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Notes on

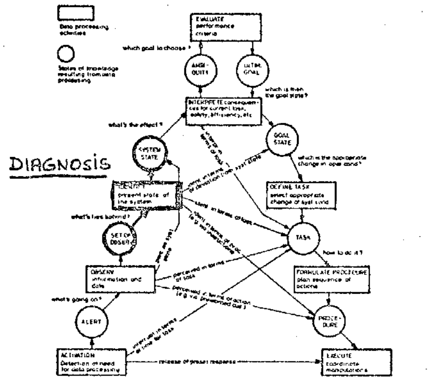
Diaqnostic Tasks in Process Plant Supervisionn

by

Jens Rasmussen

INTRODUCTION

A diagnostic task is defined as the identification of a change of the proper ties or the operational state of the process system. The purpose of the diagnosis is to be able to plan the proper treatment of the system, i.e., the diagnostic task will typically be part of a more complex task sequence. Since we have studied diagnostic strategies in workshop environments in detail- a few remarks comparing the tasks in workshops and control rooms are relevant to point to strategical differences in the tasks.



DIAGNOSTIC TASKS IN REPAIR WORKSIIOPS

The task sequence during repair will normally be:

1. Reception of the system user s complaint.

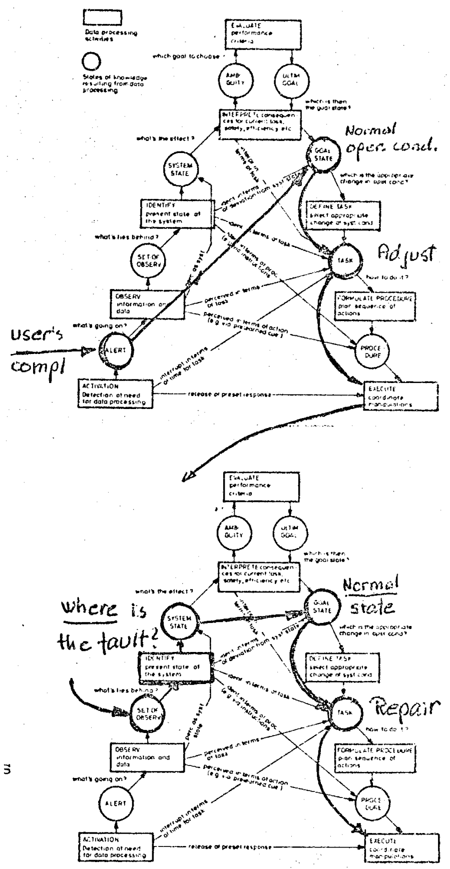
2. Manipulation to bring the system in a reference state, i.e,, adjustment to its normal operating conditions.

3. Identification of the primary change in terms of the physical location of the faulty component.

4. Replacement of the component.

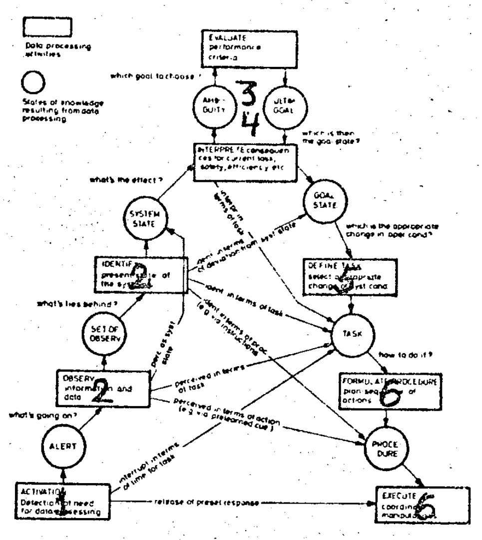
The subtasks 2 and 4 are present in all repair tasks and, accordingly, the diagnostic subtask 3 has well-defined start and goal states. The ultimate, invariate goal of the strategies will be to determine the topographic location of the change.

During diagnosis in repair workshops the task generally will not be forced by external constraints such as system dynamics which can lead to time stress and, therefore, strategies can be chosen according to internal criteria related to e.g. mental capacity limitations.



DIAGNOSTIC TASKS IN PROCESS PLANT SUPERVISION

The task sequence will typically be:



1. Detect the advent of a change in the system.

2. Identify the functional aspects of the change.

3. Interpret the actual state in terms of potential operational consequences.

4. Determine the goal state, into which the system should be brought.

5. Identify the change in the present system state, which will bring the system into the goal state.

6. Plan the sequence of actions, locate the proper means for manipulation (e.g. control knobs) and execute these.

7. Check and repeat 1-6 as necessary.

Whereas the steps 3 to 7 in repair tasks are standardized, this is not the case for process plant supervision and the diagnostic task 2 will not have a well defined output state and may not be clearly separable from the subsequent steps as a well defined subtask.

A significant influence upon strategies used during the diagnostic phase can be expected to arise from the goal state to be chosen for the .system - this means that the relevant goal. state has to be determined by a tentative diagnosis to enable the choice of a relevant strategy for a more detailed diagnosis or that several diagnostic strategies have to be used subsequently in priority level order.

At least three different types of goal states and task sequences occur during the diagnostic task in control rooms.

<u>Goal state: Normal operation</u>.

The associated task is then to correct the primary change by readjustment or replacement at a proper component level. The diagnosis thus has the purpose of locating the affected component topographically.

<u>Goal state: Alternative operational state.</u>

The associated task is to counteract the effect of the primary change upon selected vital plant variables by introduction of another change in the system. If the situation is not recognizable, the diagnostic task then aims at a determination of those causal paths affected by the primary change which, in turn, are connected to the state of observed critical variables, i.e.,, the change must be located with reference to a functional model. The goal state defines the reference states for the selected set of critical variables, and the connected task is to identify alternative causal paths to this set which are sensitive to counteracting changes.

Goal state: Predefined safe state,

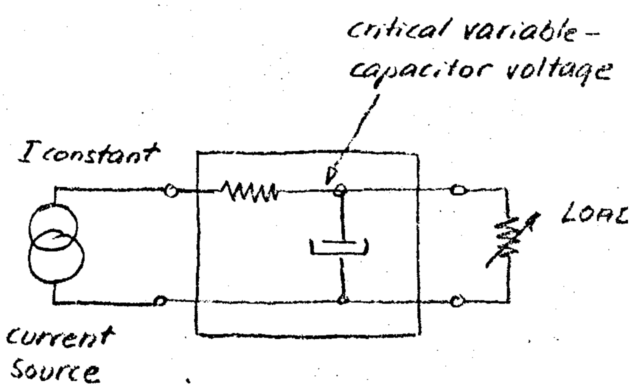
e.g. shutdown, connected to standardized operator tasks and actions. Used when specified sets of critical variables are threatened or when plant state cannot be identified functionally.

The diagnostic tasks in process plant supervision can be subject to time stress, especially if aimed at counteracting faults. If operator actions are delayed, the consequence probably will be damage to the system or drastic automatical safety actions (shutdown). Countermeasures performed by operators are only possible if there is a sufficient time delay between primary cause and critical consequences. Such time delays are typically due to integration by disturbed mass or energy balance systems. At the same time, drastic accidents are connected to loss of control of stored energy, and an important feature of the diagnostic task of control room operators is the relation to control of energy balances.

CAUSAL PATHS AND CRITICAL VARIABLES IN PROCESS PLANTS

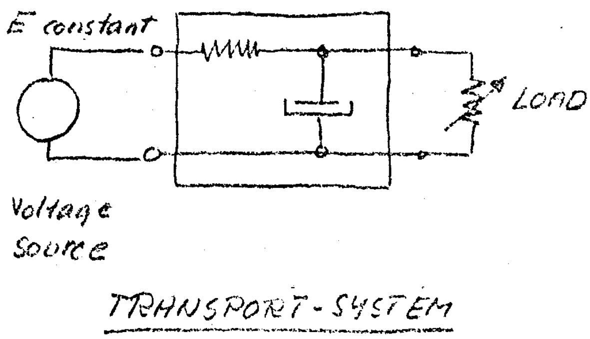
Two typical aspects of diagnosis in process plant supervision therefore are the relations to causal paths and to critical variables. A causal path is a chain of directed functional relations connected to a flow through the system of matter or energy; or to a flow of information influencing the flow conditions in energy and matter flow systems. Two classes of matter and energy-flow systems can be distinguished in the present context:

Mass or energy balance systems in which the input and output flows of the system can be controlled rather independently. In such systems there is a danger of pile-up if the flow balance is disturbed and variables related to storage level may reach critical limits before intrinsic feedback effects limit flow. (I.e. system is connected to a flow (current) source).



BALANCE - SYSTEM

Mass or energy transport systems in which the flow is only controlled from the system output, e.g. supply systems. Intrinsic feed-back effects adjust system input flow to match output flow without significant change of level variables. (The system is connected to a "flow-potential" (voltage) source).



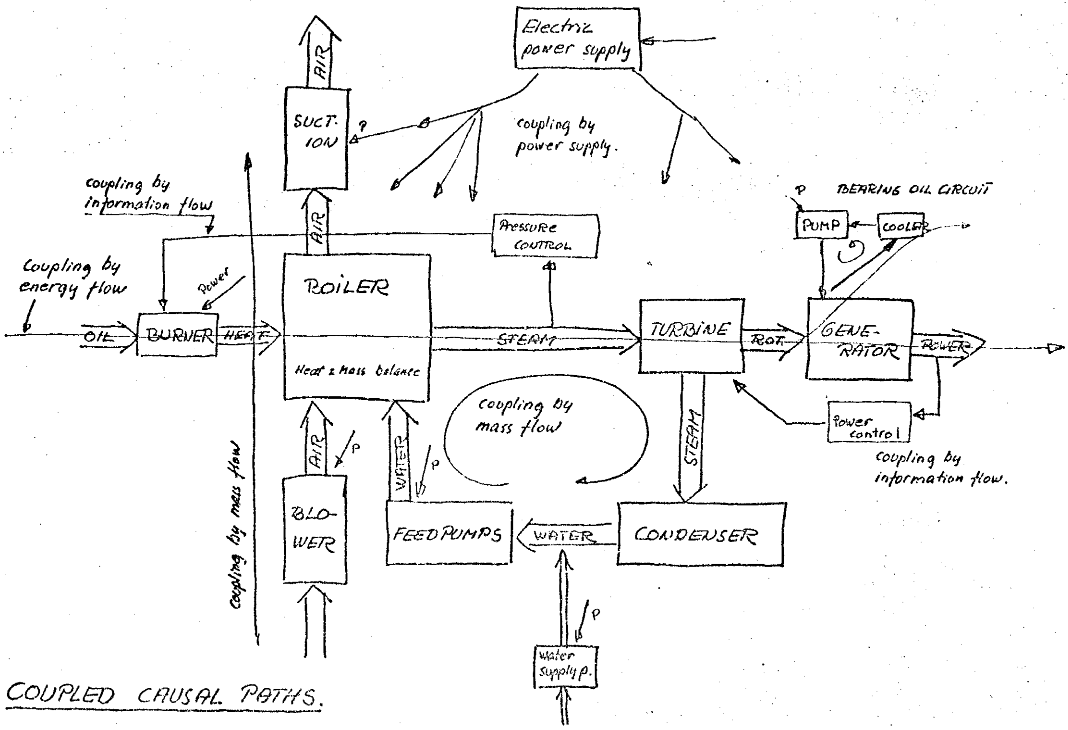
Mass- and energy balance systems are typical parts of the main process path of a plant, and since matter normally is the transport medium for energy, such balance systems are overlapping and interconnected in a complex structure.

Mass and energy transport system typically supply necessary conditions for the main processes and are connected to and influence those at many points.

Information flow systems, typically instrumentation and control systems, interconnect the different causal paths related to flow of matter or energy. Such systems introduce feed-back paths in the physical processes and disturb the basic causal relations and possibly their directions.

Critical variables are the variables of the system which have specified limit values to ensure safe or reliable operations, and which must be chosen as targets for causal paths to counteract the primary change or cause of improper operation. In energy and mass balance systems, the critical variables are basically related to the level of pile-up (pressure, temp, level of energy reservoirs) in the system, representing the stress imposed on the barriers retaining the stored energy. Other critical variables can be related to the actual state or conditions of energy containments or barriers (temp of bearings, vibration of structures etc.).

Transport systems (supply and control systems) control- the operating conditions of the energy and mass balance systems, and the critical variables in such systems are those output variables representing the interaction with the energy flow of the main process. Supply and control systems generally have highly branched structures affecting then causal chains of the main processes at many points, and changes in these systems may obscure the causal relations of the process system considerably.

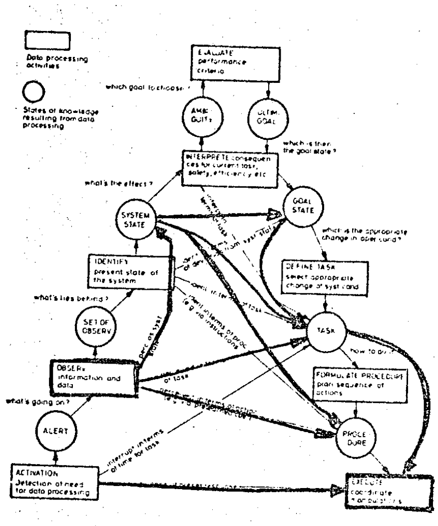


COUPLED CAUSAL PATHS.

STRATEGIES IN SUPERVISORY CONTROL

The sequence of subtasks to be performed by a novice or an unskilled operator is described by the ladder of abstraction. This normative or formal strategy can also be used by a skilled operator if he must improvise with strategies based on the causal structures of the plant system.

However, a skilled operator has a long prehistory of interaction with a specific plant in all sorts of situations and tasks, and his large repertoire of leaps and associations only very infrequently will leave him in situations where strategies involving more detailed mental data processing are used during the diagnostic phase.



The possibility of identifying search strategies underlying fault location in electronic trouble shooting in our earlier workshop studies was increased by the matching of i.nstruments and technicians such as to prevent location by immediate recognition.

In skilled supervisory control, the structure underlying the strategies used, i.e. the mental model of the system, probably will not explicitly reflect the causal structure of the system. Rather it seems to be a structure of associations and heuristic rules connecting "states of knowledge" at different levels of abstraction and related to different parts of the system.

As a basis for identification and description of strategies a description is suggested for the elements of the mental processes, i.e., the representations of plant variables and the elements and structure of the model. In this analysis attention is focussed upon the verbal expressions in short statements, rather than upon the structure of sequences. Statements used in discussions and explanations can be used as well as statements related to verbalized thinking which are only infrequently found in our control room protocols. Writ-ten procedures edited by the operational staff may also serve this purpose.

A tentative extract of an operator's statements about system properties in a protocol related to control of the water system of a power plant boiler is shown on the next page. It indicates a mental model structured in components and objects and their associated properties and actions rather than in physical variables and their functional (causal) relations.

GENERAL CONSIDERATIONS

Tentative analysis of control room protocols indicates a preference for statements in terms of system parts, i.e., the mental model is structured in physical objects. Their operational states are described by collective representations of system variables while the relevant functional relations are expressed as rules connecting object behaviour, i.e., they are represented by descriptive rather than causal laws.

Such representations are efficient in an associative structure. Prior experience can be used to link different states of knowledge irrespectively of the logical connection. However, it is necessary to analyze the structure with relation to the demands which arise in unfamiliar plant conditions and call for improvisations.

A model in terms of causal paths is necessary for improvisation. The mental tasks related to improvisation imply causal tracing back and forth between endangered critical variables, the functional change and means for introducing counteracting changes.

Cause-and-effect chains are duo to flow of matter, energy or information, but tracing this flow is difficult, e.g. because the physical variables measured and presented today are typically not direct representations of this flow.

Energy and information are abstract variables and can be followed only in a model structured in variables and relations. In a physical system the causal paths related to mass, energy and information flows overlap and are coupled together in the physical components. A fault or a change of a physical component often affects several different causal paths, and reasoning based on states and actions of physical components may not be suitable for cause and effect tracing in complex systems - especially if observations of separate, measured variables are used as signs for states.

On the other hand, a functional model relating the individual physical variables obscures the correlation of a change in physical component and the affected relations, and it will be impossible with unaided reasoning to keep track of several affected causal paths.

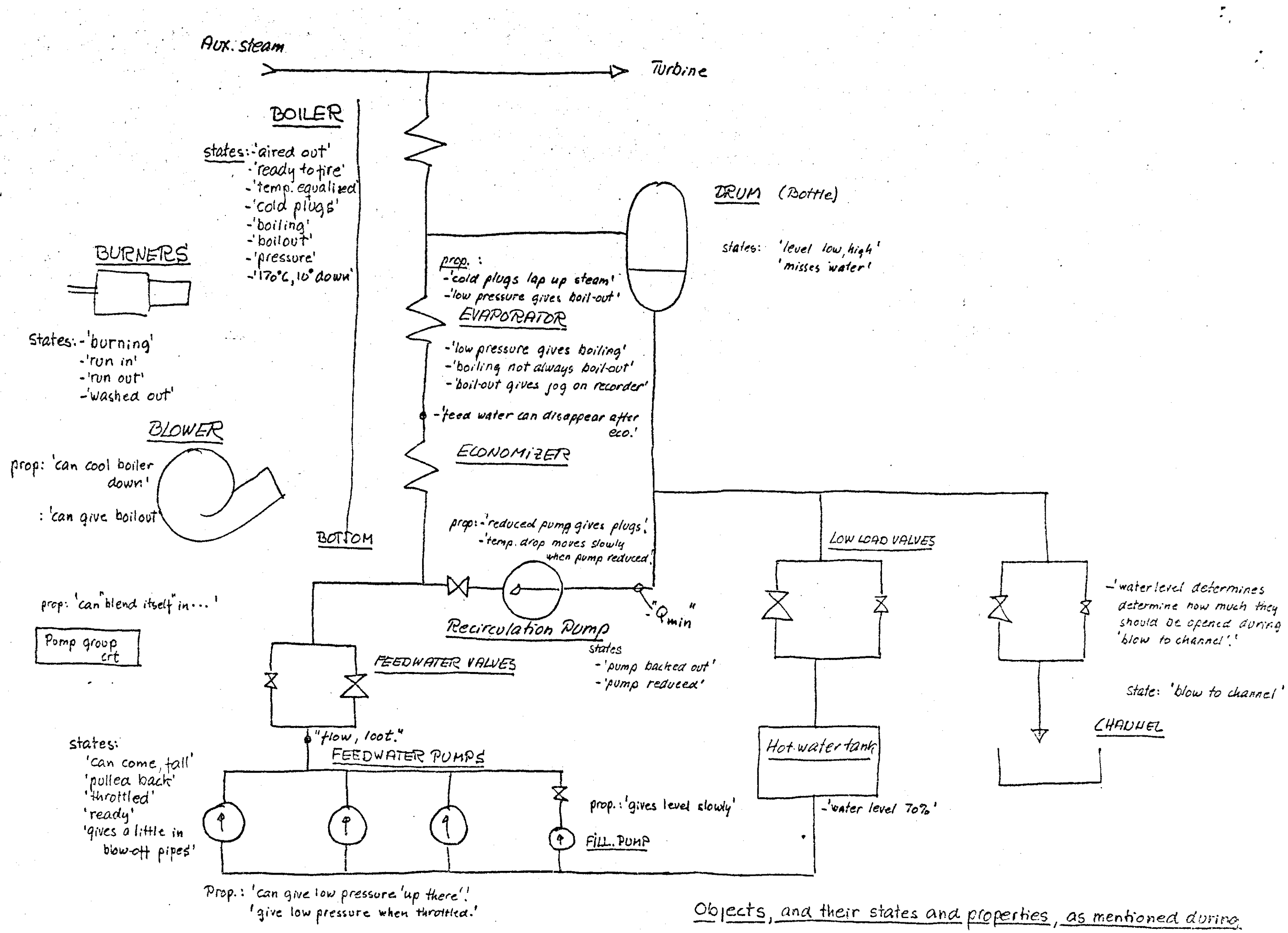
At any rate, the traditional presentation of separate measured variables in relation to physical components is probably not very suitable. Presentation of component states and properties is more naturally related to a physical, structured map of components and their interconnection; while presentation of flow and level oriented variables have a natural relation to a causal flow *map* an abstract functional model.

The diagnostic task in case of unfamiliar plant conditions will be a search to find affected causal paths reaching critical variables. It should be possible to support the operator efficiently by advanced display equipment.

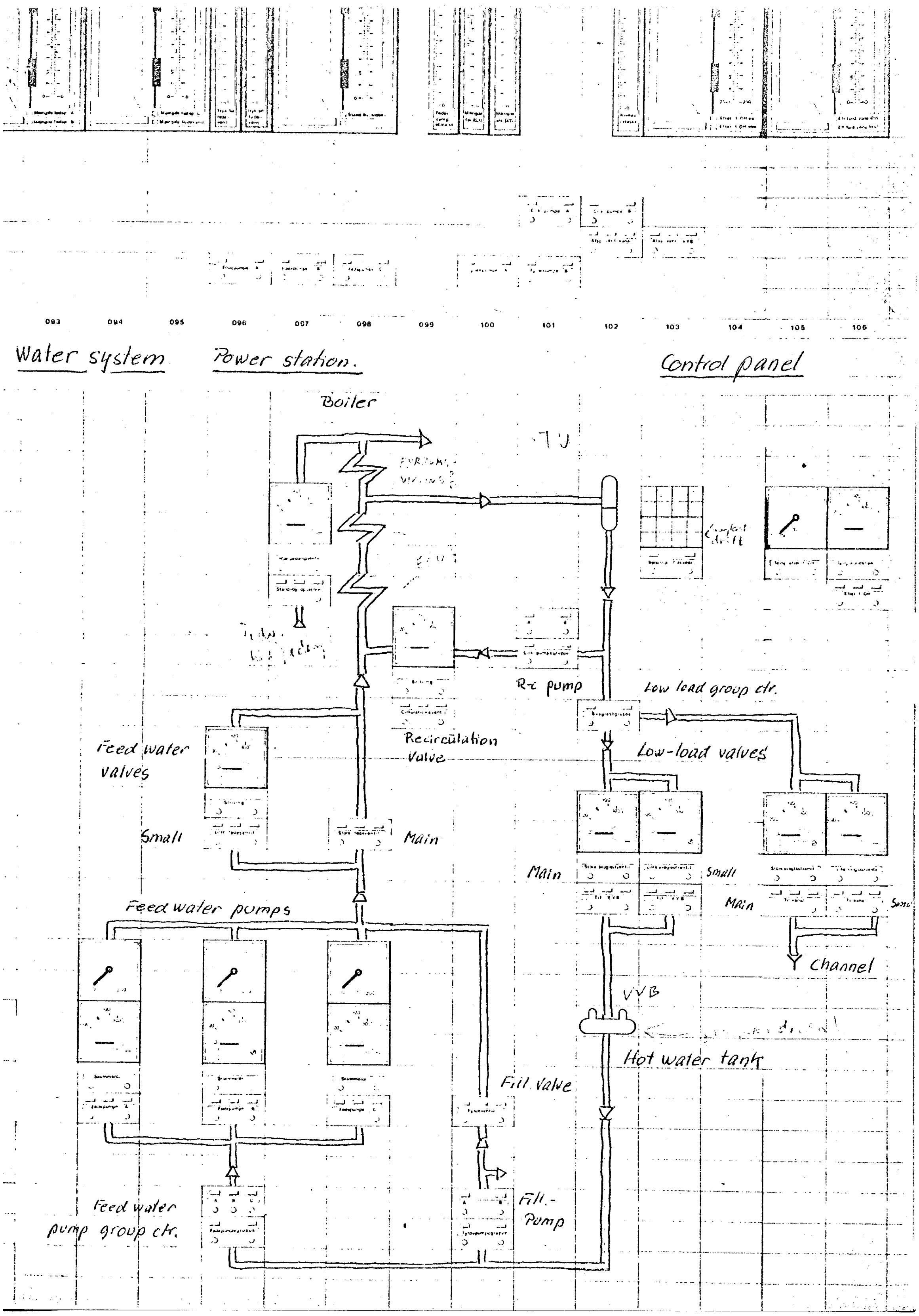
Search by a good/bad mapping of variables separately will quickly identify the proper causal patlis if variables represent flow magnitudes in a directed functional map. Normal values can be collected automatically, and the change can be displayed directly.

Search by good/bad mapping of relations can identify the relation subject to change. At least in linear systems relations are invariant with the magnitude of variables.

Search by hypothesis and test can be supported by generating hypothesis and/or by testing hypothesis by computers. Generating and testning by computer models implies the incorporation of a comprehensive and flexible functional model covering all relevant abnormal functional states, i.e., a program for extensive cause-consequence analysis and simulation. Testing by test signal; applied to the plant requires only a model of normal plant function as reference, i.e., the reference is the normal design basis or can be obtained during plant commissioning.



Objects, and their states and properties, as mentioned during start-up of Boiler water system. (litteral translation).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Water system
Power station.
Control panel
Boiler
R-c pump
Low load group ctr.
Recirculation Valve
Low-load valves
Feed water valves
Small
Main
Main
Small
Main
Feed water pumps
Channel
VVB
Hot water tank
Fill Valve
Feed water pump group ctr.
Fill.-Pump