Energy, Mines and Resources Canada
Energie, Mines et Ressources Canada

CANMET

Canada Centre for Mineral and Energy Technology
Centre canadien de la technologie des minéraux et de l'énergie

CANMET
MINERAL PROCESSING
FILE

COAL PREPARATION COMPUTER APPLICATIONS

COAL RESEARCH LABORATORY R & D

Tel (403) 987-8635

A.I.A. Salama, M.W. Mikhail and R.J. Mikula

Coal Research Laboratory, Edmonton

(Les applications de l'ordinateur à la préparation du charbon.
La R & D dans les laboratoires de recherche sur le charbon)

November 1983

For Presentation to the 85th Annual Meeting of the CIM,
Winnipeg, Manitoba, April 17-20, 1983.

ENERGY RESEARCH PROGRAM
COAL RESEARCH LABORATORIES
DIVISION REPORT ERP/CRL 83-23 (J,OP)

COAL PREPARATION COMPUTER APPLICATIONS
COAL RESEARCH LABORATORY R & D

by

A.I.A. Salama*, M.W. Mikhail**, and R.J. Mikula*

ABSTRACT

The Coal Research Laboratory (CRL) of CANMET along with other research organizations in coal-producing countries envisages major benefits from computer applications in coal preparation. Some of these benefits are greater system flexibility, improved coal preparation plant performance efficiency and efficient utilization of manpower, all of which result in economic benefits. Computer can be applied for both on-line and off-line purposes; this paper focuses on the on-line applications from the process control point of view.

A critical discussion of the different analog and digital process control systems is presented. The importance of precise and reliable on-line instrumentation for better process control is pointed out. Recent developments in Great Britain, West Germany, Poland and Australia on automation and instrumentation using on-line measurements of coal ash and moisture contents are identified.

The CRL research and development strategy aimed at achieving on-line computer control of an automated coal preparation plant is presented.

---

*Research Scientists and **Unit Head, Coal Beneficiation Research Unit, Coal Research Laboratory, Canada Centre for Mineral and Energy Technology (CANMET), Energy, Mines and Resources Canada, Edmonton, Alberta.

INTRODUCTION

In the last twenty years an enormous progress in the area of computer technology has been noticed. The very rapid advances in the computer hardware and less rapid but significant advances in computer software have led to development of the minicomputer, microcomputer and microprocessor. It has been realized that computer applications in industrial processes have potential benefits such as greater system flexibility, improved plant performance efficiency and efficient utilization of manpower. Significant computer control development in mineral processing has already been achieved. Although progress has been made in the area of computer applications in coal preparation, more effort is needed to utilize the full potential.

The computer applications in coal preparation can be viewed as off-line and on-line. Considerable progress has been reported in the area of off-line computer applications, especially in the areas of modelling, performance evaluation/prediction and statistical analysis. However, only modest progress in on-line applications has been reported (1-7). This paper will focus on on-line instrumentation and process control applications and will discuss the computer-man-process system, the importance of instrumentation for better system control, different analog and/or digital control systems, on-line automation and instrumentation in other countries and CRL strategy towards pilot plant automation.

COMPUTER, INSTRUMENTATION AND CONTROL

Long before the invention of the computer, man was an integral part of many process systems where the human sensors (eye, ear, tongue, nose, hand) were utilized to sense the process variables, and where the brain was used for decision making. Later, instrumentation was developed to replace the human sensors and was utilized by man to assist in making certain decisions for the adjustment of process variables and to achieve certain objectives (Fig. 1). The performance of the man-process system was acceptable to some degree, but human errors and delays were the main disadvantages. The response of the whole system was slow and precision and accuracy suffered. The invention of the computer revolutionized the concept of man-process system by turning over some of the human decision-making tasks to a computer. The computer can perform these tasks accurately and reliably and in much less time. As a result, the role of man has been changed to a more supervisory one with only higher level decision-making (Fig. 2). In such a system [man-computer-process], most of the disadvantages of the earlier man-process system such as human error and delay are eliminated and as a result the overall system response is fast and the accuracy and reliability are greatly improved.

The link between the process and the computer is the instrumentation (Fig. 2 and 3). To achieve good control, the instrumentation and sensors must be accurate and reliable because erroneous measurement leads to poor control. Therefore instrumentation is the key to a successful control system. As will be discussed later, accurate measurement of the physico-chemical properties of coal improves the overall computer control of the coal preparation plant.

In general, the control commands of the process are generated by the computer (Fig. 4) but some control units such as Programmable Logic Controllers (PLC) are used instead of or in conjunction with computers (8). The PLC's are dedicated to certain tasks and are relatively inexpensive and robust especially in the dirty environment of a coal preparation plant. Although the computer costs more than the PLC it has much larger capabilites.

ANALOG AND/OR DIGITAL CONTROL SYSTEMS

The measurement and control requirements of an application dictate the type of control electronics required i.e. whether they should be analog or digital. In the past, most of the instrumentation was analog but today, most of the development of computer technology and increase in computer utilization in process control has resulted in a concentrated effort being made in development of digital instrumentation. Different types of analog and/or digital control systems are summarized below (9).

ANALOG CONTROL SYSTEM

This is one of the earliest and simplest systems which offers the basic control function at the lowest cost. In this system, the measured process variables are compared with predetermined or local set points and the error signals drive the analog controllers (Fig. 5). Such a system is inherently more difficult to calibrate and maintain in proper working order because the analog components are more susceptible to electrical drift. The system is used in all coal preparation plants in Canada with only one exception.

ANALOG CONTROL WITH SUPERVISORY COMPUTER

This is basically an analog control system except that it has been expanded for data collection and process modelling by connecting a digital computer to the analog controllers (Fig. 6). Some of the disadvantages of this system are that the analog-digital interface is complicated, total system complexity is often excessive and because these systems are hardwired, system update and modification is difficult. This system has an advantage over simple analog control in that it provides for automatic determination as well as predetermined calculations of proper set point. Only one coal preparation plant in Canada uses this type of control system; a PLC is used for sequential start-up and shut-down of the plant. The PLC is in a supervisory capacity with existing control still being handled by an analog system.

ANALOG SUPERVISORY COMPUTER SET POINT CONTROL

In the analog control with a supervisory computer, a computer is utilized as a sensor-based monitoring and logging device and the control is based on output information which is acted upon by a human operator (Fig.7). There exists another level of supervisory control in which many of the control actions are determined by the process computer and implemented automatically, i.e. the controllers set points are set automatically based on the information gathered by the process control computer. As a result, the analog supervisory computer set point control system has an advantage over the analog control with a supervisory computer in that it provides for automatic determination of controllers set points.

DIRECT DIGITAL CONTROL

A Direct Digital Control (DDC) system utilizes a central process control computer to perform most of the functions of the local controllers in analog and analog supervisory control systems (Fig. 8). The DDC thus offers a means of simplifying many of the problems associated with supervisory analog control: complex analog control loops are replaced by simple DDC loops and control calculations are handled digitally. The DDC can handle the same basic process control operations as performed by an analog system but has greater reliability, more flexibility, greater ease in servicing and simpler operation. Other advantages are that a) it is able to alarm e.g. in the form of blinking lights, flashing CRT displays, bells ringing, etc., b) multiple levels of alarms are possible when process variables move outside designated limits, c) it is able to display data from a process in any conceivable form and d) it is capable of keeping records of data, changes in process variables and of decisions made. The one serious disadvantage that limits the usefulness of DDC systems in industry is related to overall system backup. For example if the central control computer should fail, the central control function is lost and almost no backup remains.

DISTRIBUTED MICROPROCESSOR SUPERVISORY CONTROL SYSTEM

In the DDC, the disadvantage that the control functions of all local controllers are handled by a central process computer can be eliminated by introducing the concept of a distributed system (9,10). In the distributed system the control functions are spread between two or three or more control computers or micorprocessors (fig. 9). These control computers or microprocessors are easily interfaced with a supervisory digital computer. The various distributed control microprocessors are interconnected by data highways. The distributed system is in a sense the digital version of analog control which utilizes microprocessors instead of analog control elements. The distributed microprocessor supervisory control has the backup that is inherent in an analog system and, at the same time, has the communications advantages of DDC. These advantages indicate that microprocessor-based distributed computer control systems will be used for process control applications in the future.

ON-LINE AUTOMATION AND INSTRUMENTATION OUTSIDE CANADA

Several coal-producing nations have realized the potential advantages of on-line computer applications and advanced instrumentation in the area of coal preparation. These nations have focussed their efforts on the development of automated coal preparation processes, machinery andcomponents and ultimately the entire preparation plant. The most extensive activity is reported in Great Britain, West Germany, Poland and Australia. The investigation and evaluation of foreign developments is valuable because some of the automation techniques and equipment can be adopted for use in Canada. This section summarizes the research and development related to coal preparation on-line computer applications and instrumentation in the aforementioned countries (11).

ON-LINE AUTOMATION AND INSTRUMENTATION IN GREAT BRITAIN

The Mining Research and Development Establishment (MRDE) of the National Coal Board (NCB) is considered to be one of the pioneers in the application of computers for coal preparation plant automation. Their program started in 1974 with the installation of Programmable Logic Controllers (PLC) for sequence control at the Thurcroft coal preparation plant. The first computer installation and full integration into plant operation was made at the Rawdon coal proparation plant. The computer system is a Bristol Automation Ltd. "Micro-B" microprocessor with 48K memory, 78 digital inputs and 53 digital outputs and handles sequence control and event logging. A larger computer system was installed at Leas Hall Colliery. This system utilizes a PDP 11/35 computer with 138K memory, color graphics and automatic alarms. It can handle the start-up of 300 items of equipment from a keyboard, continuously scan plant signals and has three-mode control of 22 process loops, set point and alarm limits for each process. In 1980, a microcomputer-based monitoring and control system was installed and commissioned at the Bold Colliery preparation plant (2). The computer system is from Babcock Bristol Ltd, and has two "Micro-B" process computers with 64K and 48K memories respectively. The 64K process computer is utilized for sequence control (automatic startup and shutdown), interlock control in the event of an alarm for rapid interlock shutdown, item status display and alarm indication and logging. The 48K process computer is utilized for monitoring and control of the analog requirements of the plant. The NCB conclusion is that a distributed control system is preferable to a design that uses one large central process computer.

Several instruments for coal preparation processes have been developed in Great Britain: the Gunson's Sortex ash monitor, the (NCB-MRDE) clarometer and the Bretby automatic refuse removal rate control for the Baum jig. A recent instrument application is the use of nuclear density gauges for relative density monitoring and control of the heavy media system. In a recent publication by NCB-MRDE, engineers describe the techniques available for monitoring the motion and vibration of coal preparation plant items and the methods used to measure such process variables as flow, level, density, etc.(12). On-line ash content measurement is done by weighing a constant volume of coal on a belt feeder and using the bulk density-ash correlation to provide a signal that represents the ash content. This phase 3A-2 NCB/AERE ash monitor can be used on undried minus 5 mm coal. On-line moisture measurement of coal using dielectric or capacitance measurements has proven to be unreliable. Moisture measurement by microwave absorption, has on the other hand produced some encouraging results, but requires testing on wider scale.

ON-LINE AUTOMATION AND INSTRUMENTATION IN WEST GERMANY

The Walsum coal preparation plant near Bochum and the Schlagel and Eisen plant nearby at Essen are the most advanced preparation plants in West Germany. Both plants are computer-controlled; the control is purely digital for startup, shutdown and other sequential functions. Closed-loop control is not a feature at either of these plants. The Walsum plant has two AEG 80-20 computers, both fully functional at all times during plant operation. The process control computer is the only one able to alter the system outputs although the backup computer contains the same range of programs as the process control computer. The process control computer sends updated process status to the backup computer every 100 ms allowing the backup computer to be brought on-line automatically if a system failure in the process control computer occurs. The computer system has 120K of memory, 1408 input relays, 384 output relays for process control and 432 output relays for indicator lights in the control room. The Schlagel and Eisen plant has four AEG computers, one for each of the following functions: process control, backup for the process control unit, control of the three color graphics monitors and direction of the other three computers and flow of information between them. The computer system has 2000 digital inputs and 4000 digital outputs.

Instrument development activities are carried out at two major West German organizations: Bergbau Forschung and Humboldt Wedag GmbH. Bergbau Forschung has developed and tested on-line ash and moisture content monitors for coal (11). A rapid determination of ash content in coal can be made by an instrument based on gamma-ray backscatter. Bergbau Forschung have carried out experimental evaluation of the following methods for monitoring moisture: electrical conductivity, electrical capacitance, infrared reflection, nuclear magnetic resonance and microwave absorption. All of these methods have some drawbacks: the electrical conductivity measurement was found to be insufficiently accurate; the electrical capacitance measurement was unreliable; the infrared reflection measurements are affected by particle size and indicate surface moisture rather than inherent moisture; nuclear magnetic resonance is accurate only for coal with a top size of 1 mm and therefore industrial application of this method is not promising: the microwave method was found to be affected by both particle size and particle size distribution. A project was started in July, 1980, to investigate the possibility of closed-loop control of froth flotaton cells using particle size, ash content and slurry solids contents as parameters.

Humboldt Wedag is applying their commercial gamma-ray backscatter ash monitor to closed-loop control of the Batac jig. Only two installations of the ash monitor for closed-loop control of jig exist in the world, one in Germany and the other in Romania.

ON-LINE AUTOMATION AND INSTRUMENTATION IN POLAND

The minicomputer has been used in Poland as a component of an on-line system for automatic monitoring of the calorific value of coal. In this country coal preparation plants have been automated for automatic start-up, automatic control and data recording of some process variables (e.g., density of heavy medium and slimes, air pressure, feed control) and for quality control and measurement of ash and moisture. There is no an overall plant control.

Most of the instrumentation development has been done by the Research and Development Centre for Mining Mechanization, Electronics and Automation Systems EMAG, at Katowice. The instruments are for determining coal ash, moisture content, calorific value, sulphur content and mass flow-rate. The centre has developed two types of ash monitor, the G-Type ash meter which is based on gamma-ray backscatter and the PR-1-Type ash meter which is based on attenuation of gamma-radiation.

Microwave and electrical impedance methods are being used for the moisture measurement of coal. The microwave unit (WILMAG 78-16) measures the variation of reflected power as a function of the moisture in a leveled coal bed on a conveyor belt. With the electrical impedance instrument, a measuring element immersed in the coal stream is used to detect impedance variations as a function of moisture. Automatic monitoring of the calorific value of coal is done by a system which incorporates a G-Type ash meter, a WILMAG 78-16 moisture meter, a minicomputer and a control unit and detectors for the coal layer thickness and conveyor belt speed. The minicomputer is programmed to calculate the calorific value of the coal using an empirical relationship between the calorific value and the measured ash and moisture contents. The detectors for the coal layer thickness and conveyor belt speed ensure proper operating conditions for the ash meter and the moisture meter. The control unit coordinates and routes signals between the minicomputer and the other components of the system.

ON-LINE AUTOMATION AND INSTRUMENTATION IN AUSTRALIA

The use of computers and closed-loop control have not been reported in Australia but work in modelling and automating heavy medium and froth flotation processes are in progress. On-line measurements of ash and percent solids are being made utilizing a radiation absorption method with both an americium and a cesium source. To implement this scheme, a physical model for the absorption of radiation was devised. For froth flotation control, the ash monitor would be used on the feed, the clean coal and the refuse.

CRL STRATEGY TOWARDS PILOT PLANT AUTOMATION

CRL has realized the advantages of the distributed process control system over the DDC system, especially when considering the backup feature and overall system flexibility. From this review of plant automation and instrumentation it appears that more research and development has to be done to achieve full automation of a coal preparation plant. At CRL, the 10 tph comprehensive pilot plant is being used for development and testing of on-line instrumentation and of a distributed process control system (13). The advantages of such an approach are:

1. Reduced risk and cost compared to developing a novel system at an operating plant
2. Flexibility in making changes to improve the system
3. Demonstration of the benefits of a distributed control system.

The present laboratory coal preparation program includes development of the different processes and circuits independently of one another e.g. the heavy medium cyclone, flotation, jig, water-only-cyclone, water recovery etc.. This will simplify the instrumentation development and reduce the risks involved. The investigation of each circuit is useful since the relevant process variables can be identified and a suitable process optimization scheme adopted. The optimization scheme, data handling and process control for each circuit will be carried out by dedicated microprocessors. The resulting process computer developed for each circuit can then be interfaced to a master computer which performs the supervisory function, supervisory control and backup to all of the process computers. Figure 10 illustrates a general scheme for the overall process control of the CRL pilot plant.

The pilot plant automation project at CRL began two years ago. The first phase of the project includes development, design and implementation of a computer density control system for the heavy medium cyclone. The second phase will include the development, design and implementation of computer quality control monitor for the flotation circuit.

HEAVY MEDIUM DENSITY CONTROL (HMDC) PROJECT

The objective of this project is to develop, design and implement a process computer system to control the process variables (fresh water addition, magnetite addition, diversion of medium between heavy medium and dilute medium circuits) to reach a desired medium density in minimum time. The proposed process control scheme is being carried out by Williams Brothers of Canada Limited (DATAP Systems) in consultation with CRL and is summarized as follows:

1. Heavy Medium Control Instrumentation: includes on-line measurement of medium relative density, distribution box, splitter boxes, level control and magnetite feeder.
2. Heavy Medium Computer Control System Hardware:
   a) Micromaster: a microprocessor with CPU, memory, clock, logic circuits and a parallel input-output interface,
   b) Operator console with a CRT for displays and dialogue, and
   c) Inter-CPU communications: various parameters are passed from the micromaster to a desk top computer or supervisory computer.

The heavy medium control system will be installed and tested in the new pilot plant facilities at Devon, Alberta.

FROTH FLOTATION PROCESS CONTROL

The main parameters to be controlled are per cent solids in the feed, flowrate, reagent addition, air addition and ash content of froth and tailings products. On-line ash monitoring of fine coal in slurry form has been reported in Australia, the United States and Canada. The development of coal flotation control can benefit from progress already made in mineral froth flotation. However achieving the overall objective of control will be difficult because of the nature of the process and the need to narrow the list of parameters to be controlled.

At CRL, contract proposals are presently considered for future development of the flotation control system.

REFERENCES

1. Sullivan, A.M. "U.K. computerize coal prep plants"; Coal Age 92-94, 97-98, 101; Jan. 1979.

2. Holmes, M.J., Leeson, B.K. and Ratcliffe, S. "Computer control-the bold way"; Mine & Quarry 11: 4: 25-28,30; 1982.

3. Roelofs, W., Philipp, J. and Becker, M. "Installation of a process computer at the New Walsum coal preparation plant"; Gluckauf and Translation 116:8: 184-187; 1980.

4. Green, P. "Space invaders hit the prep plant"; Coal Age 52-55; Jan. 1982.

5. Green, P. "Computer controls flow to cyclones"; Coal Age 90-96; June, 1981.

6. Lyman, G.J. et al. "The automatic control of coal flotation circuits"; Proceedings of the 8th Int. Coal Preparation Congress; May 21 - 26, 1979; Donetsk, USSR; 1979.

7. Philipp, K. and Pfannenstiel, M. "Feasibility and limits of automation in coal mining"; Gluckauf and Translation 117: 10: 253-256; 1981.

8. Krahenbil, L.W. "Programmable logic control applied to a coal preparation plant complex"; Presented at the CIM Annual Meeting, Technical Session "Computers and Controls for Coal Preparation";April 1978; Vancouver; 1978.

9. Reed Marchant, G. "The 80's - microprocessors, distributed control and advanced instrumentation for the mineral industry"; Proceedings of the 3rd IFAC Symposium on Automation in Mining, Mineral and Metal Processing; Aug., 1980; Montreal; 15-24; 1980.

10. Buchner, M.R. and Lefkowitz, I. "Distributed computer control for industrial process systems: characteristics, attributes, and an experimental facility"; IEEE Control Systems Magazine 2:1:8-15; 1982.

11. Carr, K.R. et al. "State-of-the-art assessment of coal preparation plant automation," Oak Ridge National Laboratory, ORNL-5699, U.S. Dept. of Energy ;1982.

12. Jenkinson, D.E., Cammack, P. and Baillie, D. "Transducers for Coal Preparation Plant Control Systems"; Proc. 9th International Coal Preparation Congress; New Delhi, India; D4 1-19; 1982.

13. Mikula, R.J., et al. "Some EMR facilites in western Canada for R&D on beneficiation of Canadian coals"; Proceedings of the 2nd Technical Conference on Western Canadian Coals, CIM Coal Division; June 2-4, 1982; Edmonton; 1982.

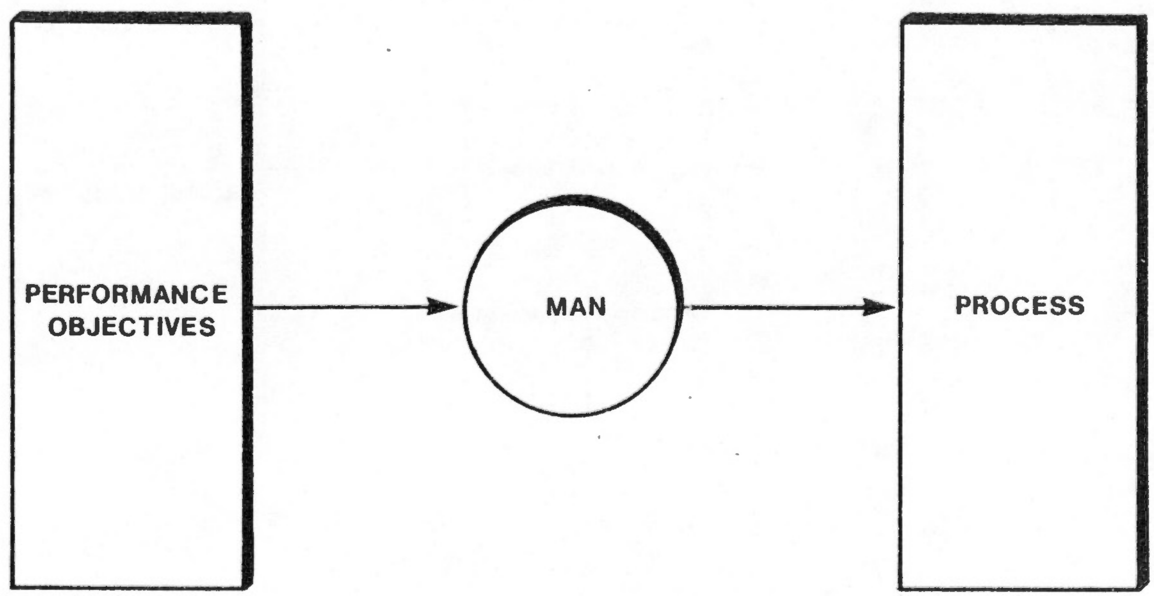

Fig. 1 - Man-process system

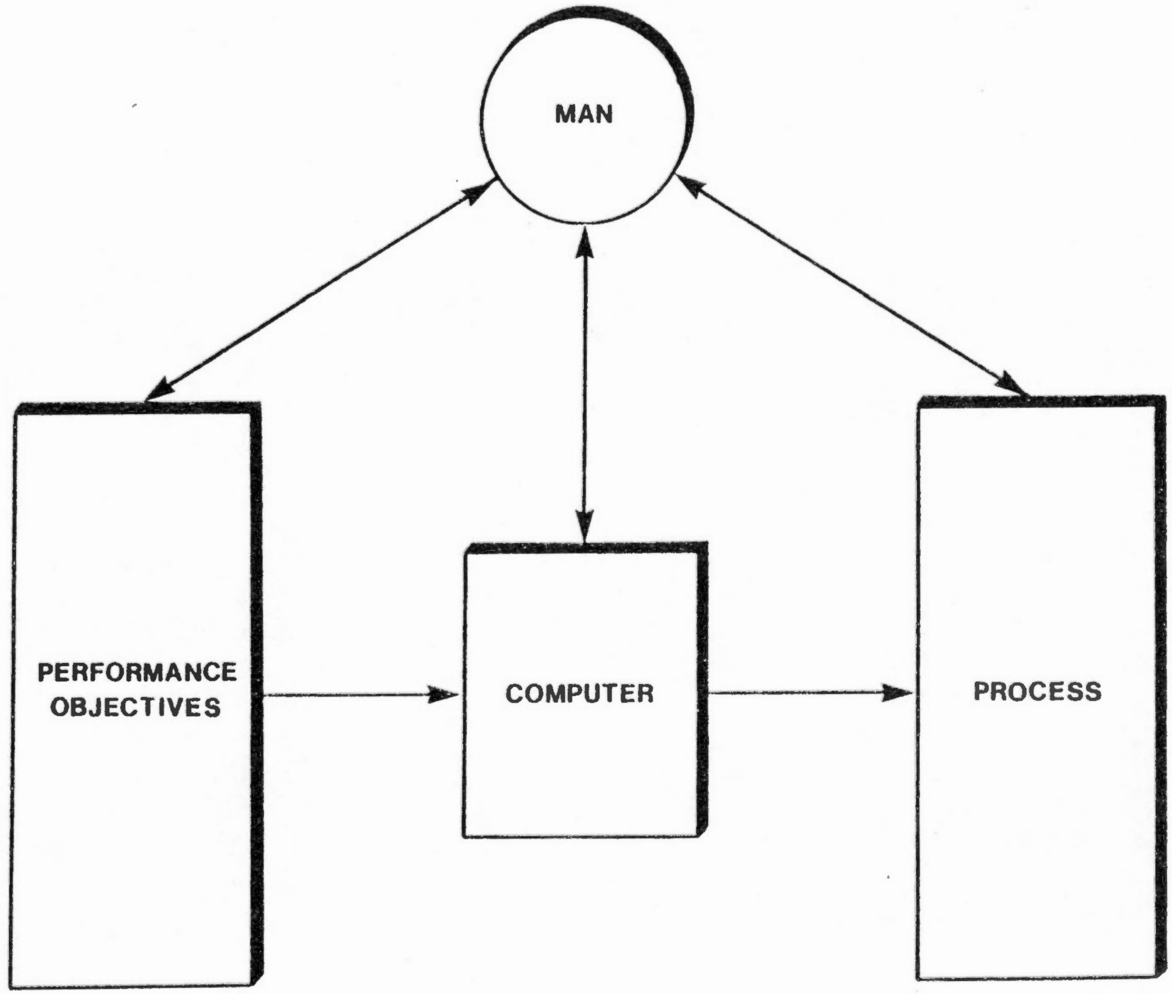

Fig. 2 - Man-computer-process system

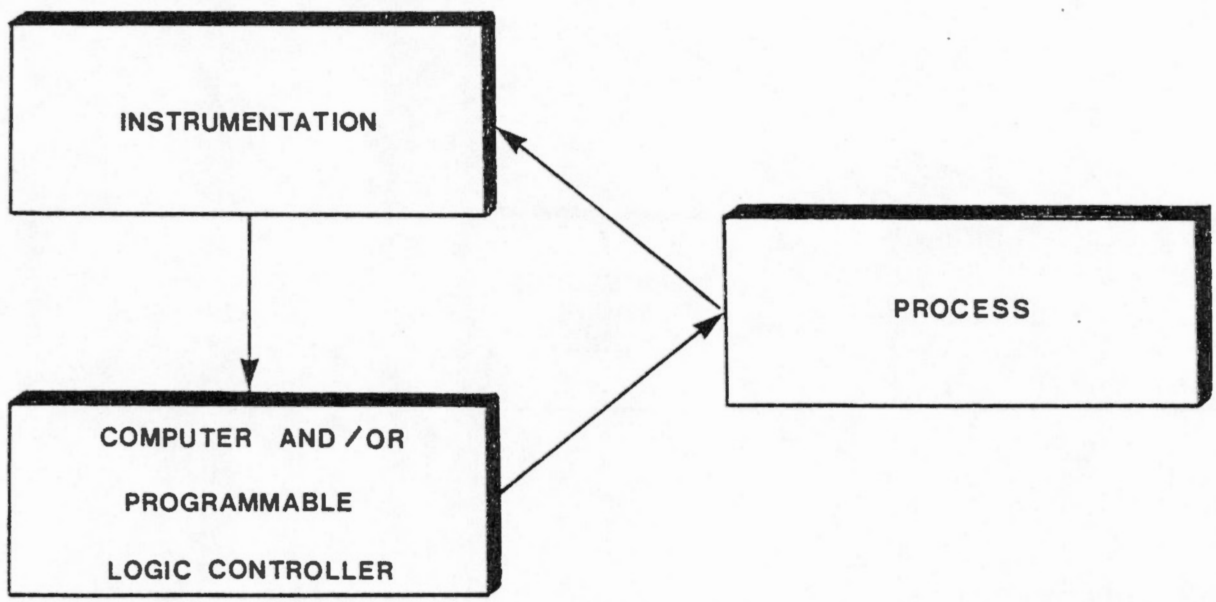

Fig. 3 - Instrumentation-computer-process system

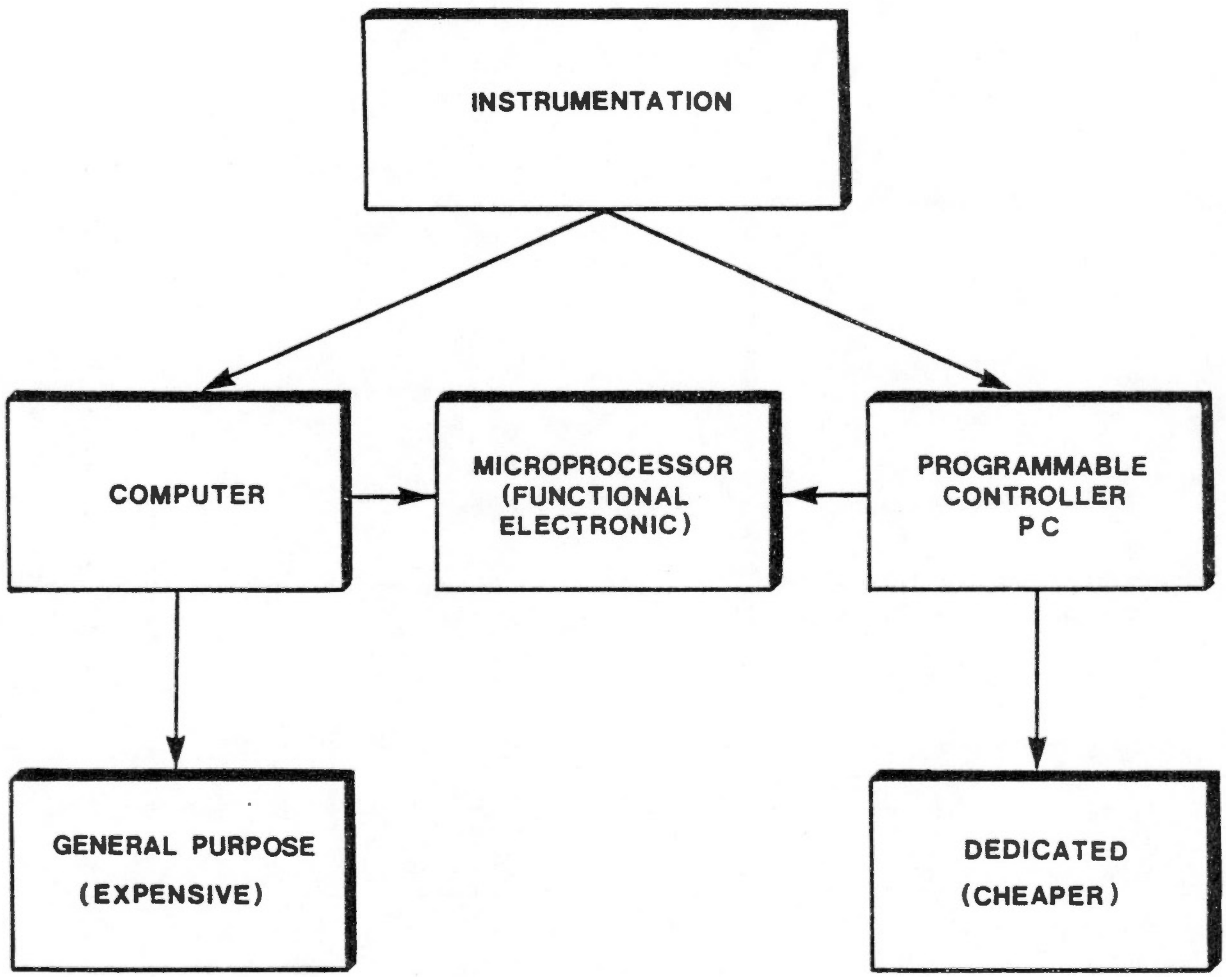

Fig. 4 - Computer-programmable controller comparison

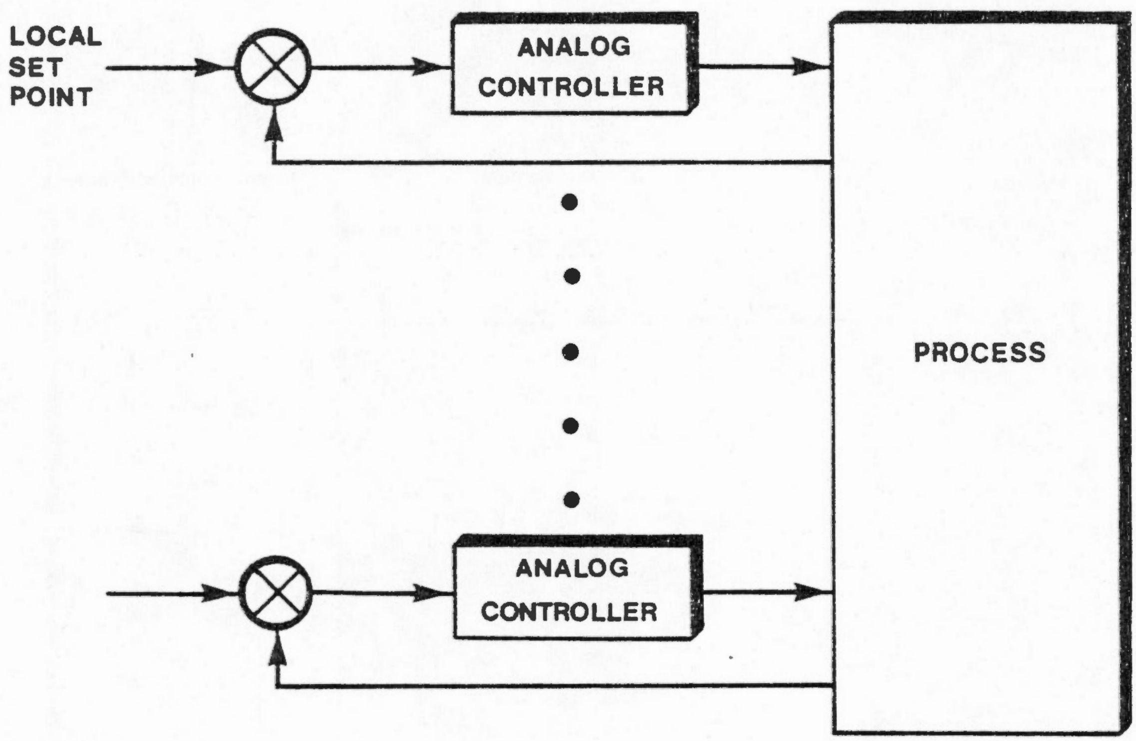

Fig. 5 - Basic analog control system

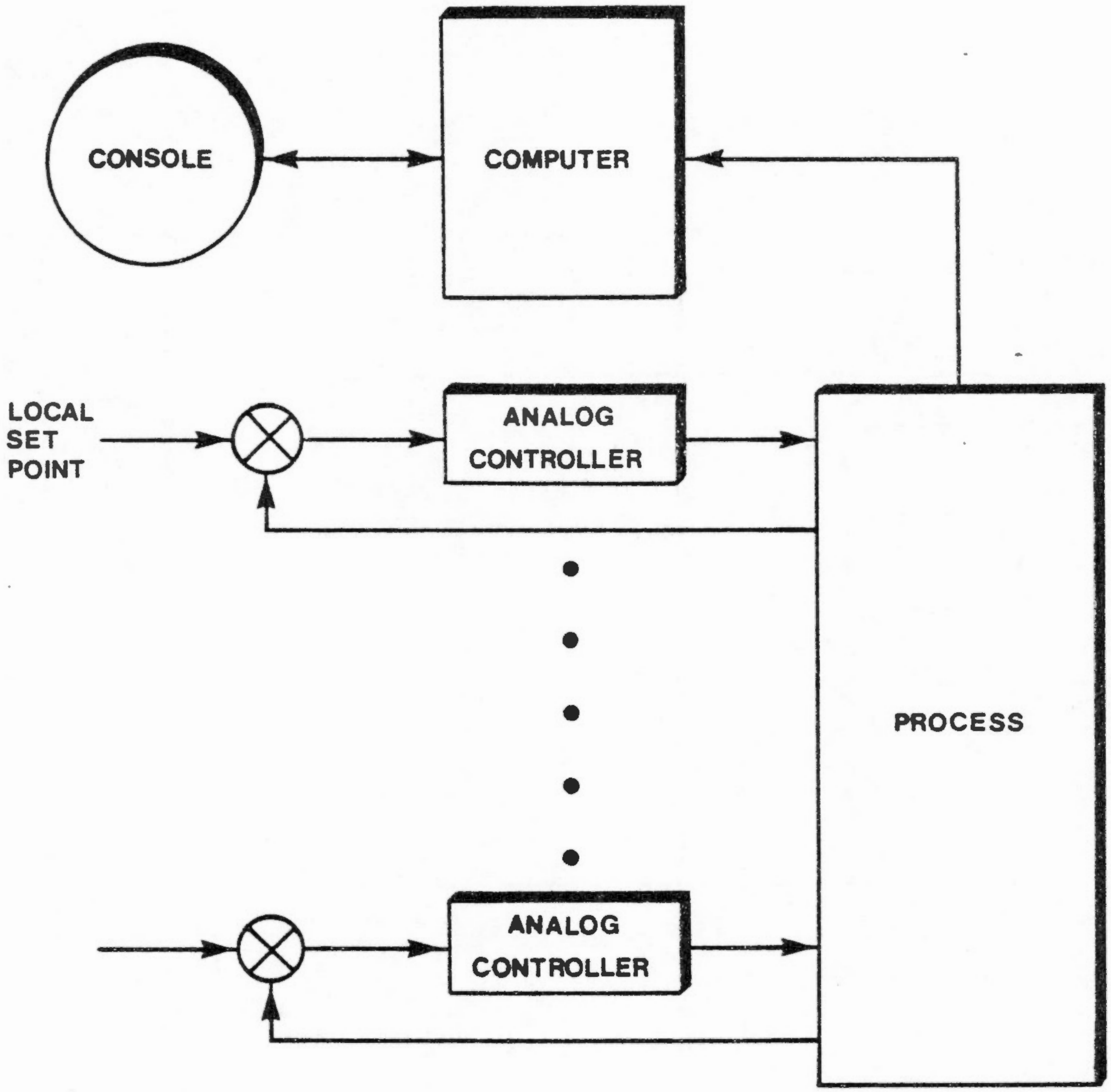

Fig. 6 - Supervisory control system

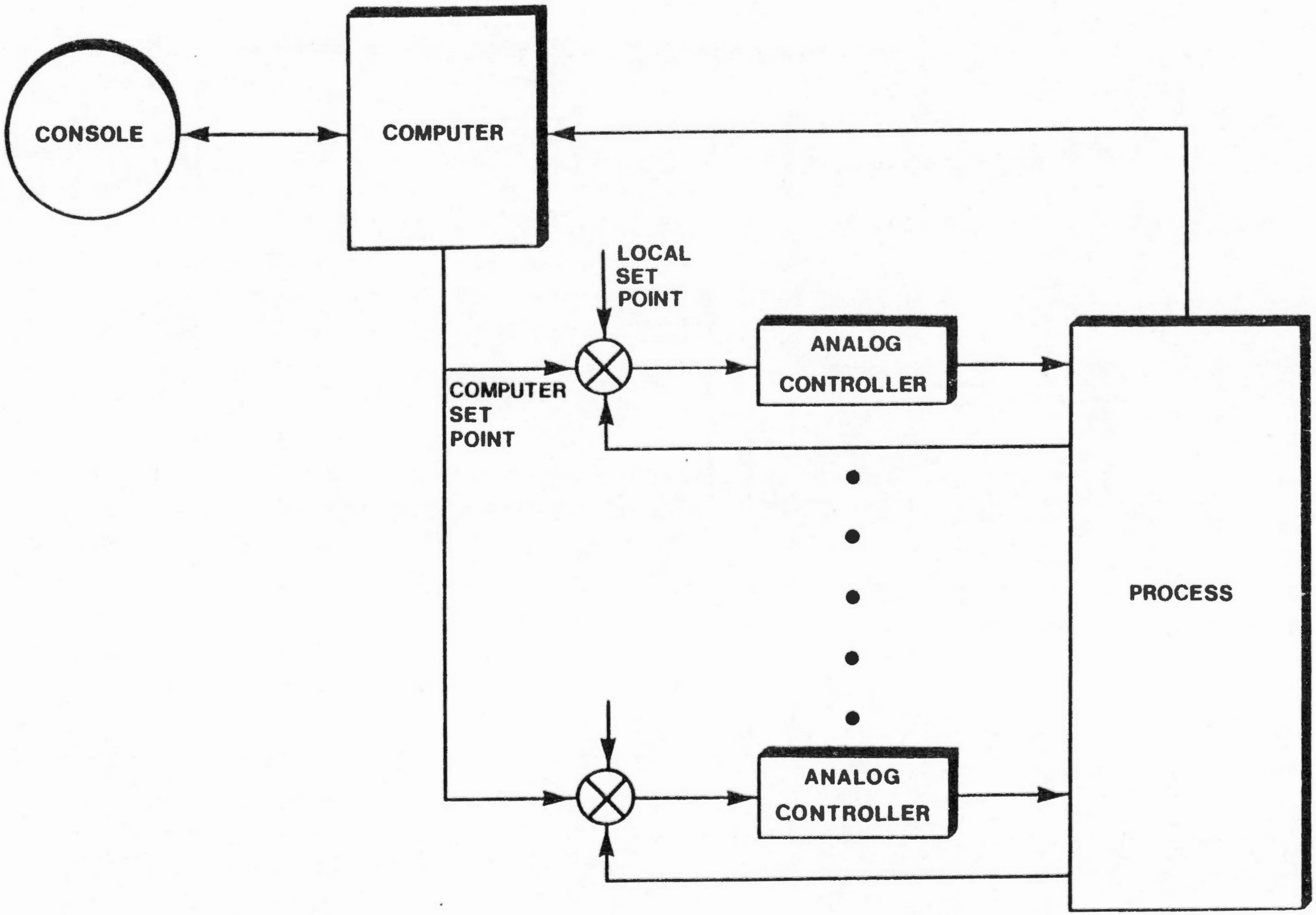

Fig. 7 - Computer set point control

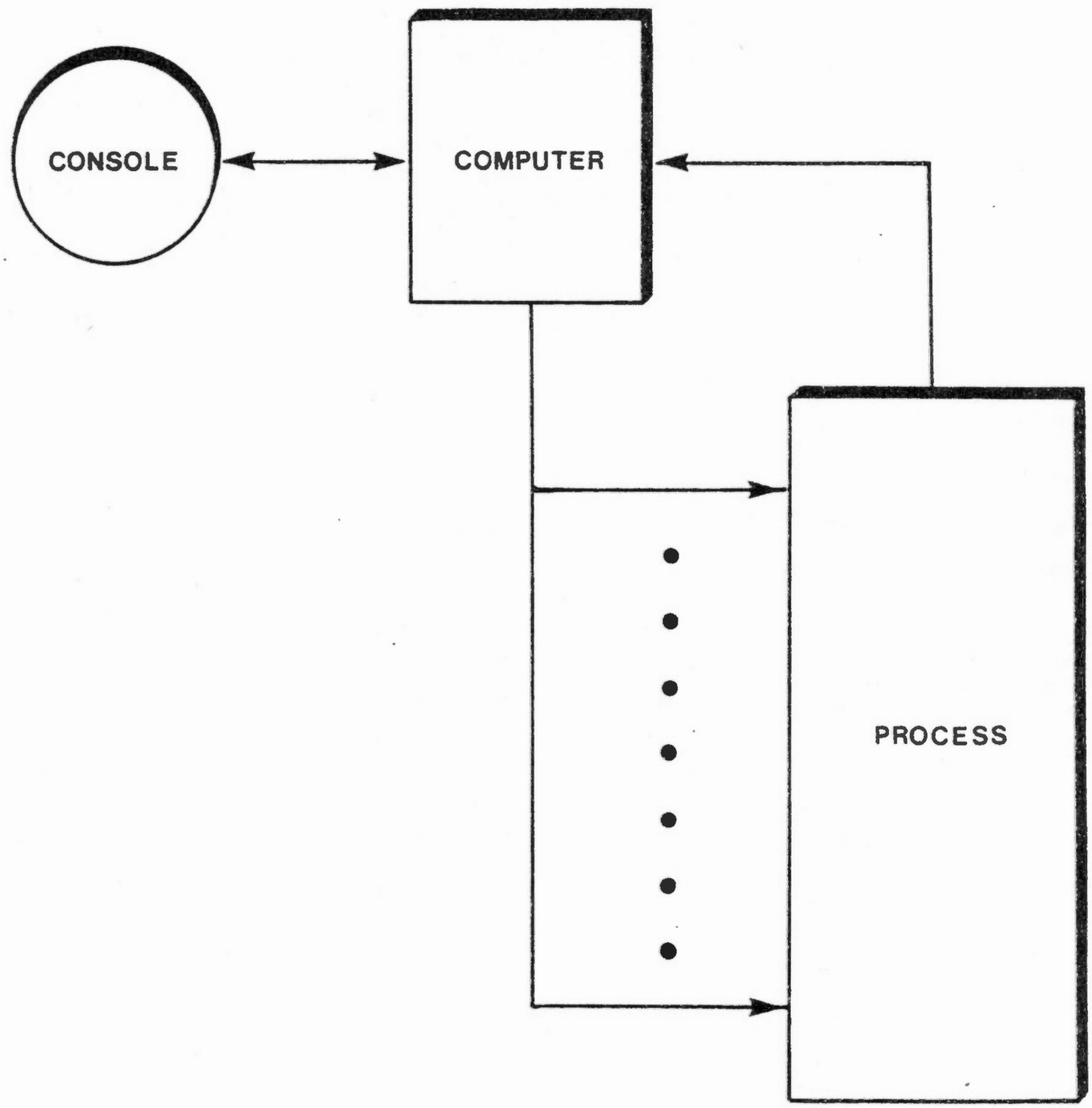

Fig. 8 - Direct digital control system

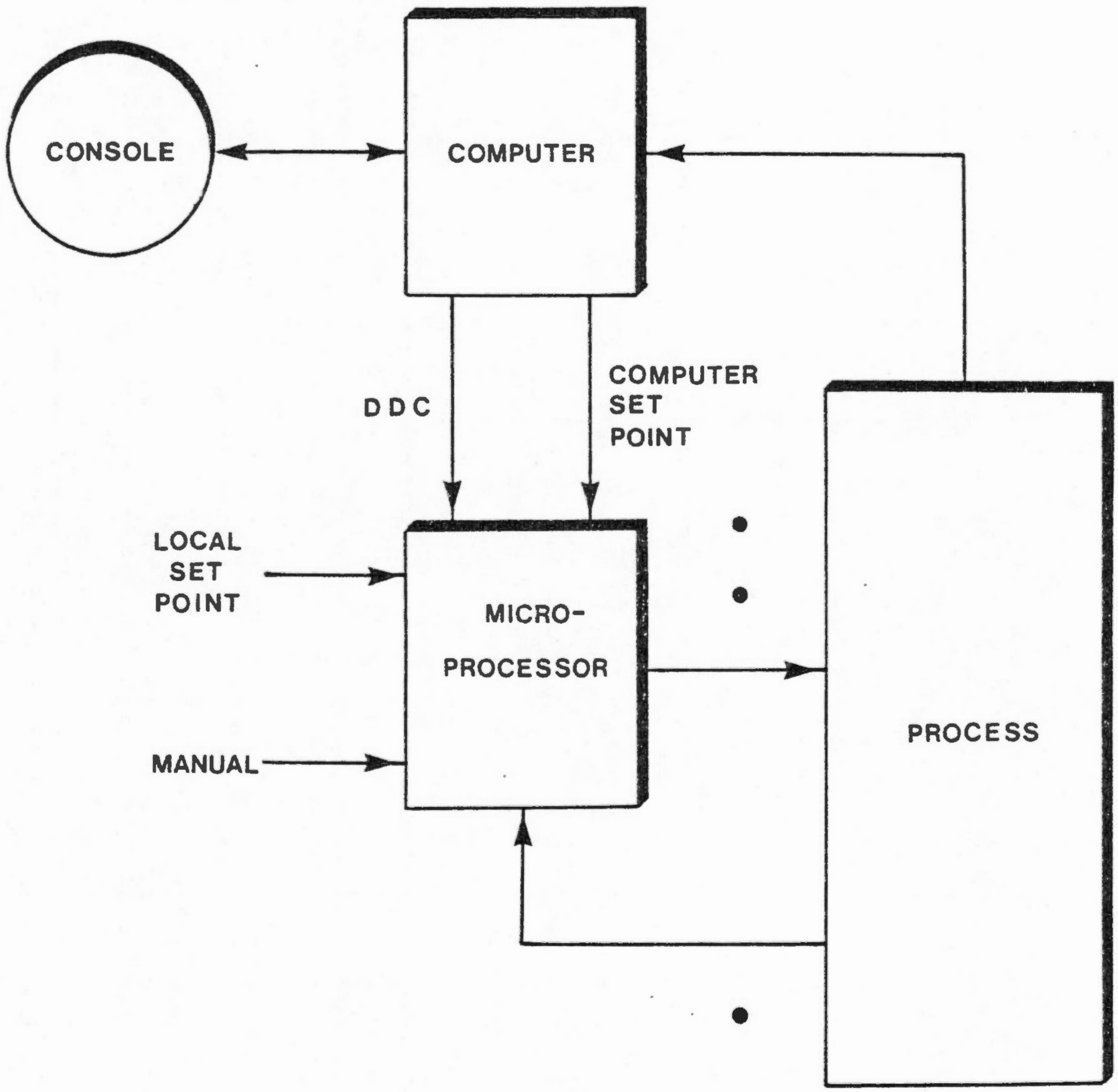

Fig. 9 - Microprocessor control system

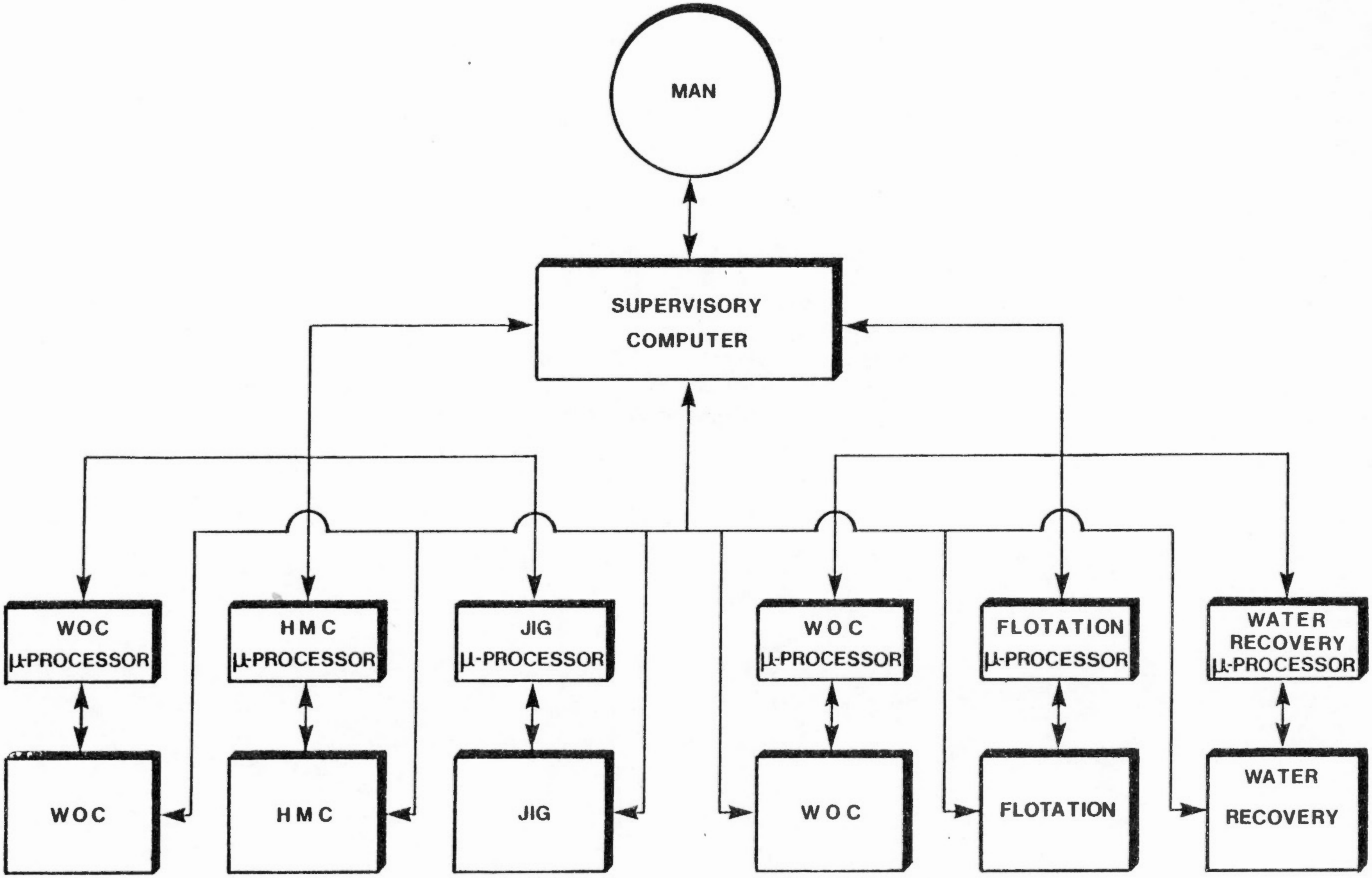

Fig. 10 - CRL pilot plant process control strategy