SAFETY SUPERVISION OF VALVE OPERATIONS

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For the purpose of safety control of chemical plant operations, the system of supervising valve operations is considered on the premise that all the open-or-closed information for important valves can be monitored by a computer.

The algorithms consist basically of two parts: finding the particular route of a stream on specification of the starting and terminating points, and evaluating the flow state in each unit of equipment in the stream. For ease of computer processing the structure of the chemical plant is viewed as an assembly of connectors and valves as done by Rudd.

In the procedure of searching routes, redundant searching and repetition of searching in loops are avoided. Once the required route is found, the flow state of each connector is evaluated with the aid of information about the topological connections among the connectors which are generated in the route-searching procedure. It is possible to determine, referring to the restrictions or requirements about the states of connectors given as the security conditions, the sequence of valve operations.

Introduction

It is evident that the goal of process control is to maintain the process accurately at the required conditions. In this respect, the technology of process control is considered to have an important role in the context of the safety administration of chemical processes. Feedback control has been widely adopted in chemical plants and is now the basis of the computer control systems including DDC or the production management system.

However, reflecting on the fact that so many accidents happened successively in chemical plants in Japan during the last couple of years, a control system is being called for that can deal with the problems of countereemergency or safety management in addition to the steady-state control modes. There is, of course, no doubt that such requirement can only be attained with the aid of computers.

It is quite essential to set up, as the philosophy of process design, a border between the functions of man and machine in plant operations. In other words, it is not appropriate to replace any part of the heuristic responsibility by a mechanical function only because the machine can handle it. Otherwise, the work left for human operators would be of a type that they may not be happy to perform, because they would be forced to function as a part of the mechanical system. In addition to this problem, there arise many difficulties in managing and coordinating the whole plant if the control system is a random mixture of man-controlled and machine-controlled processes.

The most important factor that should be taken into account in the system design of computer-aided operating systems is the matching of man and machine responsibilities, particularly in the tackling of emergency problems. The predictable defects or troubles for which the causal dependencies are clear can in general be dealt with by computers, since it is not difficult to convert the schemes of judgment of operators in reacting to such troubles into computer language or algorithms. It is, therefore, one of the most important roles for the operators to discover defects that the computer can hardly detect and to

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make proper judgements on the causes so as to take prompt reactions.

It is noteworthy that particular consideration should be given, in addition, to allowing the operators to perform controls of high quality within the limit of their freedom. In this connection, the development of man-machine communication should be much further promoted. In the present work, an attempt was made to develop a method of supervising the valve operations of chemical plants with the use of computers to eliminate the possibilities of hazardous malfunction.

1. Monitoring Valves

According to statistics, more than 80% of the accidents in chemical plants can be attributed directly or indirectly to mistakes in valve operations. This can be understood from the fact that most operations are, in practice, conducted through valve operations except the switching for electric circuits, and as a result quite a large number of valves are attached to each line and unit operation.

It is considered, therefore, that detecting the state of each valve, open or closed, would give valuable information for performing the organized control of the whole process. There seems to be no technical problems in realizing detection of valves by supplementing devices which indicate the positions of the valve stems.

Once the information about the states of all the valves are stored in the memory of a computer, one can utilize them for various purposes. For example:
1) to confirm the operators’ understanding about the states of valves;
2) to give warning about occurrence of a forbidden combination of valve openings;
3) to evaluate the level of danger of plant conditions, taking into account the sequence of operations;
4) to propose the safety sequence for operations.

Although it is possible technically to connect the output signals of the computer directly to the valves as is done in the DDC system, the purpose of the present work does not lie in mechanization of the computer outputs for effective guidance of operations, since the countering emergencies undetectable by the computer as well as of performing operations of better quality than the computer should be preserved for human operators.

The supervising system to be discussed in the present work is based on the assumption that the states of all the valves involved are monitored somehow by the computer. The present program is comprised of two parts. The first is the function of searching a process stream route which is designated by the starting, terminating and intermediate points, and the second is the function of evaluating the flow condition of each unit of equipment. It is basically possible to obtain the sequence of operations of valves when the results of the two parts are combined.

2. Route Searching

A chemical process of any structure can be represented topologically as a network of valves and connectors, where the connector is defined as a portion of the plant blocked by valves no matter what is included. In other words, the connector may consist of any kind of equipment or may be only a pipe. For convenience of discussion, the possibility of reversing the direction of flow is excluded, that is, each valve allows the stream to flow in only one direction.

Figure 1 is a flowsheet represented in terms of valve and connector. This is quite similar to the representation proposed by Rudd. The number at the side of each valve indicates the valve number, which can be set arbitrarily so long as the same number is not reused. The number in parentheses indicates the connector number, which is to be named in the same manner as for valves. The flowsheet shown in Fig. 1 is for an imaginary process comprised of two distillation columns and two alternative packed bed reactors to be switched for reactivation.

To begin with the processing of algorithms, it is necessary to prepare a pair of tables representing respectively the connections of connectors with their inlet and outlet valves and of valves with their upstream and downstream connectors. For example, the connector table and the valve table for the process shown in Fig. 1 are shown in Tables 1 and 2, respectively.

When “the route from (3) to (14) via (7)” is requested to be searched, it can be found in accordance with the procedure shown in Table 3. The searching procedure basically consists of the following steps:
(1) The number of the starting connector is registered in ICON (1) at first step, J=1.

(2) The number of the valve connecting with the connector registered in ICON (1) is registered in IVAL (1).

(3) The number of the downstream connector of the valve registered in IVAL (1) is registered in ICON (2) at the second step, J=2.

(4) When the connector has more than one outlet valve, the number of the valve to be checked is registered in the IVAL(K) table and at the same time MARK(J) is changed to 1, which indicates that the connector still leaves unregistered outlet valves.

(5) This procedure is repeated until the connector with no outlet valves is reached. If the destination is not attained, another branch is chosen by tracing back the MARK(J) table up to the last Mark 1.

(6) The number of the connector corresponding to the last Mark 1 is registered again in ICON(J) table and at the same time, if no unregistered outlet valve is left, MARK(J) of that row is changed to 2, which indicates that all the branches leaving the said connector have been investigated.

(7) If the same connector appears twice in the path under investigation, the search must be being carried out in a loop and the next branch should be chosen for the following search in the manner described in (5).

(8) When the trial for the branch (connector) with Mark 2 fails in reaching the destination, the connector is marked with 5 to prevent repetition of the same failure.

3. States of Flow

Once the desired route is found, all the valves connecting to the connector but not lying on the route should be closed and all the valves on the route should be open in order to maintain flow only through that route. There are, however, a factorial number of cases in the sequence of operation of valves. The human operator is expected to select a safety sequence of operations from his experience or in accordance with the manual of standard operations. It is, however, possible to obtain by the computer the safety sequence of valve operations if the state of flow in each connector is evaluated. This algorithm does not necessarily determine the sequence uniquely, but at least it can...
Fig. 2 States of flow in connector

eliminate hazardous sequences that meet the criteria of forbidden sequences.

Four kinds of flow states are defined for each connector as follows.

**FLOW**: Fluid is flowing through the connector. Both the inlet and outlet valves are open.

**BLOCK**: Fluid is blocked at the connector. All outlet valves are closed but some inlet valve is open.

**BRANCH**: Fluid is not flowing in the connector but the connector is possibly an upstream branch of a flowing route. All inlet valves are closed but some outlet valve is open.

**TRAP**: Fluid is trapped in the connector. All inlet and outlet valves are closed.

The states of flow are not considered individually for each connector but for the group of connectors which are connected with open valves. In other words, the states of two connectors connecting with each other by open valve, for example, cannot be BLOCK and TRAP but can be BLOCK and BLOCK.

The states of flow of the connector can be represented in the computer by two bits, since there are four kinds of states, as shown in Fig. 2.

Here it is investigated how the operation of a valve, say from close to open or from open to close, changes the states of flow in both of the upstream and downstream connectors. All the possible cases are listed in Table 4 for valve operation from close to open and in Table 5 for valve operation from open to close. For example, when the closed valve between the upstream connector (USC) whose state of flow is BLOCK and the downstream connector (DSC) whose state of flow is TRAP is opened, the state of flow of USC is not changed but the state of flow of DSC is changed to BLOCK. It is seen that the case of valve operation from open to close is rather complicated compared with the case from close to open, and it requires information about the state of flow in either the upstream connector of USC or the downstream connector of DSC, which are indicated as conditions in the remarks.

It was found, through a precise investigation of all the cases, that there is a rule for changing the states of flow of USC and DSC which can be expressed by a Boolean expression as follows.

### Table 4 Change in state of flow by valve operation

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### Table 5 Change in state of flow by valve operation

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### CONDITIONS

1. If any open inlet valves of DSC are connected with BL or F
2. If any open inlet valves of DSC are connected with BR
3. If any open outlet valves of USC are connected with BL or T
4. Infeasible combination

### CLOSE to OPEN

- **CLOSE to OPEN**
  - $A = A$
  - $A' = A$ or $A'$
  - $B = B$ or $B'$
  - $B' = B'$

### OPEN to CLOSE

- **OPEN to CLOSE**
  - $A = A$
  - $A' = (A$ or $A')$ and $(A$ or $C')$
  - $B = (B$ or $B')$ and $(B$ or $D)$
  - $B' = B'$

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where the letters and their primes denote, as shown in Fig. 3, the bits to indicate the state of flow of each connector. The lower bar denotes the new state of the bit after valve operation and the upper bar denotes the negation of that expression.

4. Application

An attempt was made to apply the algorithm of the present work to the sample process shown in Fig. 1 in order to investigate its practical feasibility.

The problem was set in such a way as to find the sequence of valve operation to obtain the proper flow of material in accordance with the route specified without infringing the forbidden conditions, that is, in this case, to keep the states of flow of the connectors 5 and 8 always as FLOW.

In other words, an attempt was made to find the operational sequences of valves for switching the reactor (7) which has been used to the other reactor (6), for purging the reacting gas in the reactor (7) by an inert gas in the source (4) to the flare stack (15), and for reactivating the catalyst in the reactor (7) with the gas flowing from the source (3) to the vent (14), while both distillation columns (5) and (8) should be operated under normal flow condition.

The block diagram of computation is shown in Fig. 4, where the route-searching routine and the flow state-evaluating routine are combined. An example of the output of the computation is shown in Fig. 5.

Specifying only a few kinds of forbidden conditions for a process with a number of valves as done in the present example is, of course, not enough to determine uniquely the whole sequence of operation. The basic ordering of the valves to be operated in the present work is, therefore, set so as to choose from the upmost valve in the stream when several valves are evaluated as equivalent.

One may want from the practical point of view to have more restricting conditions such as to prohibit mixing of specific chemical species or to prohibit reversing the pressure balance. The algorithm of the present work is basically applicable to such a problem, providing that additional variables other than the flow condition can be defined to represent some other states to be evaluated at each connector such as chemical species present or pressure in the connector.

Literature Cited

VALVE INFORMATION LIST
9/CLOSE 10/CLOSE 11/CLOSE 12/OPEN 13/CLOSE 14/CLOSE 15/CLOSE 16/CLOSE
17/OPEN 18/OPEN 19/OPEN

CONNECTOR INFORMATION LIST
9/FLOW 10/TRAP 11/TRAP 12/FLOW 13/FLOW 14/BRANCH 15/BRANCH 16/FLOW
17/FLOW

*** OPERATION *** FROM 5 TO 8 VIA 6

OPERATING ORDER OF VALVES
7/OPEN 11/OPEN 9/CLOSE 12/CLOSE

*** OPERATION *** FROM 4 TO 15 VIA 7

OPERATING ORDER OF VALVES
6/OPEN 10/OPEN 14/OPEN 15/OPEN

*** OPERATION *** FROM 3 TO 14 VIA 7

OPERATING ORDER OF VALVES
6/CLOSE 15/CLOSE 5/OPEN 15/OPEN

Fig. 5 Output for valve operation sequence