuning Regulators are regarded from a practical point of view. Different problems and some of the solutions to the problems are discussed based on experiences from laboratory experiments.

Praktiska aspekter på självinställande regulatorer behandlas. Olika problem och en del förslag till lösningar av dem diskuteras med utgångspunkt från försök med en labprocess.

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PRACTICAL ASPECTS ON SELF TUNING REGULATORS

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M S Thesis
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1. INTRODUCTION

All kinds of process controllers have to be tuned before they can be used. To tune a regulator manually knowledge of the process is required. To get rid of this time consuming procedure, and to be able to control time varying processes, different ways of tuning the regulator automatically have been developed. One approach to solve this is the Self Tuning Regulator (STR).

The Self Tuning Regulator

The ideal STR is a black box that can be connected to any process without any presettings. The only button is for giving the set point. This cannot necessarily be achieved.

This paper deals with some practical aspects on the implementation of selftuners in industrial processes.

An STR implemented on a computer can be said to consist of three parts: Regulator algorithm, identificaton algorithm and regulator design calculation. See figure 1.

The regulator is often a PID regulator but can be of any type. A good reason for choosing a PID regulator is that its behavior is wellknown.

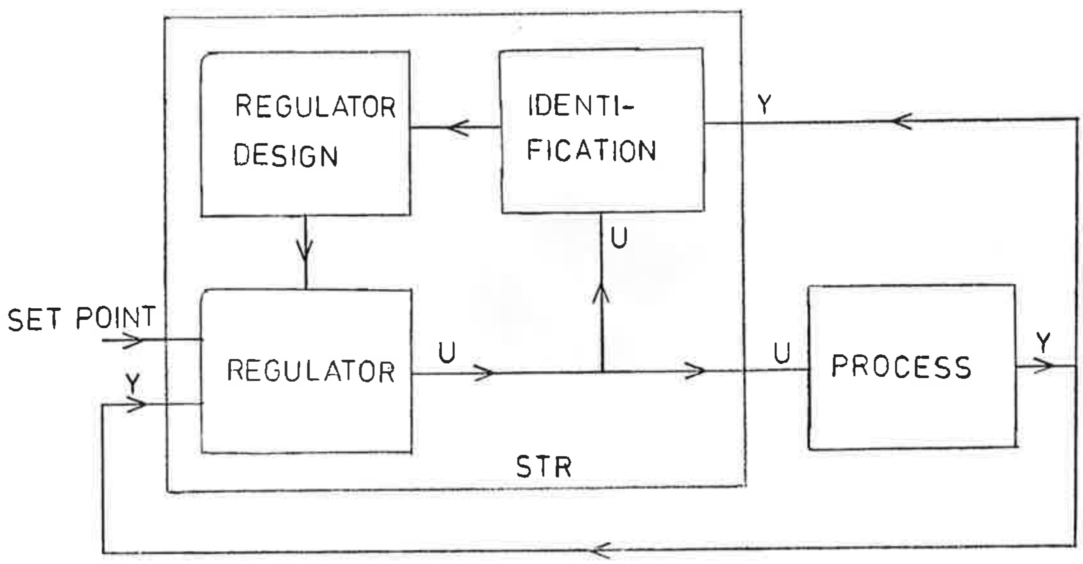

Figure 1. Block diagram of a self tuning regulator.

The identification is a recursive estimation of a mathematical model of the process that is to be controlled. The process is supposed to be on the form

$$Ay=Bu, \qquad (1)$$

where u is the regulator output (and process input) and y the process output. A and B are polynomials in the forward shift operator:

$$A=a_0z^n+a_1z^{n-1}+a_2z^{n-2}+ \ldots \qquad (2)$$

and

$$B=b_1z^{n-1}+b_2z^{n-2}+b_3z^{n-3}+ \ldots \qquad (3)$$

The least squares method is often used.

In the regulator design feasible settings for the regulator are calculated from the identified model.

Implicit and Explicit Models

If the identification and the regulator are arranged so that the identified parameters can be used directly as settings for the regulator the model is said to be implicit.

In the explicit model the regulator settings have to be calculated from the identified model. The advantage of the explicit model is the flexibility though it is more time consuming.

Theory and Simulations

Self tuners have many interacting parameters, are nonlinear, are time varying and include stochastic variables, so the possibilities of making theoretical analyses are yet limited with available theory. The use of logical tests and alternative algorithms also makes it difficult to make complete analyses of self tuners. Therefore many simulations have to be done in order to explore the behavior of the methods. But still very few selftuners are used in factories because of the uncertainty in relation to the risks and because of the hesitation of investing in new technique.

Experiments with a Laboratory Process

Tests and figures discribed later in this text come from experiments at The Foxboro Company. The lab process consists of a pump, a flow meter and pipes. To the lab process different features was added by computer simulations.

Experiments in this paper have used the model

$$y(t+k)=-a_0 y(t)-a_1 y(t-1)+bu(t) \tag{4}$$

of the process, where y stands for the flow, measured by the flow meter, and u for the pump speed. k is the asumed dead time of the process.

The parameters a_0, a_1 and b are calculated in all experiments although they are not always shown in the figures. In chapter 4, where the regulator has fixed settings, there are no constraints on the parameters. The only limits are those on the plotter.

The model may not be fully identifyable. This depends on what kind of regulator that is used.

The Fox 3 System

The STR was implemented on a Fox 3 Computer. The Fox 3 System is a mini computer based system designed for process control applications.

The system language is Foxboro Process Basic, which is very easy to learn and to use. A number of blocks are connected to build schemes. The blocks can be defined by the user or can be standard blocks. See appendix.

2. IDENTIFICATION

Perturbations Required for Identification

In order to make an identification of a process there have to be changes in u and y. This means that some kind of exitation is required whenever a model is wanted.

If a system is running smoothly and the changes in u and y are small there is little information for the identification, why after a while, the regulator may have totally wrong settings. A disturbance may then cause a burst or the system may start oscillate.

One solution is to insert perturbations to help the identification, but this may of course be a disadvantage for the process itself.

Another problem is that a series of similar disturbances may make the regulator work well for this disturbance only. Tests showed that a series of set point changes improved continuously the response of set point changes, while a load disturbance immediately afterwards caused unstability. See figure 2.

Figure 5 shows how a series of load disturbances drives a parameter to a smaller value than a series of set point changes.

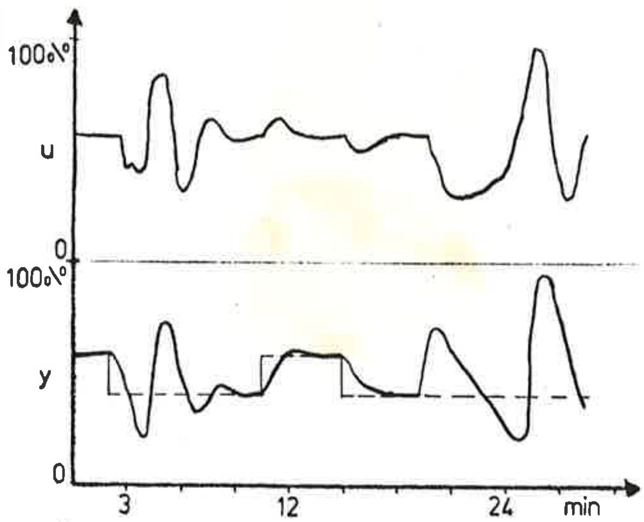

Figure 2. Three successive set point changes approved the behavior for set point changes. Adding a load disturbance caused unstability.

Filters

To get more information from the process it is often useful to use incremental values. In this case it is not necessary to identify the DC value. Other filters may also be of use to concentrate the identification on the frequency field the regulator is working on.

Forgetting Factor

The model is updated each time step using a recursive algorithm. A forgetting factor λ gives the weight between new and old data, such that λ=1 means that equal weight is put on every time step. The smaller λ the more weight is put on new information.

The dilemma of choosing λ is that a quick response for process changes also gives sensitivity to perturbations. The optimal solution would be a variable λ with λ=1 when little action is noticed and a λ<1 when there is much information available. (See also chapter 5).

Dead time

On the implementation of the regulator it is almost necessary to know the dead time of the process to make a good regulator. If the dead time is not known a priori or is time varying it can be identified. Different methods for identifying the dead time has been developed [Kurz and Goedecke 1981], but still is this a big problem.

3. PROBLEMS IN PRACTICE

When implementing self tuners in real processes a lot of problems have to be solved before they can work satisfying. The computer that is used for each purpose has certain limitations. The number of bits and the speed of instructions make it necessary to watch up with numerical behavior and the size of the model.

Recursive Least Squares Identification

Consider a recursive least squares identification of Kalman type. The updating of parameters is executed in two steps:

$$\theta(t+1)=\theta(t)+P(t+1)\varphi(t+1)[y(t+1)-\theta(t)\varphi(t+1)] \qquad (5)$$

$$P(t+1)=\frac{1}{\lambda}[P(t)-P(t)\varphi(t+1)[\lambda+\varphi^{T}(t+1)P(t)\varphi(t+1)]^{-1}\varphi^{T}(t+1)P(t) \qquad (6)$$

θ is the parameters to be estimated i.e. the coefficients of the A and the B polynomials:

$$\theta=[a_0\ a_1\ a_2\ \ldots\ a_n\ b_1\ b_2\ \ldots\ b_m]^{T}, \qquad (7)$$

where m and n denote the size of the chosen model.

P is the covariance matrix.

φ is the delayed u and y values corresponding to θ:

$$\varphi(t)=[-y(t)\ -y(t-1)\ \ldots\ -y(t-n)\ u(t-1)\ u(t-2)\ \ldots\ u(t-m)]^{T} \qquad (8)$$

λ is the forgetting factor.

Model Size

When dimensioning the model i.e. deciding the order of the A and the B polynomials there are a few things to take into consideration.

The larger the model the better identification can be expected. With many parameters it is possible to make an identification which is close to the real process. From a large model it may also be possible to make a good regulator. But at the same time it is necessary to be more careful with pole-zero cancellations. (See also chapter 5).

Least squares identification involves a lot of matrix manipulations. The time the computer needs for the identification is increasing dramatically with the order of the matrices, and the order of the matrices is decided by the model size.

Numerical Behavior - Conditioning

The identification algorithm may be ill conditioned. If the process is running smoothly the variance of y and u becomes small and the P-matrix will grow large.

The number of bits sets the limit of the P-matrix. There is a possibility of setting a constraint on the P-matrix. This makes it possible for the P-matrix to recover.Another possibility is to work with the square root of P in a square root algorithm.

Square Root Algorithm

In order to compare the behavior of the straigt forward least squares identification to a square root algorithm [Bierman,1977, Lawson and Hanson, 1974] tests were run on a process with low activity.

The square root algorithm that was used was the Peterka algorithm. [Clarke, Cope and Gawthrop, 1975, Peterka, 1975] An even more efficient method is to use a UDU^T algorithm. [Belanger, 1981, Bierman, 1977]

The tests showed that, identifying the same process, the straight forward method lost its identification because of an overflow in the P-matrix, while the square root algorithm was working.See figure 3.

A drawback with a large model is also that a numerical problem is more likely to occur than in a small model.

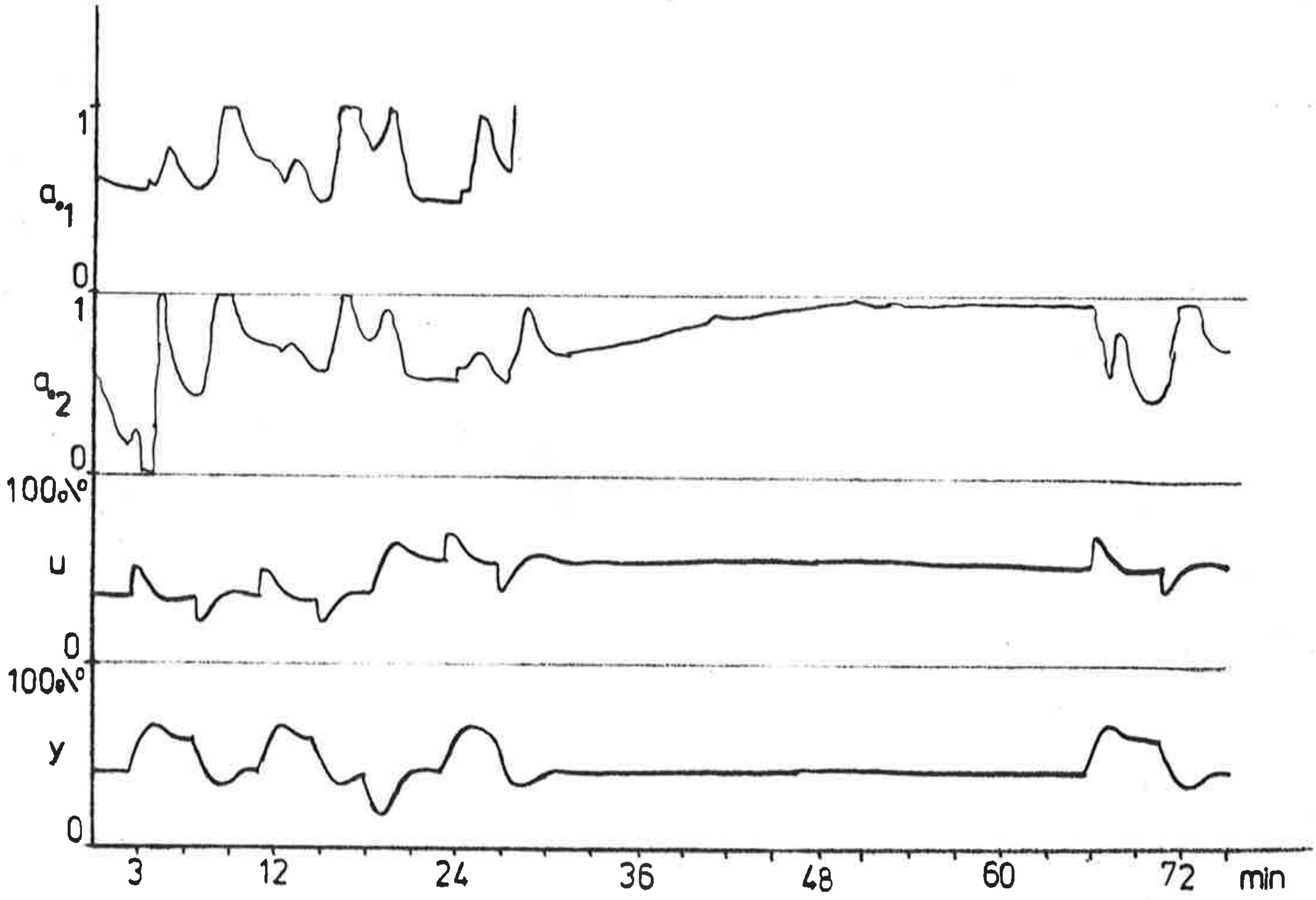

Figure 3. The parameter a_0 identified with 1) straight forward method and 2) square root algorithm. A PID regulator with fixed settings is used.

4. OPEN LOOP TESTS

As an STR is very complex, tests were run where only parts of the STR were allowed to change. Particularly the identification was examined when the regulator had fixed settings.

Forgetting Factor

To see how the forgetting factor λ affects the identification the estimated A and B coefficients were plotted for different λ.

With $\lambda=1$ the identification reached a steady state after a while. See figure 4.

The identification remained sensitive to changes with $\lambda=0.98$. See figure 5.

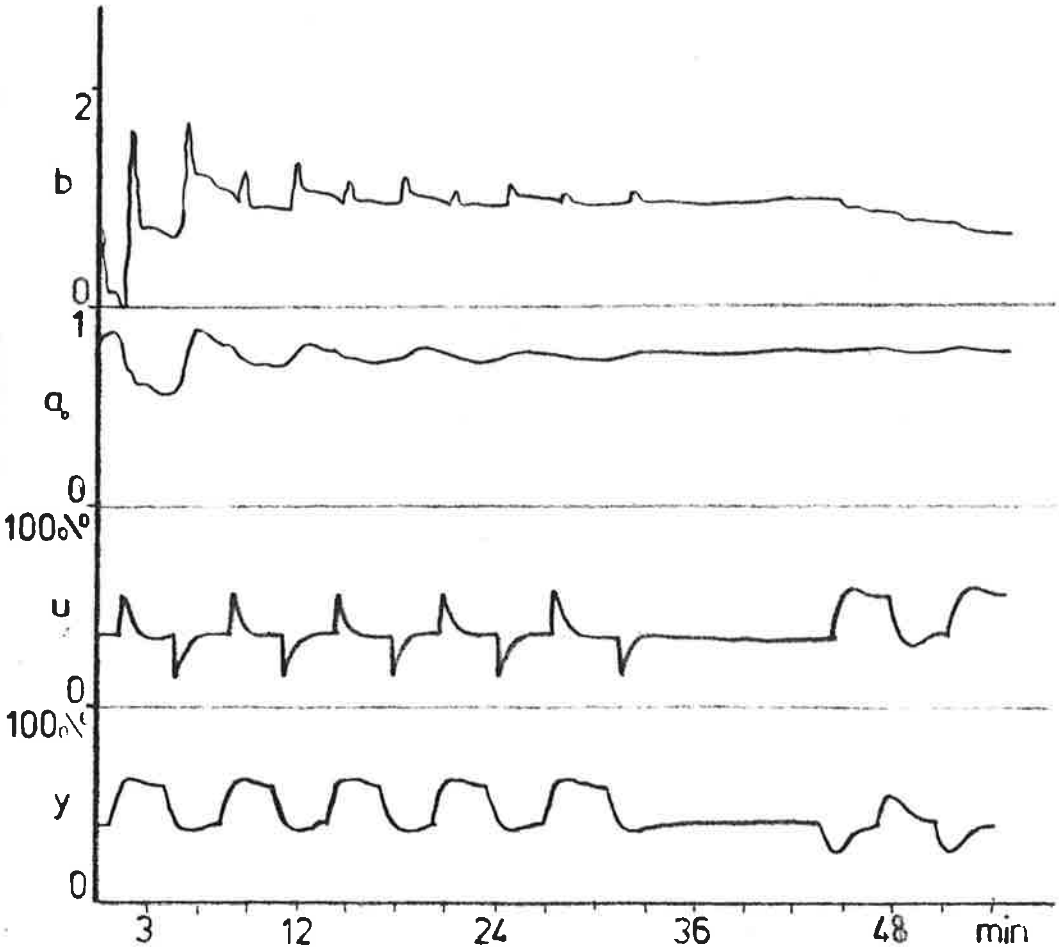

Figure 4. Identification of a_0 and b with $\lambda=1.0$.

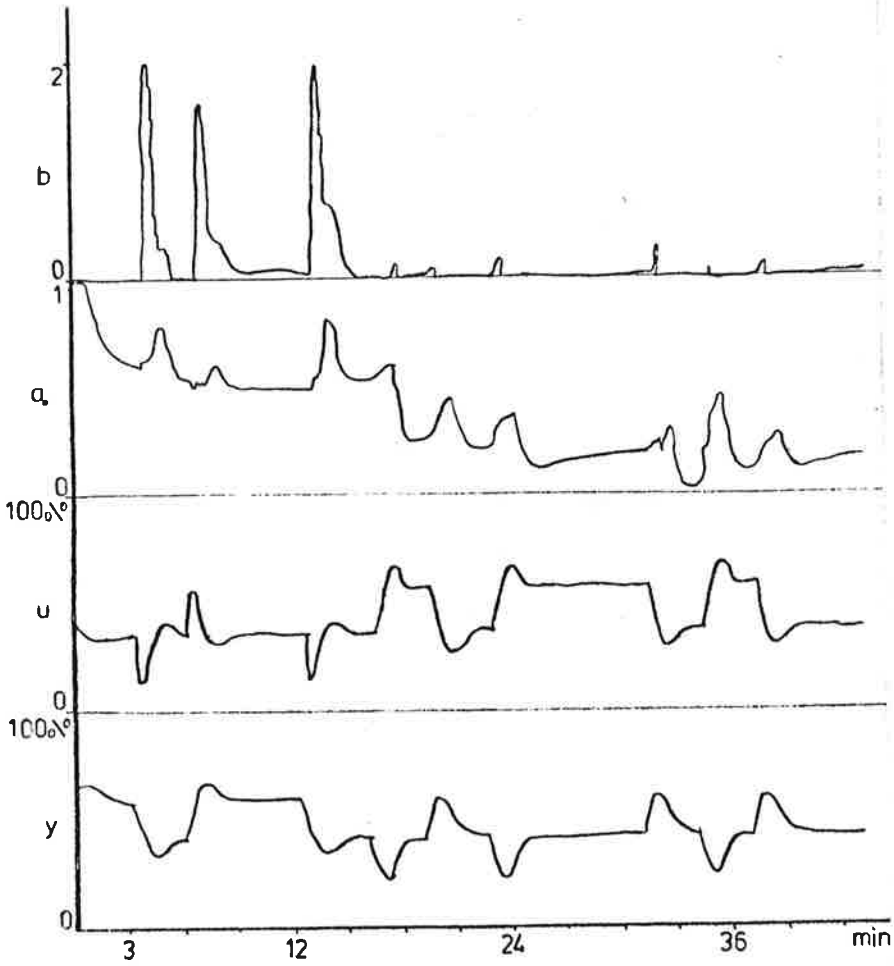

Figure 5. Identification of a_0 and b with λ=0.98.

Absolute or Incremental Estimation

It is often feasible to build the model of incremental values of u and y. The incremental model is more sensitive to changes than the absolute model. See figures 6 and 7.

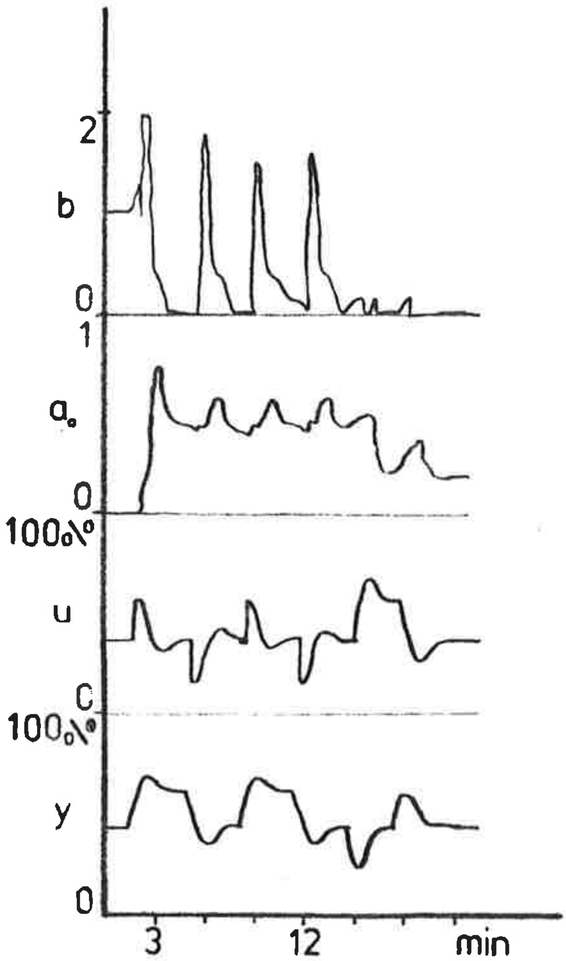

Figure 6. Identification of a_0 and b with incremental model

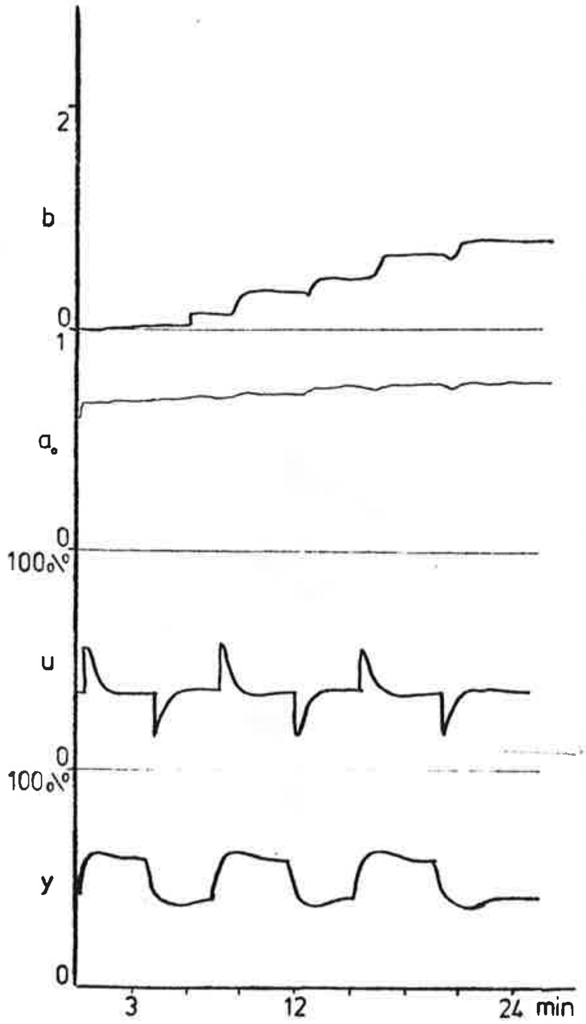

Figure 7. Identification of a_0 and b with absolute model

5. SUPERVISORY LOOP

The simple STR can be expected to work well under different conditions, but in order to achieve a more safe regulator certain options can be added. More sophisticated STR's have a supervisory loop, where certain tests give indications to make changes in the STR. [Isermann and Lachmann, 1982]

Avoid Bad Settings

According to what values the identified model has the regulator may get bad settings. Therefore it is often feasible to set limits on the parameters. Even if the identified model is close to the real process the regulator settings calculated from the model may cause unstability.

Alternative Algorithms

To be able to make decisions a supervisory loop makes tests repeatingly. Depending on how conditions fit with preconditions different changes can be done. These changes can be small or can involve a change to a completely different regulator or another identification algorithm.

Pole-zero Cancellation

The supervisory loop also has to take care of problems like pole-zero cancellation. Pole-zero cancellations are due to the regulator type as well as to the process model. There might be an advantage of choosing a small model, despite of lost accuracy, to decrease the risks of pole-zero cancellation.

Variable Forgetting Factor λ

The use of a forgetting factor λ allows the process to be time varying. The value of λ decides how much attention is paid to new data. The aim is to arrange a variable λ so that much attention is paid when there is activity in the signals, and little attention is paid when there is low activity.

The variance in u and y is a measurement of the activity in the process. So λ can be calculated from the diagonal elements of the P-matrix which can be interpreted as the variance.

Emergency

The P-matrix can also be used to discover when the STR is having bad control. When the diagonal elements are getting above certain values it may be necessary to fall back to a mode with fixed safe settings until the process has recovered.

Freezing

If the process reaches a steady state it might be necessary to freeze the identification to prevent it from drifting away. A variable λ close to 1 may, if the process is quiet for a very long period, not be sufficient as the parameters still can be drifting.

Bumpless Transfer

With a lot of alternatives it is important to make sure all changes can be done bumpless to achieve a smooth and robust control.

Complexity

With a supervisory loop a lot of extra problems are introduced together with the advantages. It is important to minimize the possibilities of being locked up in a bad mode. A complex STR also requires more CPU time and a more powerful computer.

There have been efforts to make a simple STR to avoid the problems with a complex one. Using experiences from the behavior of process controllers on line a simple STR can be designed.[Åström, 1982, Bristol, 1970]

6. CONCLUSIONS

Self tuning regulators have many useful properties. Even if parameters in an STR seem to fluctuate a lot they often interact in a way that improves the total behavior.

When implementing an STR practical problems do occur. All possibilities have to be regarded before an STR can be safely operable in an industrial environment.

There are still a lot of research to be done, but already quite a few self tuning regulators are used in real processes.

7. ACKNOWLEDGEMENT

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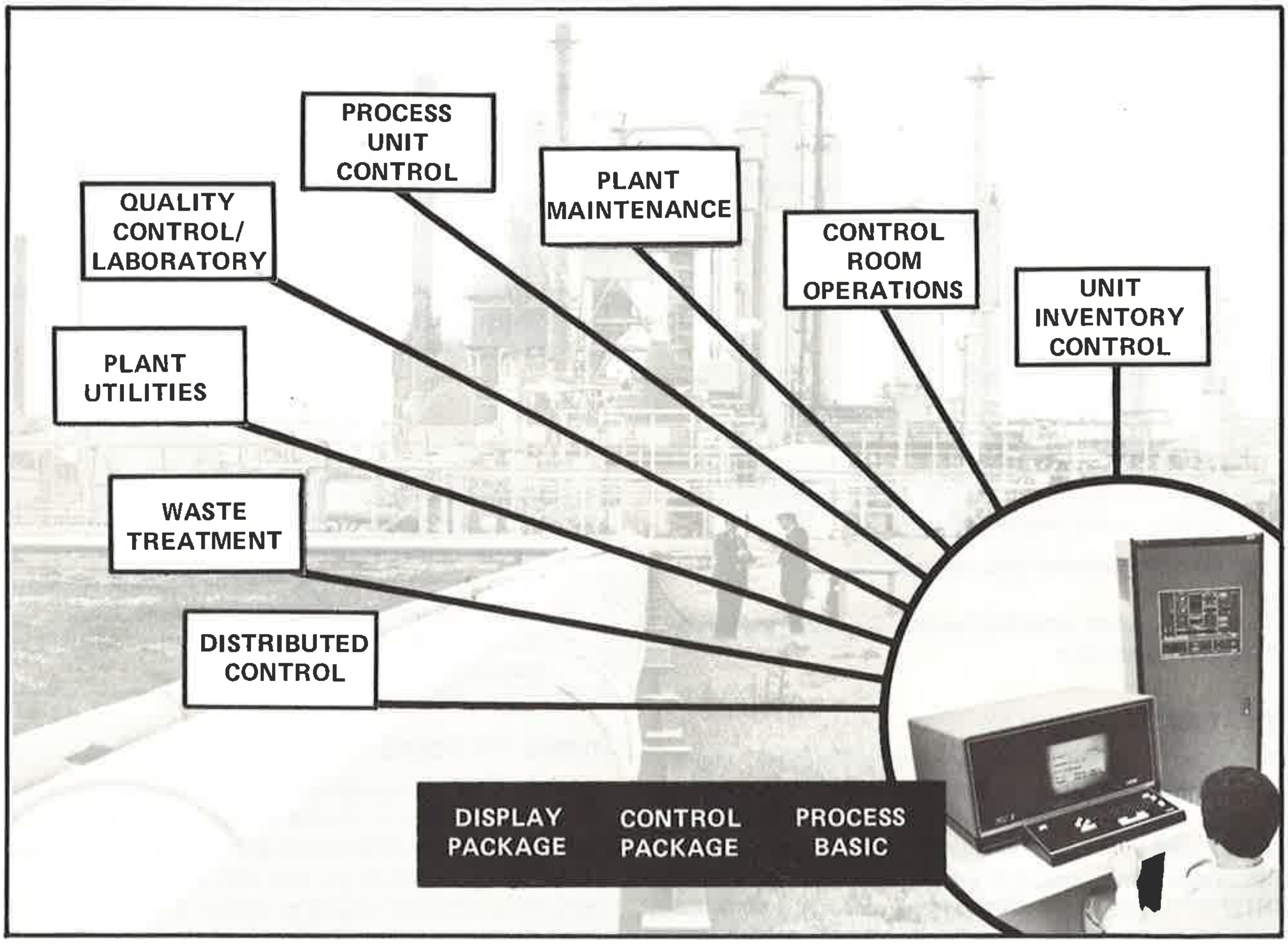


FOX 3 SYSTEM

A fully integrated equipment and software system for plant monitoring and process control

The FOX 3 System is a computer-based process monitoring and control system designed to meet the most exacting requirements of both control engineers and process operators. With a FOX 3 System, it all adds up:

COMPLEX APPLICATION NEEDS + FOX 3 TOOLS
= FAST APPLICATION SOLUTIONS
+ SAFE IMPLEMENTATION
+ TOTAL USER COMFORT

The FOX 3 System is **designed** for process control applications. It's not just an "adapted" data processing device, nor a jigsaw puzzle of many manufacturers' pieces. With the FOX 3 System, Foxboro offers single-source responsiblity and proven quality, backed by years of process control experience.

WHAT KINDS OF APPLICATIONS?

Energy management, plant utilities, quality control, process unit control, plant maintenance, waste treatment, unit inventory control—anywhere in the plant where reliability, repeatability, safety, vigilant monitoring, and tight process control are important.

WHAT DOES A FOX 3 SYSTEM DO?

The FOX 3 System gives you what you want:

- A capability for communicating with other SPECTRUM network stations, which can be other processors or process control and I/O devices.
- A computer language that process personnel can readily learn and relate to.

- The on-line capability of interactively building, checking out, and changing control loops and supervisory programs, with no process upsets.
- Visual displays in either black and white or color, to provide plant status, operator information.
- Simple operating procedures that build operator confidence and acceptance.
- Fast system startup.
- Built-in process safety and security.
- Field expandability.
- Sequential logic capability.
- Automatic set-point and direct digital control.
- Alarm logging and display.
- Bulk data storage capability on diskette(s) and, optionally, on moving-head disc(s).
- Real-time process data accessibility.

The FOX 3 System provides the tools for virtually any process control function.

WHAT KINDS OF TOOLS?

The FOX 3 System offers a user-configurable, multiprogrammed operating system with modular and highly reliable equipment. The system provides an interface to SPECTRUM networks configured for distributed process management and control, or an interface to the SPEC 200/INTERSPEC process control system. Standard software packages allow you to develop programs (Foxboro Process Basic), monitor your process and develop control loops (Foxboro Control Package), and create video displays (Foxboro Display Package). The FOX 3 System also includes system utilities.

TASKS

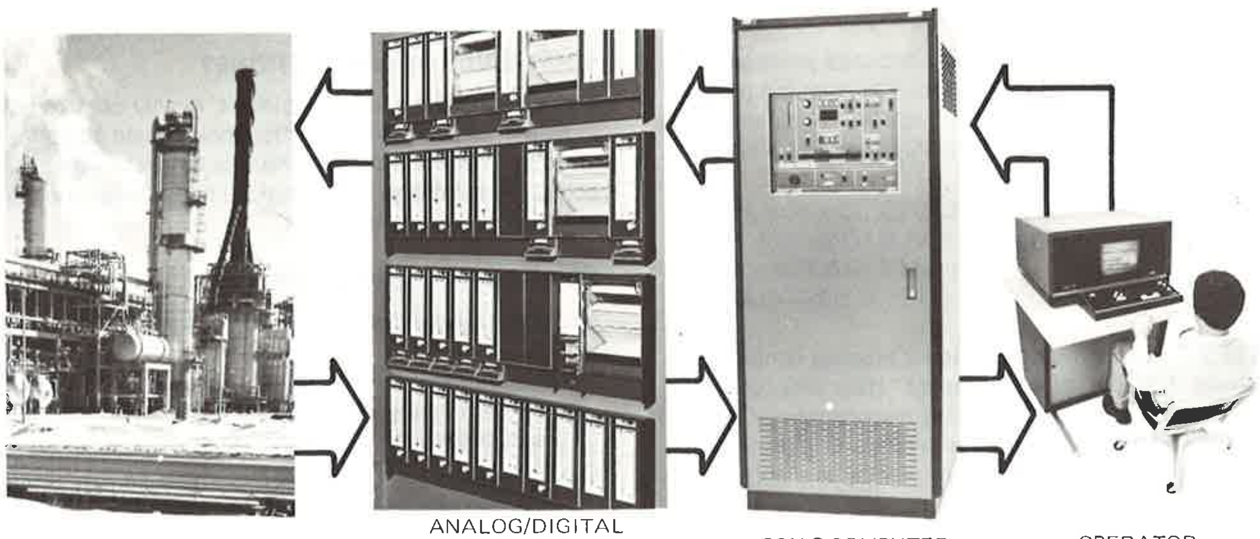
- Are written in Foxboro Process Basic
- Perform supervisory functions, e.g.,
  - Initiating control functions
  - Generating reports
  - Performing calculations
  - Batch sequencing
- Can be run and stopped by operator
- Provide display capabilities through the Foxboro Display Package
- Provide process unit coordination

SCHEMES

- Use the Foxboro Control Package
- Perform process monitoring
- Provide continuous regulatory control
- Can be activated and stopped by a task or operator
- Use and make available "live" process data
- Perform process security and control initialization functions

USING THE TOOLS

With the system's capabilities at hand, you can build two fundamental types of logical structures called "tasks" and "schemes." A task is a set of instructions to the computer telling it what to do, one step at a time. A task is actually a computer program, written in a process engineer's terms, using the Foxboro Process Basic language. A scheme is a control strategy, including input/output, computational, and control elements. Schemes comprise a group of blocks, each of which performs a specific function in the scheme. Blocks emulate analog devices (PID,



PROCESS PLANT — ANALOG/DIGITAL INSTRUMENTS — FOX 3 COMPUTER — OPERATOR

LEAD-LAG, RATIO, etc.) and are interconnected to form a process loop. All tasks and schemes are entered at a keyboard device. You can build, view, and modify tasks and schemes on line, while the system is still actively controlling the process. Once defined and activated, tasks and schemes work together to give you total, safe, and fully automatic process control.

FOXBORO PROCESS BASIC

Foxboro Process Basic (FPB) is the system's language. It has evolved from both American National Standard BASIC and several Foxboro quality-proven process control languages. FPB enables process engineers and operators to build, operate, and modify process monitoring and control tasks, using conventional process terminology. FPB comprises starter and advanced instructions. The starter instructions let personnel with little or no programming experience:

- Write and enter tasks on-line—tasks that can access "live" analog and digital process inputs and outputs.
- Design and print reports without format restrictions.
- Read and display/print data and messages through multiple terminals.
- Manage and manipulate files on diskette(s) or optional moving-head disc(s).

FPB Capabilities

FPB can readily express solutions to a variety of process applications, involving computation and control. You can use the features of the language to implement complex control strategies, to, for example, evaluate process performance, and respond to emergency operating conditions. With FPB, you can efficiently:

- Write your own control and calculation functions.
- Create special logging messages and video displays, including graphic displays.
- Implement batch applications.
- Access and change process parameters.
- Create installation-specific, application-oriented alarm messages.
- Perform material/energy balance calculations.

SPECTRUM Network Capabilities

FPB contains a powerful set of functions you can use to communicate with other network stations. These network functions enable you to:

- Communicate with process I/O devices:
  - Read/write data to blocks of process points attached to network stations.
  - Change operating states of process controllers.
  - Assume or relinquish control of process I/O devices.
- Acquire and change FOX 1/A, FOX 3 and UCM process control data.
- Request files from other stations as well as respond to file requests from other stations.
- Request that tasks be executed at other stations, pass data meaningful to these tasks, and respond to requests from other stations to execute tasks locally.
- Request other stations to print messages and respond to print requests from other stations.
- Monitor network security and report the status of network stations and linkage equipment.

Because of the modularity inherent in the system software, you can choose a subset of system functions for any given FOX 3 station on the SPECTRUM network when the system is configured. This distribution of functions enables savings in system overhead.

These features make FPB a highly versatile language for supervisory and regulatory control functions.

FPB Subroutines Reduce Repetition

Often, a particular function must be performed over and over, and at different stages of the process. You can write the FPB statements that perform that function as a subroutine—a set of instructions that can be executed as a unit whenever the functions they perform are needed. For example, subroutines can perform calculations using process data and handle the different logical phases of a batch operation.

System Commands Put Control at Your Fingertips

A full set of system commands gives you complete control over system operation. System commands allow you to:

- Start and stop tasks and process control schemes.
- Obtain a printout of current process variables, tasks, and control schemes stored in memory.
- Transfer tasks and schemes between memory and disc or diskette.
- Erase tasks and schemes from disc or diskette.
- Create or erase files.
- Change, add to, or delete tasks and schemes.

The system commands GET and SET are particularly valuable tools for a process engineer or operator, since they allow real-time access to "live" process data. The GET command obtains the value of variables or block parameters; the SET command changes the value. The GET and SET capabilities are also available within FPB tasks and control schemes. Variables can be read and changed automatically to maintain a desired operating performance.

FOXBORO CONTROL PACKAGE (FCP)

The Foxboro Control Package (FCP) is the means of describing the process interface and control structure to the FOX 3 System. In a question-and-answer format, you can enter the specific characteristics of the process control and computational elements to be used. This description is called a "block."

A block is comparable to an analog device. It is a conceptual entity, identified by a name, defining monitoring and control functions (called "algorithms"). By logically connecting blocks of various functions, you can create a block scheme in the computer which can replace or enhance an analog control scheme. This consists of receiving measurements from the plant, processing these signals, performing control and/or computational functions, and returning control signals to the plant.

Standard Blocks and Customized Blocks

FCP provides standard control blocks that perform a wide range of process control and calculation functions, including:

- Process input and output
- Analog input and output
- Digital input and output
- Proportional-Integral-Derivative (PID) control
- Computations (RATIO, BIAS, and RATE)
- Deadtime and Lead-Lag compensation
- High- and low-limit alarm detection and reporting
- Branching (SWITCH and AUTO-SELECT)
- Logical (Boolean) functions

In addition, you can define a special kind of block, called a PROC (i.e., "procedural") block, to perform control calculations that are unique to a particular process or control philosophy. A PROC block uses a user-defined FPB subroutine to perform process-related functions beyond the standard set of control blocks. PROC blocks are implemented in the same question-and-answer form as other blocks.

On-Line Scheme Development

You can create control schemes on-line and check them out in complete safety, while the system is still actively controlling the process. The question-and-answer method of defining blocks ensures that only plausible entries are used for each block parameter. Schemes are built interactively by connecting blocks. When the process requirements change, the affected scheme can be taken off-line and modified while all other schemes remain on control. The FOX 3 System assures a "bumpless" transfer when the scheme is once again placed on control.

FOXBORO DISPLAY PACKAGE (FDP)

The Foxboro Display Package (FDP) is an optional software package that provides process-oriented, interactive video displays with user-modifiable and expandable formats. FCP is written in Foxboro Process Basic and can be used with either black-on-white or color operator's consoles. From the console, an operator can request information concerning plant conditions, control states, loop interaction, and alarm status, as well as a summary display of the control blocks in a loop. In response to an operator command, FDP can "zoom" in on a particular block so that the operator can examine its parameters, such as measurement, output, set point, deviation, and alarm limits. Also, an operator can change these values or limits while the system remains on-line and controlling the process. The system first displays any values changed for verification before entering them into the system.

FDP provides four standard display types:

Library — Contains a catalog of all other displays in the system.

Group — Displays a group of up to 10 user-assigned blocks, including their measurements, engineering units, set points, and status. You can request an expanded display of a block within a group, and can then modify that block's parameters while the block is still on control. There can be up to five group displays.

Block ID — Allows you to select for display and to modify the parameters of a particular block.

Alarm History — Provides a chronological record of up to 20 of the most recent alarms, including the current state of each alarm. The system automatically prints all alarm messages and related information on its alarm logging printer(s).

In addition to these standard display types, you can build, modify, and expand displays to meet unique requirements. Display creation involves simply writing FPB subroutines and then linking them to the FDP package through a dialog with the system.

TIME SHARING

One of the principal features of the FOX 3 System is that it allows both process control schemes and user-written tasks to run concurrently, without interfering with one another. The key to this multiple execution structure is a technique that gives top priority to controlling the process. Once it has attended to the time-critical process requirements, the FOX 3 System executes tasks according to user-specified task priority levels. When the process again requires its attention, the system interrupts task execution and services the process request. The system always ensures an orderly transfer of execution without the need for operator intervention. In this way, it appears to be doing several things at once. System integrity is ensured, because only one scheme or task is actually executing at any given time.

FOX 3 SYSTEM EQUIPMENT

The FOX 3 System equipment provides the speed, storage, and input/output capabilities needed for real-time, online data acquisition and control applications. It is both reliable and modular.

The system is composed of basic building blocks. You can initially select just the configuration to meet your requirements. Each user receives a complete, customized control system that Foxboro has designed, checked out, and shipped as a unit. You can expand the system—easily, in the field—by inserting another logic card or connecting another device to the system bus. If a replacement is ever required, spares can be inserted and operation resumed in a few minutes.

The major hardware components of a FOX 3 System include:

- Processor cabinet
- Moving-head disc drive
- Peripheral equipment
- Process I/O interface

Processor Cabinet

A single cabinet houses all of the electronics necessary for system operation. This cabinet contains:

- **Processor**—Incorporating the latest advancements in large-scale integrated circuit technology, its major functional elements are four microcontroller chips chosen for their high-speed characteristics and application flexibility. The microcontrollers form a 16-bit processor that interprets the language statements, stored in memory, that direct the FOX 3 System to perform its control functions. It can perform arithmetic calculations in both fixed and floating-point formats.
- **Memory**—Memory comprises solid-state storage devices for high reliability, low power requirements, and fast access times. Memory size is readily expandable in modular 8K increments to 64K words. Memory word parity is generated and checked for each operation. If it detects a single bit error the system automatically corrects it.
- **Diskette Panel**—The diskette panel in the processor cabinet can contain either one or two diskette drives. Diskettes provide a simple, fast, and convenient method for you to save a permanent record of tasks, schemes, data files, or the entire contents of memory. You can reload data from diskette to memory at any time.

- **Communications Interfaces**—The FOX 3 System communicates with other devices via either an INTERSPEC interface or the FOXNET process communications link. The INTERSPEC interface accepts, converts, directs, and transmits the signals flowing between a SPEC 200/INTERSPEC System and the FOX 3 System. The devices in an INTERSPEC System can include: Controller Communication Modules, Analog Input Modules, Universal Input/Output Subsystems, and Universal Field Multiplexers. The INTERSPEC interface allows the FOX 3 System to perform process monitoring, supervisory set-point control, or direct digital control of even the most complex loops.

The FOXNET process communications link enables the FOX 3 System to communicate with other stations in a SPECTRUM System. These stations can be processors (FOX 1/A and FOX 3) and the process interface devices listed above with the addition of MICROSPEC unit control modules. You can arrange stations in the SPECTRUM System to perform both distributed process control and process management and supervisory control. A FOX 3 System connects to the FOXNET process communications link through a Linkport. A second Linkport can be added for path redundancy. One of the central features of the SPECTRUM System is backward compatibility, allowing you to use devices, previously attached to an INTERSPEC cable, in a SPECTRUM System.

- **Processor Service Unit**—This unit is an integral part of the processor and is used for off-line functional testing of critical processor operating parameters. It is used in conjunction with a diagnostic diskette and eliminates the need of procuring separate processor test equipment.
- **System Clock**—The line frequency clock provides a time reference that schedules many functions vital to accurate and effective control applications. Operators can use the system clock for generating interrupts and sequencing control programs. It also provides a reference for measuring elapsed time.
- **Peripheral Interface Logic**—This logic provides an RS-232-C EIA standard interface channel for easy interconnection with all keyboard/printers, alarm loggers, CRT consoles and asynchronous links between FOX 3 Systems. Each interface channel supports full-duplex operation. The FOX 3 System provides up to eight channels for devices that may be located up to eight kilometres (five miles) from the processor cabinet if optional modems are used.
- **System Bus**—All communication between the processor and device interface modules, including memory, is via a single, high-speed data bus. The tri-state bus design results in fast access time and minimal bus loading from nonactive devices, which reduces power consumption. Data transfers on the bus occur asynchronously—that is, they are independent of time. This asynchronous operation makes the bus compatible with devices having different operating speeds.
- **Security Features**—The cabinet includes a battery backup unit that provides power to system memory for up to 30 minutes (optionally for 24 hours) during power outages. Power fail/restart circuits ensure continuous process control during power dips or outages. A service panel monitors cabinet temperature and power as well as the mode (normal/backup) of the process controllers. The cabinet also contains the system power supplies.

Moving-Head Disc Storage Unit

The optional moving-head disc unit greatly increases the system's file storage capacity. The FOX 3 System can interface with up to two moving-head disc units, each of which contains two moving-head disc drives.

- **Model F2101A Moving Head Disc Storage Unit**—The Disc Storage Unit consists of up to two disc drives housed in a freestanding cabinet. Each disc drive contains one fixed disc platter and one top-loading, removable disc cartridge. Storage capacity is 1 658 880 16-bit words per disc for a maximum of 6 635 520 words of on-line storage.

Peripheral Devices

The FOX 3 video and keyboard/printer devices provide a fast, yet simple, means of entering and modifying new tasks and schemes. You can use them for nearly all supervisory and control functions—from obtaining a measurement or changing a set point to storing a task or scheme on diskette. The operator can designate any of the devices listed below as the "system terminal," at which the operator enters tasks, subroutines, schemes, and system commands and receives system messages. Although only one device at a time can be the system terminal, the designation can be changed at any time to a different device, as required. All peripheral device operations are performed in a safe environment without upsetting either the process or the system.

Standard devices which can be used as a system terminal are:

- **Model F7501B Keyboard/Printer**—A microprocessor-driven communications device capable of printing all 94 upper and lower case ASCII characters in either a red or black printout. Unique electronic control techniques eliminate up to 80 percent of the moving parts found in conventional printers to provide high print quality and operational reliability. A light-weight, self-contained desktop configuration containing modular printed wiring assemblies makes the unit easy to maintain. Nominal printing speed is 38 characters per second.

- **Model F7701A Monochromatic Video Terminal**—A desk-top sized terminal providing alphanumeric displays and an easy-to-use keyboard for function control and data entry. Display capacity is up to 1920 characters. Information can be displayed as fixed or variable data for easy entry of new data. A graphics capability generates displays in the form of bar charts, trend curves, and process diagrams. You can combine alphanumeric data with graphic information on the display screen for detailed annotation of charts, graphs, diagrams.

- **Model F7504A Keyboard/Printer**—A tabletop microprogrammed communications terminal capable of printing all 94 ASCII characters. Characters are printed by a dot matrix head for the high print quality expected of modern printers. Quiet and reliable servo systems automatically position the carriage and paper for positive line location. Nominal printing speed is up to 120 characters per second. A pedestal is optionally available.

Other peripheral devices which serve as message and alarm logging devices include:

- **Model F7401B Printer** (Optional)—A self-contained desktop printer capable of printing all 94 ASCII characters in either a red or black printout. The terminal is identical to the Model F7501B except that it has no keyboard.

- **Model F7404A Printer** (Optional)—A freestanding device capable of printing all 94 ASCII characters. The terminal is identical to the Model F7504A except that it has no keyboard.

FOX 3 video consoles which serve as operator control stations include:

- **Model FWS1-DA Multipurpose Display Bay**—A Foxboro workstation-oriented display bay that provides convenient data display and optional data entry. A high-resolution color display or monochromatic video display may be selected as the medium for data presentation.

- **Model F4301A Monochromatic Operator's Console** (Optional)—A tabletop sized communications console that provides convenient data display and data entry for operator interaction with the FOX 3 System. The console produces high-density displays using alphanumeric characters and graphics. The dedicated keyboard allows fast and easy data entry. Up to 1920 characters can be displayed on the video screen.

- **Model F4302A Color Operator's Console** (Optional)—A tabletop-sized communications console that is identical in operation to the Model F4301A except that the displays are enhanced by eight individually controlled colors—six hues plus black and white.

Also available are:

- System-compatible keyboards, video monitors, and controllers for specializing display consoles to meet individual requirements.
- Standard video monitors for use as video repeaters.
- Modems to extend data transmission.
- **Model FWS1-AA Annunciator Subsystem**—An independent, self-contained alarm console that provides a central control panel for effective alarm management. The panel audio-visually indicates alarm conditions requiring operator intervention. Push-button switches enable the operator to take appropriate action.

FOXBORO WORKSTATION CONCEPT

Alarm consoles, annunciator bays, recorder bays, and operator consoles can be joined together in an efficient manner to create a fully integrated operator workstation. A workstation is a sectional console consisting of one or more standard modular units. You can select the number, type, and arrangement to meet your system's requirements. Workstations can expand to meet future needs as your process requirements become more demanding. The workstation arrangement simplifies maintenance of installed equipment.

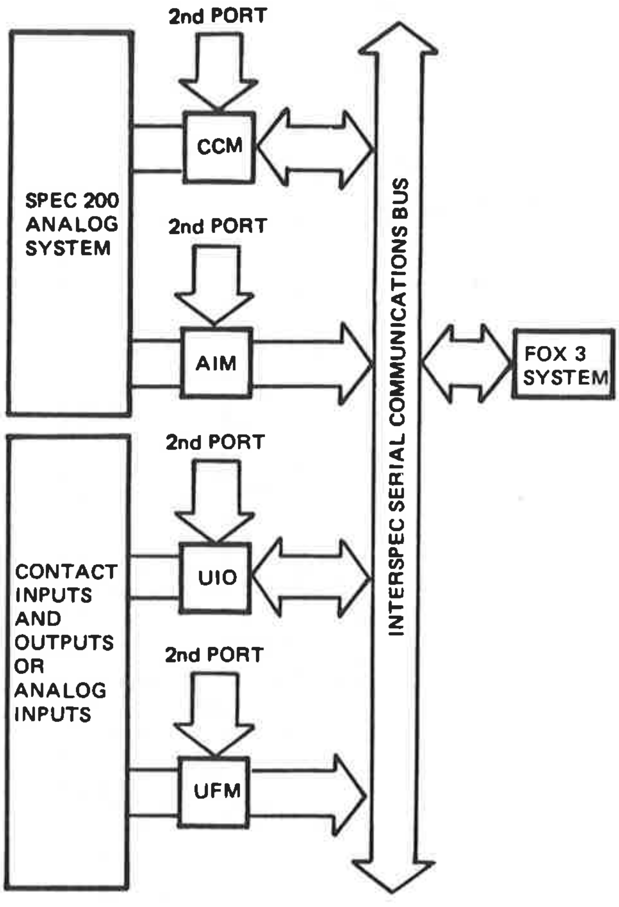
PROCESS I/O INTERFACE

The FOX 3 System can communicate with process I/O devices through either the INTERSPEC serial bus or the FOXNET process communications link.

INTERSPEC Subsystem

INTERSPEC is a simple and economical interface between the FOX 3 and SPEC 200 Systems. It is a serial data interface package that is plugged into the FOX 3 System in the same way as a peripheral device. INTERSPEC enables the FOX 3 System using SPEC 200 analog instrumentation, to monitor and control complex processes. SPEC 200 provides the conversion, communications, and control functions required to read and change the control values and operating modes associated with process controllers. A single serial-communications bus (which can extend up to 1500 metres (5000 feet) from the processor cabinet) links the FOX 3 and INTERSPEC systems. INTERSPEC consists of a number of functional subsystems:

- **Controller Communication Module (CCM)**—A CCM allows the FOX 3 System to read and change control signals and operating modes associated with process control loops. This permits the FOX 3 to perform monitoring and supervisory set-point or direct digital control. A CCM can interface with up to 16 controllers or 48 analog inputs.
- **Analog Input Module (AIM)**—An AIM provides the FOX 3 System with an efficient means of processing analog data in conjunction with SPEC 200 analog instrumentation. Each AIM can accept up to 48 analog input values and supply them on command to the FOX 3 System.
- **Universal Input/Output Subsystem (UIO)**—A UIO reads analog and digital data from process sensors and accepts signals for output to the process from the FOX 3 System. Each UIO interfaces with up to 240 field devices.
- **Universal Field Multiplexer (UFM)**—The UFM accepts both high- and low-level inputs, as well as digital contacts, providing a cost-effective means of acquiring thermocouple and resistance temperature detector (RTD) information. The UFM scans and linearizes input signals and stores them in its memory for later transmittal to a requesting processor.



Up to 16 CCM, AIM, UFM and UIO Modules in any Combination

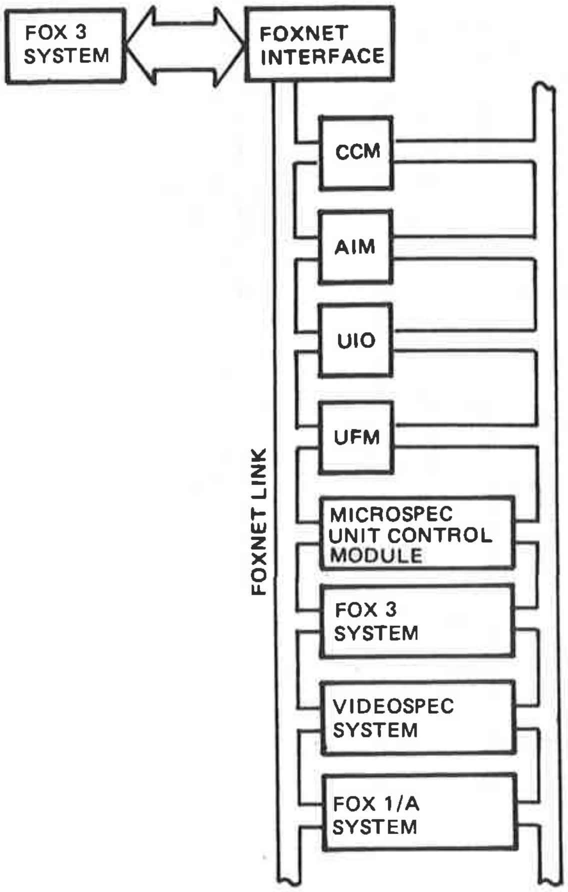
FOXNET Subsystem

The FOXNET process communications link provides high-speed network communications between the FOX 3 System and:

- Process control and management stations (FOX 1/A and FOX 3 processors).
- Operator interface stations (VIDEOSPEC consoles).
- Process control stations (Controller Communication Modules and MICROSPEC Unit Control Modules).
- Process interface stations (Analog Input Modules, Universal Input/Output Subsystem, and Universal Field Multiplexers).

The **MICROSPEC Unit Control Module (UCM)** performs first-line regulatory control, logic, and simple sequencing of process units. You can configure standard block functions into control strategies which are then implemented by a UCM. Thus, a FOX 3 System, through a FOXNET process communications link, can supervise UCM's which are controlling the process.

Network stations can be up to 4500 metres (15 000 feet) from the FOX 3 processor.



FOX 3 SECURITY FEATURES HELP ENSURE A SAFE PROCESS ENVIRONMENT

The FOX 3 System goes beyond merely performing continuous and extensive monitoring of system components; it ensures reasonable system behavior in the event of an error. For example:

- If a control block detects an out-of-range measurement, the system automatically switches to standby, and holds the block output at the last good value. The process continues with this output but the operator is informed of the error condition.
- If a module connected to INTERSPEC process I/O fails, the system immediately disconnects and its associated blocks are put on standby until the module is repaired.
- With a FOX 3 console that has been designated as the network monitor, you can monitor Linkport and Link Control Station status. You can request the system to print a report of link error counters.

The system prints operator messages specifying the cause of the actions taken. The following table lists the typical errors that the system detects. In each instance,the system initiates some alternative action to maintain control of the process.

If a power failure occurs, the system maintains process security by switching all controllers to backup mode. The system's CONTINUE/RESTART feature causes either: (1) control to resume when power is restored as though the power failure had never occurred, or (2) a power recovery sequence to be executed, which may include a user-written restart task to perform application-specific power recovery procedures. In the event of a long term power failure, where the batteries are unable to sustain power to memory, a complete system restart is simply a matter of reloading memory from a diskette. As with RESTART, you can define an application-specific reload sequence in order to initialize the system.

The system not only monitors the equipment, but it also makes extensive legality checks of operator actions, system commands, and FPB statements as they are entered. If a statement contains an error (e.g., incorrect syntax, undefined symbol), the system does not accept it. Instead, it generates a brief message indicating the cause of the error. When the statement is entered correctly, the system accepts it and allows the next statement to be entered. A programmer can't make an entry error; the system won't allow it.

Condition	Action
Memory Parity Error	The system automatically corrects single-bit errors. For double-bit errors, the system halts.
System Timer Failure	All controllers are switched to backup condition.
Peripheral Device Failure	Input/output operations are automatically retried. If error persists, all I/O operations to the affected device are stopped or routed to an alternate device.
FCP Control Block Parameters Out of Range	The offending block is switched off, and the last good value is used.
INTERSPEC Failure	Extensive error checking is performed on SPEC 200/INTERSPEC operations. All I/O operations are automatically retried. If the error persists, communication with the failed CCM, AIM, UFM, or UIO is terminated and associated blocks are switched to standby.
Network Station Failure	Network station status monitoring occurs automatically and link error counters are maintained. When a station fails, it is marked failed in the FOX 3 network station table. A message is issued for the operator. If the station is a process I/O station, then any of the FCP blocks attached to that station are switched to standby.
Power Failure	System performs orderly shutdown. Memory is preserved by battery power. The operator can define an application specific RESTART/ RELOAD sequence for power failure recovery.

SYSTEM SUPPORT FACILITIES

The FOX 3 System can offer fast system startup and continuing growth potential because of its conversational system structuring capability. This facility consists of a program that prints questions on the system terminal regarding:

- Memory size.
- Number and type of keyboard/printers and video devices.
- Logical "addresses" of devices (user-assigned numbers telling the system where to find and how to access the various devices).
- Addresses of stations in the system.

Based on your responses, this program effectively brings together all of the building blocks and connects them, so that they form an integral, usable, efficient system built to your own specifications. This simplified approach to system description minimizes the time required for system startup or modification, because you can do the whole procedure conveniently at your site.

Because the program totally structures the system, and nothing else runs at the same time, it is called an "off-line" support facility. At any time, the system structure can be changed by taking the system off-line and rerunning this program. Typically, this might be done when adding new devices to the system.

Once the system is structured, you can add FPB tasks and control schemes and run other system utilities (described below), all of which can operate concurrently.

The FOX 3 on-line utility features provide error checking and diagnostic testing of nearly every phase of system operation. These support facilities continuously monitor processor, memory, INTERSPEC operation, and SPECTRUM network security, maintaining a history of operational conditions. This easily accessible information can be a valuable aid to service personnel in diagnosing system failures. Additional facilities enable an operator to determine the operating status of peripheral equipment. On-line system tests are performed while the system is controlling the process. This simplifies problem isolation and eliminates the need for special test equipment.

A FOX 3 SYSTEM OFFERS . . .

. . . Total Control Capability

A FOX 3 System is ideally suited for a variety of applications in all industries requiring:

- Efficient and economical batch control
- Sequential control
- Feedback, feedforward and multivariable control
- Data recording and reporting
- Equipment performance monitoring
- Quality control
- Process analysis
- Analytical calculations
- Many other data acquisition and control functions.

The FOX 3 System is a tool that you can easily implement for effective control of your process.

. . . Easy-to-Use On-Line Programmability with FPB

The system's language, FPB, was developed especially for process control applications. Tasks are written in FPB using terminology already familiar to the process industry, enabling you to quickly acquire a command of the language. Almost immediately, without extensive training or programming experience, you can write tasks to provide logs, reports, and to perform supervisory control.

. . . Easy, Flexible Loop Building with Block Structure of FCP

The Foxboro Control Package is another reason why you can bring a FOX 3 System on-line quickly. Its control block structure handles all the usual process control functions of alarming, logging, and regulatory control; and handles set-point or direct digital control outputs with equal ease. FCP lets your process experience pay off in better control.

. . . Closer Operator Relationship with the Process than is Possible with Traditional Analog Control Panels

A FOX 3 operator need not search long rows of meters and lights to acknowledge alarms, take readings, or make adjustments. At the touch of a key, an operator can have a view of the process via the displays of the optional Foxboro Display Package. From the console, an operator can call up any assigned block for examination, and change selected block parameters.

. . . Built-In Process/System Security

Entering new data, changing parameters, or accessing information stored in a computer is not the costly, error-prone adventure that it is with some systems. A FOX 3 System allows tasks, schemes, and subroutines to be added, modified, deleted—even entire control strategies to be changed on-line—while the system remains in control of the process. The FOX 3 extensive security features help prevent operator mistakes from upsetting either the process or the system. Task/scheme development, testing, and debugging are performed on-line in a safe, error-proof environment.

. . . Designed for Growth

A FOX 3 System comprises state-of-the-art hardware components designed for years of dependable, reliable, efficient use in most industrial environments. Its modular construction enables a system to grow as a plant's requirements grow. Field hardware expansion is accomplished without extensive and expensive redesign, while software modifications can be accomplished on-line using standard system packages.

. . . The System for Your Process

In summary, a FOX 3 System includes every facility needed for plant control activities, from alarming and monitoring through supervisory and regulatory control. The FOX 3 System provides an immediate response to all supervisory and control demands made upon the system.

FOR MORE INFORMATION . . .

Foxboro provides a complete set of user documentation, including:

Product Specification Sheets (PSS's)

These comprise summaries of the features, benefits, and specifications for each of the following FOX 3 System equipment components:

PSS Number	Title
8D-1A1 A	Model F1300B Programmable Processor
8A-2A1 A	Model F2101A Moving-Head Disc Storage Unit
8A-6A1 A	Model F7701A Monochromatic Video Terminal
8A-6A1 F	Model F7812A Monochromatic Video Monitor
8D-3A1 B	Model F4302A Color Operator's Console
8A-6A1 G	Model F7811 Color Video Monitor
8D-3A1 A	Model F4301A Monochromatic Operator's Console
8D-4A1 A	Model F7816A Process Operator's Keyboard
8A-6A1 D	Model F7802A Monochromatic Video Controller
8A-6A1 E	Model F7803A Color Video Controller
8A-6A1 J	Model F7851A Video Copier
8A-3A1 D	Model F7002A Modems
8A-3A1 E	Model F7003A Modems
2E-4A2 A	Foxboro Workstations
2E-4A2 D	FWS1-DA Series Multipurpose Display Bays

Technical Information Sheets (TI's)

These are functional descriptions of the FOX 3 System software components. For a comprehensive picture of the system, read them in the order listed below.

TI Number	Title
800-001	System Overview
800-002	Foxboro Process Basic (FPB)
800-012	Foxboro Process Basic with FOXNET Interface
800-003	Foxboro Control Package (FCP)
800-013	Foxboro Control Package with FOXNET Interface
8-130004	Foxboro Display Package (FDP)
800-014	Foxboro Display Package with FOXNET Interface
8-130007	FOX 3 Bulk Storage
800-015	FOX 3 System Support Facilities with FOXNET Interface
800-016	FOX 3 System Security with FOXNET Interface
821-050	SPECTRUM Network Configurations

Master Instructions (MI's)

These are detailed, "how-to" instructions on all phases of the FOX 3 System planning, installation, implementation, operation, and maintenance. These documents assume that the reader is familiar with the fundamental material in the appropriate PSS's and TI's. A complete set of MI's is supplied with the system.

Summary of the Most Outstanding Features of the FOX 3 System

- ☆ Conversational implementation
- ☆ FPB—Foxboro Process Basic language
- ☆ FCP—Foxboro Control Package
- ☆ FDP—Foxboro Display Package
- ☆ An easy-to-learn and familiar block and language structure
- ☆ Concurrent operations of tasks and schemes
- ☆ Proven process interface through SPEC 200/INTERSPEC
- ☆ Enhanced process management and control through SPECTRUM network communications
- ☆ FOXNET processor-to-processor communications for process and data base management
- ☆ Extensive error correction and system security
- ☆ Powerful process control capabilities
  - Adaptive control
  - Nonlinear
  - Feedforward
  - Dual mode
- ☆ Power failure detection and automatic restart
- ☆ On-line task or scheme entry and modification
- ☆ Open-ended control capability with a procedural block feature
- ☆ Process control using either set-point or direct digital control
- ☆ Ability to change system terminal device on-line
- ☆ Reliable equipment operation in industrial environments
- ☆ Bulk Storage capability for enhanced management functions