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ASPECTS OF COMPUTER CONTROL FROM THE HUMAN ENGINEERING STANDPOINT*

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ABSTRACT

A Computer Control System includes data acquisition, information display and output control signals. In order to design such a system effectively we must first determine the required operational mode: automatic control (closed loop), computer assisted (open loop), or hybrid control. The choice of operating mode will depend on the nature of the plant, the complexity of the operation, the funds available, and the technical expertise of the operating staff, among many other factors. Once the mode has been selected, consideration must be given to the method (man/machine interface) by which the operator interacts with this system. The human engineering factors are of prime importance to achieving high operating efficiency and very careful attention must be given to this aspect of the work, if full operator acceptance is to be achieved. This paper will discuss these topics and will draw on experience gained in setting up the computer control system in Main Control Center for Stanford University's Accelerator Center (a high energy physics research facility). (In this complex system both open and closed loop computer controls are used, as well as large numbers of manual functions.

INTRODUCTION

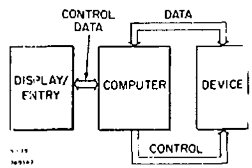
A computer control system has high operational reliability, is easily modified within limits, and has low initial cost and maintenance. For these reasons computer control has become more and more used for industrial processing in recent years. In the development of a complex control system the detailed specifications for the computer system can only be determined after the machine control requirments are known. Once these are known, the operational mode can be chosen, and specifications can be set. Regardless of the mode chosen, the "operator" (we used the word operator loosely, he can be a design engineer, a system developer, a programmer, a researcher, or simply a machine operator), operates the machine and therefore a certain degree of intimacy between man and machine is established. Since operators are human, naturally human engineering aspects should play an important role in system interfacing, console layout and control room layout.

OPERATIONAL MODES AND SYSTEMS

In the allocation of functions between man and machines there are three possible operational modes normally used:

1. Computer full automatic control--Digital, analog, linear or non-linear data and information is acquired from devices and fed into the computer. The computer actuates the devices based upon those data and information as programmed. It is also programmed to make corrections within set limits. If a condition has been changed outside of these set limits for any reason, the whole process will come to a halt. The human operator will diagnose the problem and make a decision whether to clear the faulty situation or reprogram the computer. This scheme is known as "closed loop" control system.

Figure 1. "Closed loop" mode.



2. Computer assisted control--This scheme is similar to automatic mode, except not all data from the devices and/or from the book values are fed into the computer, and it is not programmed to make corrections. Instead, it will send an alarm to alert the operator to make an operational decision. This scheme is known as an "open loop" control system.

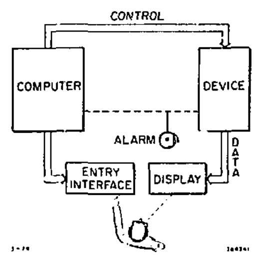


Figure 2. "Open loop" mode.

3. Hybrid control--Some portions of the control system are computer controlled in either closed or

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open mode, and the rest of the system is under manual control. Sometimes it is desirable to put in a manual over-ride for the whole system for safety or other reasons.

COMPARISON OF OPERATIONAL MODES AND SYSTEMS

Certain operational modes are suitable only for a particular type of plant. This determination is a complex analytical decision; nevertheless, the ground rules or basic considerations are elementary. We should always remember it is the operator, not the computer who operates the plant. The choice of system must be based upon the plant's nature: WHY it is necessary to put the process under computer control; WHAT caliber of operational staff or operators are to be placed at the console, who is to perform the actual operation; WHERE should the control console be located; WHEN should the control console be installed. Should it be installed before the whole plant is ready for production, or should it be installed in different phases? HOW should the system be designed, by an in-house engineering group or contract consultant firm. The former gives more freedom in design modifications, the latter limits flexibility. WHO determines the design concept and funding allocation. The pros and cons of the possible operational mode can be generalized as follows:

Fully Automatic Mode--Least initial investment on hardware because it needs only a minimum number of instrumentation displays. All the data and information can be shown on Computer CRT or printers, but it may require much time for the operator to search for a piece of information, thus it could delay operation when troubles occur. Software development could be expensive for the initial setup, but it will taper down. If there is no redundant backup system the whole plant's production can come to a stop if the computer fails for any reason. If a plant can tolerate a reasonable temporary downtime, closed loop control is the least expensive scheme. Higher caliber operational staff is required because the operation tasks are not so defined.

Computer Assisted Mode--More expensive because a full instrument array is needed for monitor display and surveillance. It is costly for both initial and periodical calibration and maintenance. On the other hand however, the computer is only assisting the operator to do tedious calculations and repeated cut and try setup which takes away a lot of the burden from the operator. As the machine interface is intimately under the operator's command it is unlikely that the whole plant's production will come to a full stop too often. Since the operational tasks are more defined, job descriptions are easier to set so as to reduce the labor expenditure eventually.

Hybrid Control Mode--This system is most commonly used because the extreme of pure computer operation is often not very feasible, especially if security and safety are involved. Sometimes the controls of a plant are so complex and the plant is large; a small computer or microprocessor network scheme should be seriously considered.

HUMAN ENGINEERING ASPECTS

One of the most difficult tasks associated with a computer control system is the interfacing of devices to be monitored and controlled. In selecting and designing, we have stressed the importance of human engineering aspects if full operator acceptance and cooperation are to be achieved -- after all they are the ones who operate the plant and their operational behavior governs the operation efficiency. The application of human engineering principles in choosing interface equipment is not an exact science, rather it is a philosophy or an approach. Due to the space limit of this paper, we can only generalize as follows (please refer to the References for details):

Human's Physical Limitations

1. Vision--One can see only so far for a given size of object such as alpha-numerical characters or the details of a graphic presentation on CRT or printer, etc. Sensitivity to various colors and brightness is different to different age operators, so if color CRT presentation is chosen, it must not contain too much information or too complex color indications on one "page". In addition, visual cone angle should be taken into serious consideration in equipment layout of a console if the console consists of more than four standard racks.

2. Hearing--If the console consists of more than four racks in width, a flashing light alarm is not as effective as sound. To alert for emergency, it should be loud and unpleasant to the ears. However, for purely reminding purposes, the "Ding-Dong" type is recommended. For verbal communication from control console to various points of the plant, the intercom should be used. The intercom should be of hi-fi type for easier personnel identification so as to eliminate unnecessary confusion.

3. Body Movement--Console design should have the average physical build of an operator in mind. Distance of arm reach and leg space movement are important for both sitting and standing operations. Display and monitor equipment should not be mounted too much below the eye level, and control panels should not be below the waist, otherwise it contributes fatigues and eventually may even develop ill-posture for the operators.

Operating Environment

Environment has a great impact to comfort of the already overstressed operators. Uncomfortable operators tend to make errors or take a longer time in decision-making. Mistakes can then be made in performing controls. Special attention should be paid to: a) Humidity and airflow; b) Temperature in the control room; c) Noise level; d) Dust level; e) Illumination; f) Foot traffic disturbance other than operating staff.

Operating Position

There are only two basic normal operating positions: sitting or standing. Most likely, this had been already determined according to the nature of the plant, thus the control interface devices should be chosen accordingly. We point out some of the installation rules of commonly used interface components as follows:

1. Keyboard--Except for simple four function calculator type, the regular keyboard for data or control entry almost must be operated in sitting position.

2. Tracker Ball--Usually mounted on a desk top so it is normally used in a sitting operation. It it must be used for standing, install them on a horizontal mounting bracket.

3. Joy Stick--Motionwise they are similar to the tracker ball, therefore installation considerations are similar.

4. Teletype-- Installation is similar to keyboard,

5. CRT Lightpen--Best results: vertical mount to avoid parallax.

6. Touch Panel--A very convenient I/O device (refer to Reference Page). It can be mounted in vertical for standing position or in a slanted angle in a desk for sitting operation.

CONTROL ROOM AND CONTROL CONSOLE LAYOUT

This topic is too wide a scope to discuss in detail, we would like only to point out some human factors on this subject.

A control room may have more that one control position or console, in this situation easy verbal and eye contact communication between operators are extremely important, but when one operator is talking with some other remote location, the disturbance to the other operators should be kept to a minimum. As for individual control consoles, its width should be kept under four standard racks. All consoles should be identical in function, and zoning or grouping of instruments so that the operators can operate them when switching operation console positions according to a new assignment

A Typical Example

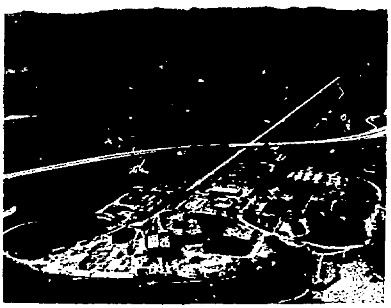

Figure 3. Stanford Linear Accelerator Aerial View.

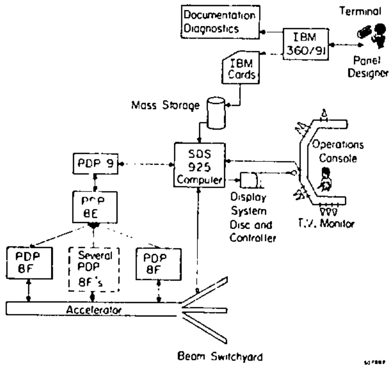

Figure 4. Computer control system.

The Stanford Two-Mile Linear Accelerator (SLAC) is a high energy physics research facility designed, installed and operated by Stanford University for the United States Department of Energy. The Linear Accelerator is two miles long. Energy supply is by a total of 240 klystrons of accelerating electrons to 22 Billion Electron Volts or greater. It is divided into two portions: the accelerator proper, and the Beam Switchyard. There are two control rooms, one is for accelerator controls, the other for the Beam Switchyard. Both were manually controlled in the early stage of operation. Some ten years ago, the two control rooms were consolidated by linking computers. There are approximately 4000 status, 650 analog, and 1400 output controls. Personnel protection and fire alarm systems are not included in computer system. Man/machine interface are by SLAC developed touch panels. Recently three PDP-11-34 computers were added for data acquisition system and control. We are progressing toward "closed loop" for energy setting and beam steering. The control room consists of three operating positions and recently, a fourth one was installed for our new PEP (Positron Electron Project) storage ring injection controls. Operation is 24-hr/day and 7-day/week.

During initial beam setup or when parameters are being changed, control room activity can be intense and highly interactive. After the consolidation phase, with all three operation positions in commission, operators complained of the console layout, electronic backup rack equipment distribution, and the sudden change of operating behavior from manual to computer (which is another important human engineering factor). We have solved many difficulties by applying human engineering principles; we set up an Engineering/Operation Control Console Dialog Committee to gain operators' viewpoint. We learned that many practical points of view which were overlooked or neglected from engineering standpoint. Therefore I repeat once again, the application of human engineering in equipment design is not an exact science, but is an approach, and the right approach decides operational efficiency.

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