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SPECIFICATION PROBLEMS OF A PROCESS CONTROL DISPLAY

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1. INTRODUCTION

Several reasons have motivated the development of new means to control, monitor and in an indirect form to increase the reliability and resilience to unexpected situations of actual industrial processes. Up to the present, panel board type display systems have been used to monitor the real conditions of industrial plants. However, because of the complexity of the plants themselves, and the increase of information due to the expansion of the systems and to the use of computer controls,the panel board display systems have become larger and more complex. It has now become uncomfortable to monitor and control the plants and often becomes complicated beyond practical operation.

Recently, as a result of this trend, the demand has emerged for a display system which is able to show a selected area of the plant in a relatively detailed form, and which is able to be connected to a computer system easily. Moreover it should facilitate reliable human communication with the process through the computing system, permitting adequate control of the part of the plant schematically displayed. This should increase the automatism and reliability of the process, so that all these characteristics, conveniently handled, may increment the control efficiency and overall process productivity.

What is the bes approach to this problem?

The answer is the graphical display.

Of course, not all kinds of graphical display can be used adventageously in this new field of application, because of the many economic, technical, ergonomic, reliability, environmental interface and other reasons described later in this paper.

2. GENERAL REQUIREMENTS OF A PROCESS CONTROL GRAPHICAL DISPLAY

The most important characteristics, which must be satisfied by a graphical display to be used in process control applications are the following:

- it should be able to show the symbolic diagram of any part of an industrial process conveniently, clearly, in such a form that is possible to identify unambiguously each sector of the plant. In this diagram the operator must distinguish those parts of the system which are functioning correctly, those which are being repaired, out of service, etc. It should be able also to show the values measured by any instrument, to indicate any abnormality in the values measured /i.e. absence, out of rating value/, to indicate the time in hours, minutes and seconds /if required/, and update all these indications; it must indicate any abnormality in the functioning of each part of the plant; for electro-mechanical components /i.e. switches/ the diagram must indicate the change to different stable states and the corresponding influence on the system; using tables, lists, and so on, it should be able to update any item in them and to indicate any abnormality in its value /overloading, out of range, etc./; and finally, in connection with the overall system, any alarm or dangerous situation, non-permissible overload and so on, must be conveniently indicated in time by visual and/or sound means, etc.;

- to include alphanumeric possibilities, the 64 standard character set used in most of the present alphanumeric displays being fully sufficient;

- to have a flexible positioning possibility, which gives flexibility to programmers and operators and permits relatively detailed graphics;

- to include a wide variety of symbols, oriented to the application, and to create some mean to change them whenever required. These symbols must be self-descriptive, i.e. easily interpreted by the operators to avoid disastrous ambiguities;

- to include graphic possibilities, a restricted graphics intimately related to the application field being sufficient;

- it must provide picture processing software, by which the computer can handle a picture displayed on the unit;

- to have interactive possibilities to permit an effective and reliable man-machine communication, and through it to influence the process conveniently and in time;

- it should be easily connected to a computer system and controlled by it;

- it must be able to work in an "on-line" fashion;

- it will have a wide range of different transmission speeds and work with different computing modules using appropriate interfaces;

- to include color possibilities, which with adequate coding, offer a more flexible information medium;

- it should comply with ergonomic requirements, mainly those specifically imposed by the application field;

- the decision operations, as much as possible, must be decided by the computer, and only be considered by the operator when there is no other possibility. This means, that a non-intelligent display with graphic capabilities may be used to play the required role in most industrial applications;

- to have a minimal cost, thus permitting the use of many units in a cluster form, all handled by only one mini-computer;

- because of its possible cluster operation with only one mini-computer, it shoud be able to refresh the picture itself, thus saving computing time when it is not required to update or change information;

- it should include adequate visual and sound alarms to avoid catastrophes due to possible operator's missattentions;

- it must withstand the common hard conditions encountered in an industrial environment;

- it should be highly reliable;

- it must be easy to operate, and must require a minimum of training for the operators.

3. SELECTING THE BEST SOLUTION

a/ General

Most of the above mentioned requirements are met by the monochromatic graphical display using a cathode ray tube /CRT/ as the means for showing information to the operator. The graphic display is the most significant use of the CRT in the computation field. but particularly in the case of complicated images in specific applications, it is still a costly proposition. That is one of main reasons, that have motivated the new tendency for using cheaper possibilities in specific purpose applications based on minicomputers. This tendency had been notable mainly where many stations are needed /multiterminal systems/ handled with a powerful computer, or when only reduced possibilities are needed, or the demands on the equipment, like its resolution, its possible viewing facilities, its required memory capacity, and so on, are not very ambitious, or any combination of these factors. It is practically impossible economically to meet all the imaginable demands in only one system. There will always be tradeoffs, which require the designer to make correct decisions between "niceties" and "useful features", considering only those parameters, which really should be taken into account for attaining the specific objective.

Several different approaches have been used to build graphic displays, each one with well-defined characteristics and advantages, but also with its logical limitations and disadvantages [19].

The simplest display systems, used with the earliest computers, generally had two digital-to-analog converters that drove the deflection plates or coils in a CRT. A stream of values fed into the converters caused the CRT beam to trace out any desired pattern. These values came from a display list, which was fed repeatedly to the CRT to maintain or "refresh" the volatile image. This "programed-path" arrangement was simple, reliable, and relatively inexpensive, but also very slow and it required the computer's entire processing capability to draw a picture.

To overcome these two strong limitations,by the early 1960s vector generators, character generators, high-speed CRT beam deflection systems and independent display-list memories were being included in display systems. With these sophisticated subassemblies, systems could display several thousand c' racters and over a thousand vectors without flicker and in addition, once the computer had loaded the display-list memory, the picture could be maintained with almost no load on the computer. But these new display terminals cost $ 100.000 or more, limiting computer graphics to a few specialized commercial and military applications.

The breaking of this cost barrier, mainly due to the display-list memory and the high-speed refresh circuitry, took place with the invention of the direct-view storage tube /DVST/. This tube lowered circuit costs, eliminated memory elements and could display more complex pictures than even the most expensive refresh CRT systems, but the DVST terminal does also have some drawbacks /enumerated later in this paper/ which have not been solved so far and consequently have limited its utilization.

A technology competing with the DVST is the electrical read-out storage tube [20]. This tube overcomes most of the disadvantages of the DVST, but it requires two analog subsystems: the deflection circuits and the raster-scan monitor, instead of one. This causes some problems of stability and maintenance, and because the read-out scan only samples the signal, the viewed image is less detailed than the written image.

Another commercially successful technique stores the raster signal for the display images on a magnetic disk, from which a monitor is refreshed. The signal is streched out along one or more linear tracks around the disk [8].

The most radical departure from previous display technology, however, is the plasma panel. This has a DVST-like memory, but can be selectively erased. Besides this, it is digitally driven and, provides a crisp distorsion-free image. Since it is flat and thin, it does not have the bulky physical characteristics that the conventional or DVST tubes have, and can be combined with a rear projector, or the display picture can be copied from the back side of the panel which adds a new advantage. Unfortunately the resolution is currently limited to a relatively coarse 70 cells per inch, and color and gray scale, though possible, are not at present offered commercially. Worst of all, panel costs are high and it is necessary to have extensive circuitry and tight tolerances for its correct functioning. Meanwhile, the original programed-path refresh CRT systems have not been ignored. On the contrary, they have been given new emphasis for the low-cost market. These displays present high-quality images and allow maximum flexibility in picture interaction. Light pens can be used to point at objects, which are readily identified by correlating the word being processed with light detection by the gun, but in such systems the display and its drivers form a complex analog subsystem requiring high-speed signal generation. In addition, compensation circuits are necessary, to correct nonlinearity, pincushion distortion, and problems arising from varying beam speed and fast, random beam positioning. This analog subsystem, moreover, is still relatively expensive, in spite of declining component prices.

Another alternative is the raster-scan principle which creates a screen picture in the same way as a television system. This will obviate some of the above disadvantages, for instance, the complex analog subsystems required in the high-speed signal generation and those problems arising from varying beam speed and fast random positioning. By its principle of functioning and its intrinsic characterics, the only task in this kind of system, apart from the stable generation of a reliable raster, is the appropriate blanking and unblanking of the electron beam /which always follows the same path through the screen/ depending on the information to be displayed. Obviously the cost of the display itself is thus a minimum, compared with that required by the expensive circuitry of the random-scan type. At the same time, however, very considerable additional storage costs are usually incurred.

Now our main purpose is to analyze the real possibilities within each of the different integral parts and possible performance alternatives of a graphical display, and to select the most advantageous to be used in process control applications, taking into account the general requirements discussed above.

b/ Display medium

This is one of the fundamental parts of a graphical display. Its aim is to show to operator all the information required, and to facilitate his direct interaction with the computer which handles it. The correct selection has a direct influence on the performance of the whole display, which is the reason why it will be analyzed first.

At the present there are several different types of display media to show the computer's output to the operator, namely:

- the conventional cathode ray tube
- the direct view storage cathode ray tube
- the liquid-crystal device
- LED arrays
- the plasma display
- the photochromic display
- the laser display

The last five types of display media are not very suitable for a process control display, at least at present, either because of some non-desirable characteristics or because they have serious limitations. The most important of these are the following:

Liquid-crystal devices require an exact and elevated functioning temperature to operate, making it indispensable to use a critical temperature controller; the liquid-crystal substance has a limited lifetime; it has reliability problems; difficult organization and operation of the hundreds of thousands of light-reflecting elements and the associated solid-state components required; finally, its cost is high.

LED arrays are costly and their price is very much dependent on the size of the display surface; they have a poor resolution, so far prohibitive for graphic displays; though at present it is possible to get two colors from the same LED by varying the driving current /red, green and yellow are already available/ the color facilities are still deficient; to achieve matching in brightness within each color is a very cumbersome task; they need too much power to work and wash out in bright sunlight.

The plasma panel has a poor resolution; color and gray scales, though possible, are still under development; major research continues to deal with techniques for reading data by computer from the panel and writing data onto the panel by the operator; its cost is still high and needs extensive circuitry and tight tolerances for correct functioning; it has relatively slow write and erase rates.

The photochromic display does not permit the operator selectively to change any particular element within a displayed image. Image erasure is generally slow and many photochromics age quickly.

The most important drawbacks to using laser technology in a display are its very high cost, high power consumption and large physical size.

These drawbacks constitute the main reasons why these types of display media have not been used so far in graphical displays, although they are already used in some other very specific applications where their present limitations are not prohibitive. All of them are still under development. The display medium most widely used in graphical displays at present is the non-storage type CRT, and because all the other types are still a costly proposition /except the DVST/ and have the disadvantages already mentioned, they are not going to be analyzed in this paper.

The DVST is practicable for use in some process control applications, but only in limited cases, because of its several drawbacks: the DVST has a low brightness level and low contrast which renders viewing in high ambient ilumination conditions difficult; the screen size is limited to generally less than that needed in many process control displays; it has slow response, dynamic or real-time operation being impossible with it; finally, the updating of displayed information is difficult and/or time-consuming, because of it has no selective erase capability for the whole screen. Additional drawbacks include the ageing of the DVST and the fact that reasonable sized ones are only available from one supplier throughout the world.

Taking these factors into account, we shall deal only with the "refreshed type" cathode ray tube. Moreover, because of the inherently greater possibility to show more explicitly the actual conditions of the system being analyzed using a convenient color codification, we shall consider only those color CRT's already widely used. Nevertheless, the black and white picture tube used in conventional home TV-sets or any other monochromic tube already widely used in alphanumeric displays can also be used, but without the color code information.

The types of color cathode ray tubes most widely used at present are:

- the shadow-mask tube
- the Trinitron tube
- the penetration tube

Briefly the principle of operation of these tubes is the following:

In the shadow-mask tube three electron guns are used, with their beams arranged to converge upon a single spot on the shadow mask. This mask is actually a perforated screen placed near the phosphor screen to limit the area of phosphor which may be reached by any of the beams. Since each beam approaches the screen at a different angle, different areas of the phosphor will be illuminated by the different beams. Each of these different areas has different color phosphors deposited, thereby ensuring that each gun can write in only one color. Any desired color may be produced by utilizing the proper beam combination of beams. This type of tube therefore, employs three separate devices to produce the desired color: individual electron guns, a perforated screen /shadow mask/ and a display screen made up of a triad phosphor arrangement /Fig.1./.

The shadow mask in a typical 21-inches tube has about 400.000 holes, one for each triad composed of red, green and blue phosphor dots.

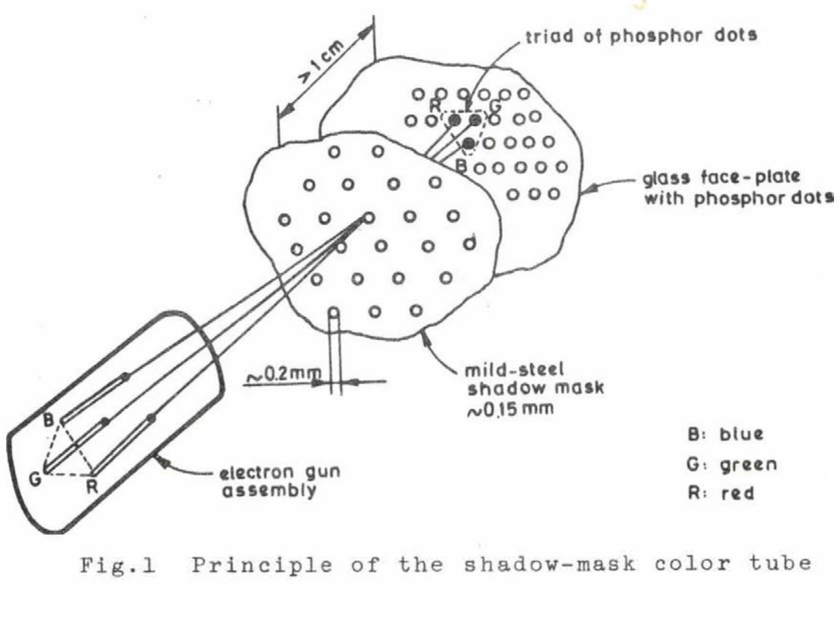


Fig.1 Principle of the shadow-mask color tube

The Trinitron tube differs from the shadow-mask tube mainly in that it replaces the 400.000 hole mask with a metallic grill, the elements of which are perpendicular to the TV horizontal scan lines /Fig.2./. Instead of using a dotted tricolor screen, the Trinitron uses a vertically striped tricolor screen; this improves the vertical resolution and eliminates the moire patterns generated by the interaction of the raster and the mask. The number of phosphor elements allows a horizontal resolution of about 700 TV lines.

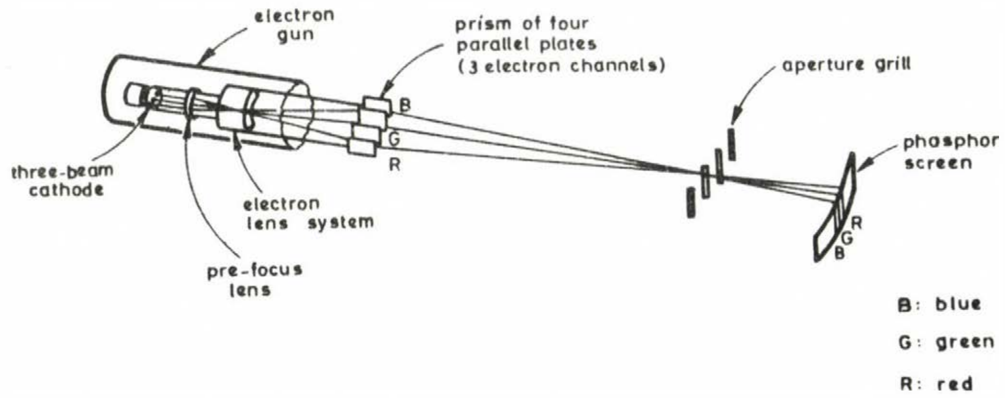


Fig.2 Principle of the Trinitron color tube

In the penetration color tube several colors can be produced by controlling the voltage of a single gun through a multiphosphor screen. The CRT has a multilayer screen, consisting of two or more phosphor layers separated by layers of transparent dielectric material /Fig.3/. The two phosphors

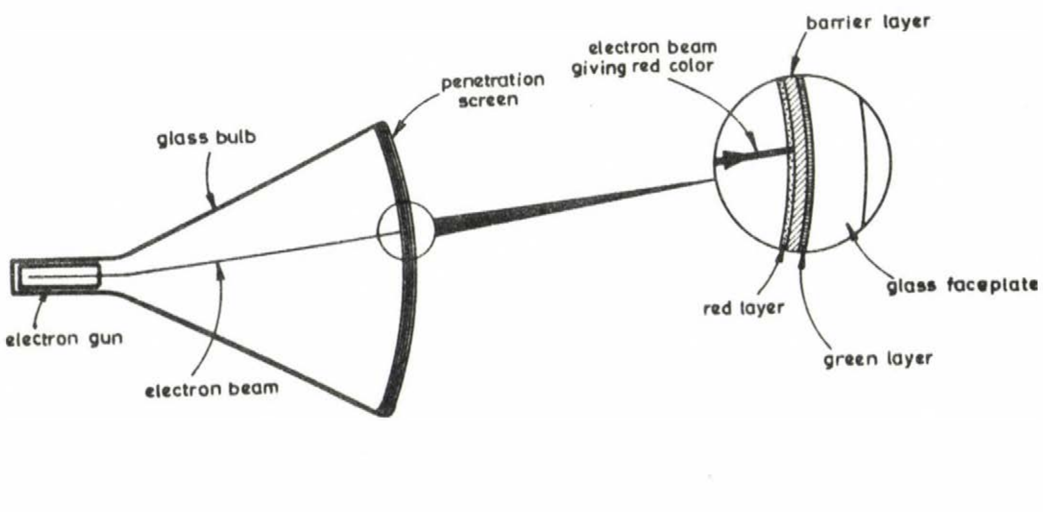


Fig.3 Principle of the penetration color tube

produce different colors when excited by an electron beam. A beam of too low a voltage to penetrate the dielectric barrier layer will excite only one phosphor. Higher voltage will excite both phosphors, and the color contribution of the second phosphor increases as the voltage increases. Several colors can be produced by a single electron gun /commonly four: green, yellow, orange and red/ by simply switching the gun's acceleration voltage.

There have been other types of color tubes, such as the Chromatron tube /or Lawrence tube/, the Prismachrome /or Geer tube/, the "banana" Mullard tube, the Goodman tube, the Hughes tube, etc., but they have found only limited applications.

The advantages and disadvantages of these three color tubes are the following: [11], [25].

Shadow mask tube

Advantages:
- color purity is good with properly adjusted signal feeding the tube
- brightness is correct
- range of colors is good, eight different colors are possible: blue, green, yellow, red, cyan, magenta, white and black /when blanked/
- it is the world standard color-TV tube today, so that its cost is low and it is easily available from stock.

Disadvantages:
- resolution is poor because of the periodic structure of the screen
- circuitry must be provided to maintain dynamic convergence of the three beams
- the focus cannot be sharp over the entire screen because the focus and convergence planes cannot be coincident for 3 beams emanating from guns at 120°
- the electron transparency is low due to the shadow mask
- it is sensitive to microphonics and stray magnetic fields
- the dot pattern is objectionable for short-distance viewing

Examining these disadvantages, most of them are not a serious problem when this kind of color tube is used in process control applications. Contemporary technology had developed new temperature-compensated masks which have improved color stability, and improved electron optics have enhanced the resolution. With new phosphors developed to improve its brightness, its low electron transparency is not of importance when the display is properly adjusted. With the high-density color tube developed by Matsushita Electric Corp. [10] it is possible to display 120 lines of about 150 characters each for a total of about 18.000 characters using a two million hole shadow mask in a conventional 22-inch rectangular shape with 90° deflection angle. To reduce the size of the crossover diameter and so obtain a finer spot, this tube uses a reduced grid opening of only 0.4 millimeters. To maintain the same electron-beam current, the cathodes are operated at a higher temperature /$1000^{\circ}C$/ using a dispenser-type cathode originally developed by Philips for use in other tubes. Also, to improve the focus, the high-resolution tube uses electron guns with a 12.4 mm inner diameter, rather than the 9.5 mm inner diameter usual in other 22-inch size tubes. The larger-diameter guns decrease aberrations and further improve focus. With regard to sensitivity to microphonics and stray magnetic fields, a good solution to this problem is to locate the equipment in a suitable place, from where it should not be moved after it has been properly adjusted. Finally, so far, the dot pattern matrix has been widely used for character generation in alphanumeric displays with very good results. The distance between the operator and the screen in these displays is the same as that required in graphic displays, perhaps higher. Thus the dot pattern structure of the screen in a shadow-mask tube cannot be considered an objectionable characteristic.

Using this kind of color tube in graphic displays, it is possible to make use of all the circuitry commonly used to maintain dynamic convergence of three beams. Moreover, it is possible to include any of the commonly used devices for overcoming pincushion distortion. Finally, dynamic convergence is easy to get with a repetitive fixed-frequency raster.

Trinitron tube

Advantages:
- color purity is good when properly adjusted
- brightness is even better than for the shadow-mask tube
- range of colors is the same as that of the shadow-mask one

Disadvantages:
- resolution is medium, /though higher than for the shadow-mask/
- circuitry is needed to maintain dynamic convergence
- it is sensitive to stray magnetic fields and microphonics
- the electron transparency is low, but higher than in the

shadow-mask tube
- deflection angle is 90^{o}

Because basically there is no fundamental difference between the Trinitron tube and the shadow-mask tube in the principles behind their color-separation techniques, all the observations pointed out before are valid also for the Trinitron tube. In this, the resolution is better, the demands on the convergency circuitry are less and the full screen brightness is higher than in the shadow-mask tube.

Penetration tube

Advantages:
- good resolution
- good brightness
- no convergence circuitry needed
- deflection angle not limited by the color-separation device

Disadvantages:
- range of color is generally limited to four /e.g. red, orange, yellow and green/
- requires instantaneous adjusting of the current through the magnetic deflection yoke to keep the deflection amplitude constant, and the beam current must be modulated to keep the picture brightness constant when colors are changed
- it is impossible to produce more than one color at one time
- at the present its price is higher than the shadow-mask and Trinitron tube prices

Analyzing the advantages and disadvantages, we can conclude that the penetration color tube's most important characteristic is its high resolution, but the reduced range of possible colors and its price make it a prohibitive proposition at present for a medium or low price display for process control applications. On the other hand, the limited resolution of the shadow-mask and Trinitron tubes does not represent a serious disadvantage when aiming at an economic solution, even less so as they have already been used with good results in picture quality, in other applications.

c/ Refresh memory

By intrinsic characteristic of the phosphors commonly used, all the information to be shown onto a conventional CRT, must be repetitive to remain continuously visible. The persistence of the phosphor used in the tube due to its phosphorescence, is only about some milliseconds and a few seconds in long persistence tubes. To see statically on the screen the image of some voltage variation applied to the deflection amplifiers of a conventional CRT, the sweep must be exactly synchronized with the frequency of occurence of the phenomenom being analyzed or some submultiple of it. This is the case when it is used as a laboratory oscilloscope.

Relating to a graphical display, on whose screen it is possible to show graphic entities that are somewhat different than the analog functions shown on the screen of an oscilloscope, refreshing of the information must be assured. Of course, the refresh function depends on the principle of operation of the graphic display.

Information to be displayed is stored in digital form and data relating to the format and information content must be passed to the viewing unit back up equipment or interface. In the back up equipment the digital data is converted into analogue waveforms which are used to drive the CRT.

Display systems should present the required information to the operator for a period long enough to allow him to comprehend and utilize the data. Since his reaction time is measured in seconds, and typical CRT decay times are measured in milliseconds, an interim memory system must be provided to allow continuous presentation of the required data. This memory can be located within the display system through the use of such techniques as display storage tubes, recirculating delay lines, magnetic core storage or some type of semiconductor memory. Alternatively, the basic computer memory can be utilized, in which case the information must be transmitted to the display at rates sufficiently high to provide a flicker free display. This refresh rate is usually 25 to 50 times per second depending on the phosphor.

Flicker is an unwanted modulation of brightness level [4]. For a bright display, there are two possible ways in which to combat flicker. Firstly, by choosing phosphors with "overhang" characteristics, the flicker can be reduced by smoothing. This technique is embodied in many of the displays currently available, their manufacturers claiming considerable success thereby. However, such phosphors have the disadvantages that there is not a free choice of color; they are prone to burn easily when driven; they are not among the most rugged, long-lived phosphors available, and they therefore tend to require more frequent replacement; and some "flash" effects may still be present /this depends on the phosphors used/ which can still give flicker effects. Even the best phosphor have an "ideal" refresh rate for minimum flicker which imposes yet another restraint on the display system. Alternatively, a refresh rate well above the flicker threshold can be accepted as a basic design requirement. Apart from disposing of the flicker problem completely, this has two other important advantages: high brightness which comes from frequent writing, and a free choice of color with the additional ability to select phosphors for rugged long-life performance.

With respect to the refresh function there are three typical computer-display configurations [24]:

a/ The computer providing the refresh /Fig.4/

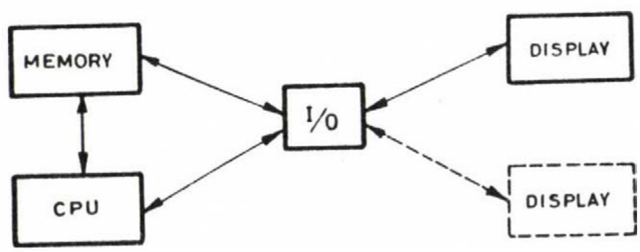


Fig.4 The computer provides the refresh

In this case it is possible to have higher capacity and more flexibility.

b/ A separate refresh memory is provided with each display /Fig.5/

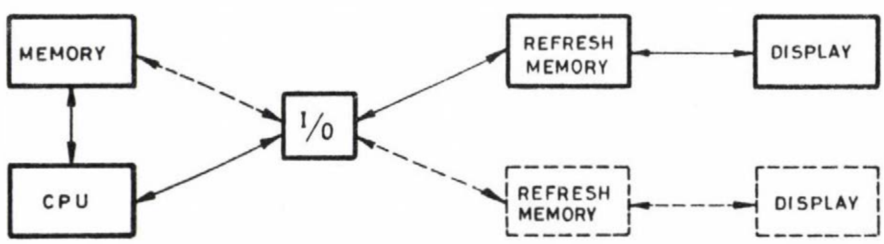


Fig.5 Separate refresh provided with each display

In this case, the bandwith required is lowest and the display is self-contained.

c/ Providing one common refresh memory to drive a cluster of displays /Fig.6/

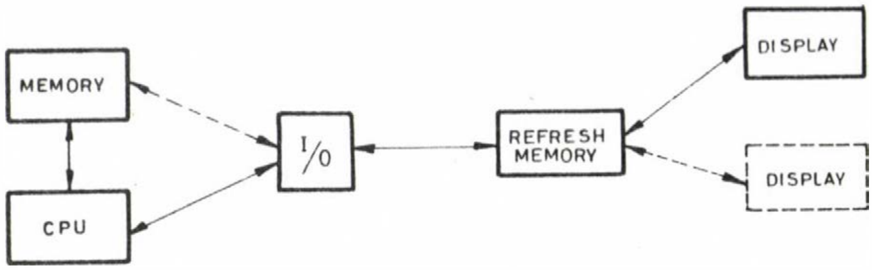


Fig.6 Providing only one refresh memory to drive a cluster of displays

In this case, minimum hardware is used and least I/O time is necessary.

The major advantages of utilizing a separate display-refresh memory are:

1. Less memory cycle stealing from the computer
2. Lower bandwith requirements on the computer I/O
3. The advantage of a self-contained system for some display operations as well as for test and maintenance purposes.

The major disadvantages are:

1. Added hardware required at each display location
2. An adverse effect on display timing and capacity
3. Limitations on the flexibility of the display.

Very often, if the display has its own refresh memory, the computer is forced to maintain a duplicate of this memory file to allow it to update display information or to interpret and to obey operator inputs. Therefore, the question to be resolved in a typical system is usually one of input/output capability and limitations, and timing requirements on the computer and the display.

On the other hand, computers which have sufficient capability to provide refresh for a display have direct I/O access to computer memory as well as the capability for simultaneous I/O, and have central processor memory operation through an access bus arrangement and modular memory system. Data being transferred to the display in systems of this type must come from the computer memory, whether for refresh purposes or for updating a buffer memory located in the display. The required memory access for refresh typically occurs lo to 30 times as often as update. If a memory located in the display is not used for refreshing, it follows that the bandwith requirements on the I/O channel and the communication link are also greater. This becomes a problem if the distance between the computer and display is long or if the number of displays being serviced by the computer is large.

In conclusion, it is safe to say that if both the computer and communication system have the necessary capability, it is usually less expensive, more reliable and more flexible to have the computer refresh the display. For limited capability computers, multi-display systems, or long communication paths, it is more desirable to have the refresh memory in the display.

If there are a large number of displays in the same area to be driven by the computer, it is possible for the display system to be comprised of multiple analog displays /including the CRT, deflection amplifiers, video amplifiers, and power supplies/ with but one common interface and control area including the computer interface, refresh memory, category selection logic, character generator and vector generator. This approach saves appreciably on the overall hardware costs.

The Fig.7 illustrates this type of multiple display system

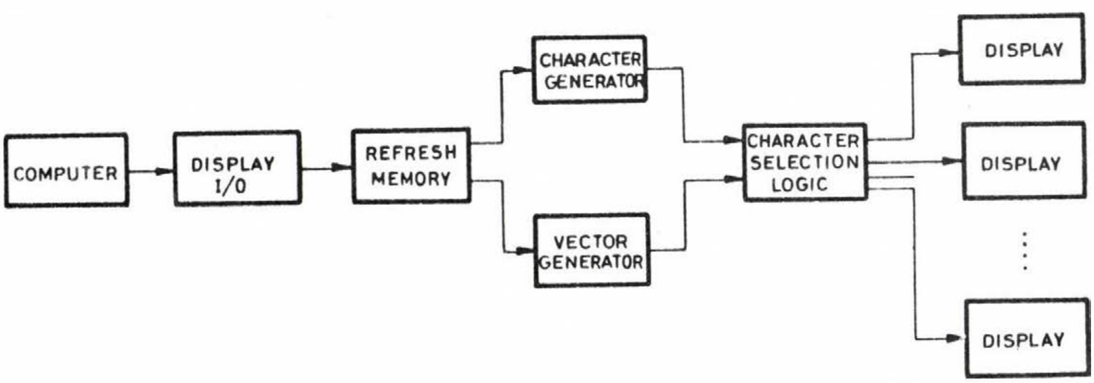


Fig.7 Multiple display system with common interface

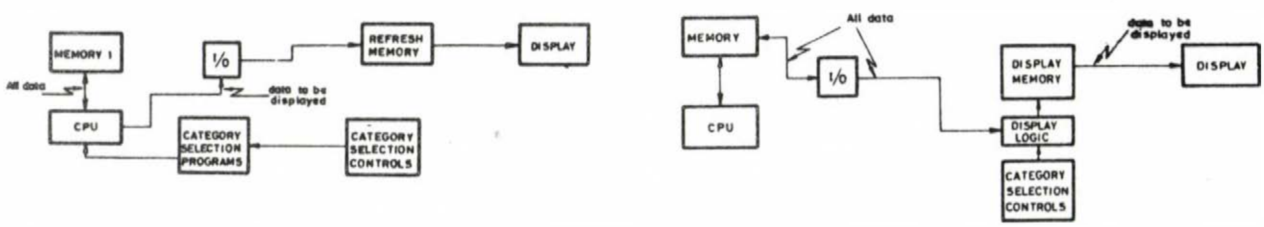
Taking this into account, considering a display for process control application, it is difficult to decide definitely on the best solution. In this application it may be common and necessary to arrange multi-display systems and the communications paths may be relatively long. Moreover, it is not economic to designate a very large capacity and powerful computer to handle the displays as a general situation, although its use in very complex plant or with very ambitious potential computing possibilities in medium size control and monitoring systems, is possible. For this reason, it is more advantageous to include the refresh memory in the display's hardware. High integration levels, new technologies and the no longer so expensive semiconductor memories available, also facilitate this decision, saving cost, weight and size.

d/ <u>Display Category Selection</u> [24]

When the operator requests new types of data, the implementation of this request can be performed through computer programming or through display hardware. If the display performs the selection, the computer is required to send all the available data to each display. However, if the computer performs the selection, only the desired data must be transmitted, with separate data being transmitted for each display. The choice, obviously, has an impact on both computer programming and display hardware, and also affects a number of other areas, such as data word format and length, display load capacity, reliability and timing, and display flexibility. Although it has only limited impact on the refresh memory location, it does have an effect on its size.

The two configuration for performing category selection with the refresh memory in the display are shown in the Fig.8,

a/ Via programming
b/ Via display hardware.



a/ Via programming b/ Via display hardware

Fig.8 Display category selection

Some category selection means must be provided to select those classes of data the operator wants to see. Actual data classes depend on the function that the display is called upon to perform. In our application, they may include such items as: networks from different parts of the industry, tabulated data, ratings from specific subsystems, information of a critical or emergency nature etc.

For the display to provide a category selection capability, category information would have to be transmitted with the data. Selection logic in the display would determine the data to be presented on the display by examining the mode bits associated with the data. This approach involves difficulties both in implementation and in display capacity, because an appreciable amount of additional hardware is required for the display and quite an amount of time is required to look at each word to see if it should be displayed, thus reducing the available time for displaying the data. Moreover, the additional mode bits required for the data words increase the total number of data bits required, thus increasing the size of the refresh memory. In addition, since all possible data must be in the refresh memory, rather than just the selected data, the size of the refresh memory is further increased. Finally, if there are a number of data words which belong in more than one class /which often occurs/ these data words pose new coding problems. It should also be considered that some additional computer time would have to be utilized, since new information which will not be displayed must still be updated.

If the computer performs category selection by programming, special subroutines must be called up every time the operator desires a different category to be displayed. Fortunately, these category selection subroutines will be called up relatively infrequently,since the operator must have time to analyze the information which he has just received, before he will request new data. This does not constitute an excessive computer load. System reliability is improved, because less hardware is required. Identical displays can now be utilized for different types of operations since different category selection logic is not required for each console type.

In process control application, it is obvious that if there are a large number of displays, each with their own memory, category selection by the computer as proposed above, is the best approach.

e/ Scanning

Most computer graphics systems in existence today are based upon the direct view refreshed CRT. They commonly use random scan techniques to display data on the screen. These systems are fairly expensive. On the other hand, the direct-view storage CRT available, makes possible full computer graphics systems and they are less expensive, but due to some present disadvantages already enumerated above, will not be analysed here as a solution. However with their high resolution and very high information density, they also make use of random scanning techniques.

Our analysis will center on random and raster scan refreshed displays using the conventional CRT.

The standard commercial television receiver can be used as a computer graphic terminal as well. They use raster-scan methods to display the generally different succesives pictures in broadcasting applications.

The most relevant characteristic in a raster-scan monitor is that the beam path is fixed, and only beam intensity must be varied to display all desired information. This means that the deflection speed of the beam is completely independent of the quality and amount of information to be displayed. On the other hand, the rate at which the brightness of the electron beam of the CRT changes from blanked to unblanked states /through gray scale tones if required/ and viceversa, is strongly dependent on the quality and quantity of the information to be displayed.

In raster-scan monitors it is only necessary blank and unblank the electron beam opportunely, and it is not necessary to impart to the deflection amplifier at each moment the position information of the electron beam, together with the intensity information. Fortunately, the task of blanking and unblanking the beam can be done at high speed by the tube itself, controlled by the logic which drives it, in a relatively simple form. The only problematic question is the form in which this logic should be fed and the inherent timing exigencies required to accomplish this and show comprehensible information on the screen. This depends, of course, both on the specific application and on the characteristics of the information we want display.

In random-scan devices the question is completely different. Here, the information to be displayed /stored in some storage medium/ is fed to special purpose generators /i.e. vector or circle generator, etc./ together with the positioning information, and after accomplishing the task of positioning, the electron beam is moved on the screen as required, with the electron beam blanked or unblanked as programmed, all the time this is carried out. The larger the amount of information to be displayed, the longer the time consumed by the whole system to display it. In this case the amount of information which can be displayed is large enough, but it is limited by the minimum refresh frequency required to give a flicker-free picture.

Some characteristics of random scan and raster scan low cost graphics systems using the refreshed CRT are [24]:

With random scan:

- it draws the picture by tracing the lines on the display on a one to one basis
- the refresh memory required needs high speed circulating and/or random access
- the driver circuitry must be of very high speed and of high accuracy
- the signal bandwith required is high
- the source memory requirements are large
- moderate information density
- resolution is very good
- good brightness
- the available sizes are sufficient for almost any application
- interactive devices are available for almost any existing technique
- immediate response
- it is most costly.

With raster scan:

- it must first transform the picture into a TV raster pattern
- the refresh memory must be of high speed with recirculating features
- the driver circuity must be of high speed, but may be of low accuracy
- the signal bandwith required is very high
- source memory requirements are very large
- moderate information density
- poor resolution
- brightness is good
- the available sizes are sufficient for almost any application
- interactive devices so far used are the generated cursor or the light pen
- response is intermediate, depending on processor speed
- it is the least expensive since can use the full benefits of television technology

More explicitly, the major advantages of television devices in computer display applications are the following [9]:

- they are by far the most inexpensive general-purpose display components available and come in a wide variety of sizes, resolutions and brightness levels
- they readily handle gray scale, color and video mixing and may be used with inputs from TV cameras and flying spot scanners
- they are the only display devices with a simple, widely accepted interface specification
- monitors of different sizes, wall-sized projectors, hard-copy units and recorders from different manufacturers can be easily connected together
- the fixed beam path and constant beam speed of raster-scan systems require inherently simple compensation and can work with a digital driving source
- the display signal can easily be transmitted thousands of feet along a single line to feed multiple display units and can easily be handled by switching systems
- the synchronising is easily achieved and the regular clocking pulses can be used to derive coordinate data from the display device
- from the human factors point of view, in some cases it is beneficial to invert display image polarity for operator comfort as ambient ilumination varies. Such image inversion, although impossible or impractical in conventional computer random-scan display systems, is readily accomplished with television devices
- it has a relatively high picture regeneration rate assuring freedom from flicker and the availability of ready operator control of both brightness and contrast to his personal taste. This simplifies the control of the display system
- it has gray-scale capability
- maintenance is easy, component parts are cheap and commonly stocked is most neighborhoods.

On the other hand, drawbacks of television systems in computer display applications are [9]:

- the fixed scan-line positions quantize the beam position, so that picture quality suffers, because of the limited resolution obtained, particularly with the 525 line monitors used in America. Quality is considerably better on 800- or 1000-line monitors, but these units are much more costly and require as much as four times the signal bandwidth
- to convert the normal computer format into the raster-scan signal

format is quite complicated. Scanning the picture from top to bottom, left to right in two interlaced fields per frame has the effect of disecting the image in an awkward manner from the computer point of view

- light-pen operation is more complex, because the timing of the light pen's output is not easily associated with the object being pointed at.

To overcome these drawbacks, several solutions have been proposed which in some measure resolve these problems. This will be a subject for a future paper.

In conclusion, the use of raster-scan techniques instead of random-scan techniques in a process control display, offers many advantages having a very good performance with a very low cost per display unit.

f/ Graphic capability

In the case of process control application displays, they do not need a full capability to display greatly varied information, i.e. they can have restricted capabilities. In many specific applications, this restricted capability may indeed meet the whole requirement.

The set of restricted capabilities in process control applications might be:

- alphanumeric capability to produce letters, numerals and punctuation marks
- special symbols oriented towards the specific field of application within the industry
- straight horizontal and vertical lines and straight lines with slope values of $\pm$ 1 /inclined 45° and 135° with respect to the horizontal/
- some types of modifiers, also restricted, to give more freedom to the programmers and give more facilities /e.g. continuous and intermittent lines, blinking, etc./ to the display.

Some other features must also be considered to offer broader facilities to the display, such as:

- make use widely of graphic subroutines
- to find adequate solutions to save bits in the instruction-word or to save instruction-words in a picture program, without detriment of the display's possibilities. This can be done using hardware to create complex parts of pictures with a minimum number of instructions, to select statistically all the most frequently used graphic entities and,

to handle them if possible with only one instruction /may be consisting of more than one computer word/, etc. This can be done relatively easily in raster-scan displays, where the scanning has fixed paths.

g/ Vector, character and symbol generators

Vector generators already widely used in graphic displays were created to be used mainly in random-scan displays, to display straight lines at any slope, circles or arcs with a good quality and using as input one instruction-word and one or more data-words with a specific format. These vector generators gave the graphical display a strong capability to draw on the screen whatever the operator wanted to display, including characters, symbols or non-common curve shapes. They are widely used in expensive random-scan graphical displays.

Any picture displayed in these displays, is generally formed on the screen by drawing with the electron beam one part after the other, in a random sequence, depending on the program performed. This program consists of graphic and other instructions and data-words all conveniently stored in the refresh memory. Its display capacity is limited, as was pointed out previously, by the number of graphic items required to complete the picture, i.e. it depends directly on the complexity of the picture to be displayed and the memory allocated to store the program.

In raster-scan displays, the situation is different. The electron beam always travels the screen in an ordered fashion, independently on what kind of information must be displayed. The scanning may be vertical, horizontal or any more complex structure depending on the specific design. Thus, the use of vector generators like those commonly used in random-scan displays is not advantageous in raster-scan displays, because their more significant advantages are then lost /i.e. the tracing of continuous lines in any part of the screen, with arbitrary slopes, curvatures, and so on/ due to the finite vertical resolution of raster-scan displays systems and the cumbersome handling of the information to produce it. For instance, to draw a straight line with arbitrary slope using a raster-scan device, it is required to store digitally all the points which belong to it. These points are obtained by finding out which are those points which belong at one time to both the stright line and all sweeps of the scan which traverses it. The position of these points on the screen must be determined and stored. After this, all that is needed is the timely unblanking of the electron beam, when the scan travels through the whole screen of the CRT.

In the past this problem has been handled in two steps. First, the display list was processed sequentially, and the pulse trains corresponding to the various vectors were stored in a memory array containing, in its simplest form, one bit associated with each image point. Second, after the display list had been completely processed, the bit map so formed was scanned and its output drove a monitor. As can be seen a very big memory with aproximately 300.000 bits or over is needed even for 525 lines in black and white, and although the newest memories have a low cost per bit / 1/2 cent or less / this will be very expensive. In color pictures, which require three bits for each image point or when it is used a monitor with more than 525 lines, the requirement exceeds a million bits per map.

If we wish to have addressable points everywhere on the screen, to permit the drawing of all kinds of straight lines, curves, etc., we need a so-called bit map as a refresh memory in such displays. Hitherto, that has been the solution generally encountered, but it requires a relatively large memory capacity and also presents other disadvantages.

The image-oriented memory, because it contains a point-by-point representation of the visual image, is likely to be much larger than an object-oriented memory in which is stored a display list of words that are successively addressed to control the CRT beam [19]. Changing any part of the image requires merely the changing of corresponding words in the list. With the radical decrease in cost of semiconductor memories in recent years, it could be argued that the bit map solution to store the information to be displayed in a raster-scan display is the most advisable, but unfortunately image-oriented memories lack some of the advantages of the object-oriented display list systems, mainly the capability of computer interaction with a displayed object. This can be noted, for example, when two objects cross each other. The object memory "knows" that two points are overwritten at the intersection, and it can remove one without disturbing the other. But when the same information is stored in a image memory, the intersection data is lost as illustrated in Fig.9; an attempt to remove one object can unexpectedly change the other.

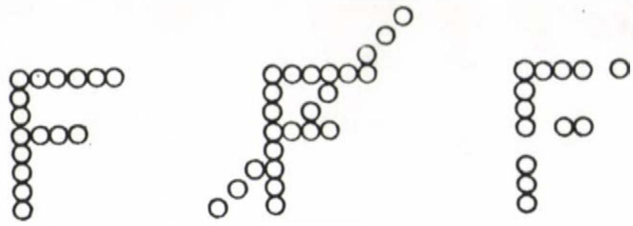


Fig. 9

A similar problem is found when data is to be read back from the memory. The independent information /such as vectors and characters/ in image-memory are only collections of dots, difficult to recognize as single entities and often impossible to identify uniquely; they provide no indication that they belong together. This implies that if interaction is needed, there must be a secondary memory to store a display list. With an object memory, on the other hand, the display can be altered directly.

Further advantages of the object-memories over image-memory displays are, for example, that text in an object list can be easily edited, while text editing in an image memory requires separate storage and additional manipulation. Similarly, tasks involving blinking or moving vectors, characters or sections of the image are easy with object memories, but very difficult with image memories.

Because of the above drawbacks, it appears evident that the memory should not be image-oriented, but object-oriented or of some intermediate solution, avoiding inherently the use of a bit-per-intensifiable map memory or a bit memory map.

We may thus see that if we want to use a restricted graphic facility in a raster-scan display, we must develop a convenient method for handling the information using some adequate form of data compression, and design the corresponding software to manipulate it. This will enhance the graphic possibilities without recurring to the bit map solution, or to using more complex means, such as video disk memories, to store the information to be displayed.

Regarding character and symbol generators, several approaches have been used to date to generate the alphanumerics and symbols needed in graphical displays.

Most important are:

- dot-pattern generator
- stroke-pattern generator
- Lissajous pattern generator

The dot-pattern generator may be of two kinds, namely, with fixed format and with variable format.

In fixed-format dot-pattern generators the electron beam is deflected in incremental steps through every dot in the matrix. The beam is then unblanked only for dot positions which contribute to the selected character.

In variable-format dot-pattern generators the electron beam is deflected only through those dots which will combine to form the desired character. This task is accomplished generally, by use of two binary counters, one to count the row dots and another to count the column dots. Several dot-matrixes have been considered to accomplish the desired results, but the most widely used is the 5-dot-per-row and 7-dot-per-column matrix, mainly, in alphanumeric displays. Fig.10 shows the letter R formed in a 5x7 dot-matrix.

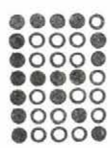
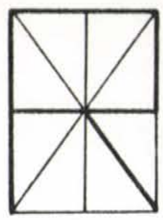
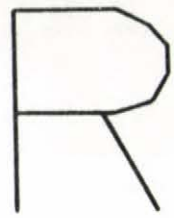


Fig.10 Letter R formed in a 5x7 dot-matrix

The stroke pattern generator also may be of fixed and variable format. This generator accepts digital inputs from some source and provides a sequence of ramp voltages of different slopes to generate the appropriate deflection patterns. Depending on whether it is of fixed or variable format, all the strokes are produced and only those unblanked which contribute to the selected character, or only those strokes needed to form the desired character are traced by the beam. The number of strokes may vary from a minimum of seven to a maximum controlled by the complexity of the pattern to be generated and the accuracy of reproduction desired. Generally the variable-format stroke generator uses more strokes than the fixed-pattern one, which uses only seven strokes. The strokes are generated by means of integrators, one for the x-direction and one for the y-direction, to produce the corresponding ramps for each stroke to be traced. Fig.11 illustrates the letter R produced with a/ fixed-pattern stroke generator, b/ variable pattern stroke generator.



a/



b/

Fig.11 Letter R produced with a/ fixed-pattern stroke generator, b/ variable-pattern stroke generator

The Lissajous pattern generator produces the characters and symbols by means of different sinusoidal and cosinusoidal waves using one fundamental frequency and at least four of its harmonics. It has somewhat cumbersome and therefore costly circuitry. Fig.12 illustrates the letter R produced with this kind of generator

Fig.12 Letter R produced by a Lissajous pattern generator

Some other techniques have also been developed for the generation of characters, some using special cathode ray tubes to carry out this task. Among these are the shaped or extruded beam tube, the multibeam tube, the monoscope tube, the Matricon, etc. Because they can be used only in character generation and not to produce arbitrary graphics, they will not be treated.

In alphanumeric displays read-only memories /ROM/ have been widely used, both to store the words which generates the strokes to form the characters and symbols, and to store those bits which cause the unblanking of the corresponding dots in a dot-pattern matrix. The use of programmable read-only memories /PROM/ for this purpose further enhances the possibilities and increases the flexibility of a symbol generator, because they make it possible to change the font being used, whose selection depend on the specific application.

The use of the dot-pattern matrix to generate the characters and symbols in a raster-scan display using the color shadow-mask tube, is almost obvious.

Another advantageous possibility at present is to use stroke-pattern character generation, but the periodic structure of the shadow-mask tube's screen presents some inconveniencies. They were observed when we dealt with vector generators above. For this reason, we shall refer to only dot-pattern character generators.

Investigation have been made to find the best characteristics which must be met by a dot-pattern matrix to achieve good legibility of the characters and symbols to be displayed on the screen.

This matrix must meet some general requirements, e.g.:

- The number of horizontal and vertical dots of the matrix, should be high enough to achieve good legibility, but is limited by the display's horizontal and vertical resolution, by the sizes of symbols and characters to be obtained, by the size of the screen to get good character-per-row and character-per-column relations, by characteristics of the read-out device and by economic factors.

- The aspect ratio should be pleasant to the sight, generally recommended values are 3 to 4 /horizontal-to-vertical ratio/ or 1 to 1.

- The number of horizontal dots in a row must be an odd number, because many characters and useful symbols are symmetrical with respect to a vertical centre line /i.e. in a case of letter T/.

- Preferably each alphanumeric character must include a free leading column and a free rear column to assure good spacing between two sucessive characters in a string of letters or numerals. The same observation is applicable with respect to the number of vertical dots to assure a necessary space between sucessive rows in lists, tables, text and so on.

- The angle between each two adjacent sides must be 90°, thus the matrix must be rectangular or square in shape.

- The dots must be circular in shape.

From the literature reviewed, the following results justify the ideas exposed above [16], [21].

- The 7x9 circle dot matrix is superior in reaction time and error rate to all other fonts tested /5x7 circle dot matrix and stroke fonts/

- Dot elongation adversely affects legibility

- Dot matrix symbol generation is superior in legibility to stroke symbol generation. In some sense, this contradicts those results obtained by G.Kosmider [7] who pointed out that the speed of identification is slower for all words produced by raster scanning /finite vertical resolution like the dot matrix font/ than it is for words composed of solid-stroke letters. However, the difference is insignificant.

- The slanting of symbols adversely affect legibility, it being better to use a font with upright symbols.

Some other factors which must be taken into account to select the convenient matrix and use it to design the dot disposition for obtaining symbols and characters required, are the following:

- The use of uppercase letters is recommended for displays instead of the lowercase ones, they are recognized more quickly if are arranged with one space between adjacent letters and with style and spacing similar to ordinary print, although there is no difference in reading accuracy [6].
- Standard Leroy, or even better the revised Leroy symbols are recommended for television displays because of their familiarity, easy of construction and greater availability [13].
- For high accuracy of identification a vertical visual size between 12 and 15 minutes of arc, and a vertical resolution between 8 and 12 lines per symbol height are required [16]. /The optimum distance between the display screen and the operator's eyes is 28-30 inches, approximately./ Kosmider [7] points out also that there is a loss in speed of identification as word resolution decreases below 10 lines.
- Viewing angles up to 19 degrees from the normal line of view do not decrease accuracy of identification. The critical angle at which some loss in accuracy of identification occurs is between 19 and 38 degrees from the normal line of sight [16].
- From [3] and [15] it can be concluded that, with respect to the number of scan lines actually used, the quality of interlace is not a major factor in accuracy of identification of characters.
- Scan line orientation with regard to the base of the symbols, has no significant effect on either accuracy or speed of identification [17].
- The mean time required to complete the identification of a horizontal array of alphanumerics is less that that required for the vertical array of alphanumerics [23].
- Light on dark symbols are recognized more accurately under low intensity of ambient illumination, while dark on light symbols are recognized more accurately under medium and high ambient illumination. However, with extremely high ambient illumination, accuracy of identification becomes so poor that this condition would be unacceptable for system applications [5].

- For system applications video bandwidths of less than 2 megahertz are undesirable [14].

Considering the features pointed out above, it is now possible to make a good selection in any application depending on the real conditions to be encountered, the auditorium, the font of characters most adequate to the job, the best shape of the symbols to use, the relative position between the display and operator, the type of phosphor of the screen, etc.

h/ Interaction

There are three general types of CRT displays widely used, namely [24]:

- Alphanumeric Displays for softcopy display of retrieved information composed of letters, numerals and punctation marks used in text edition. Generally, they are monochromic.
- Graphic Displays, with ability to display pictures as well as text, applied wherever a diagram is conventionally used to show the conditions of a system, for monitoring, etc. These exist in both monochromic and color versions.
- Interactive displays, where interaction between operator and computer is possible via an interactive device such as a light pen, rolling ball, keyboard, digital tablet, etc., applied mainly as a tool for designing and whenever is needed a direct communication between the operator and the computer to carry out actions in the process being monitored, to search for information from computer storage, etc.

In our application, at least initially, the interaction exigencies are not very great, that is, they may be restricted. Taking into account such factors as who is going to operate the interactive device, the quality of the demands in process control applications and considering only widely used possibilities to get an economic display, it is sufficient to propose only the light pen and/or a generated cursor, and the familiar keyboard with a reduced number of function switches included.

Some possible uses of these interactive devices in process control applications are:

- In open-loop processes, the control of pumps, valves, etc. by the operator /to connect or disconnect them, change their setting, etc./, using the function switches and the light pen or the generated cursor, over the symbolic representation of the corresponding component

displayed on the CRT's screen as a part of a more complex network;
- Call up with the keyboard and the corresponding function key, the symbolic diagram related to each one of the different parts of the plant being monitored. Through the same means, that is, keyboard and function keys, to call up actions by means of predefined subroutines indluded into the program;
- Interrogate the computer about some information needed and not displayed, or the system when it is carrying out sequencing operations at predefined time intervals;
- Take actions against emergency situations displayed and announced conveniently to the operator, from the display console, thus avoiding disastrous accident in the plant;
- and others related to different possible applications.

i/ Transmission forms of the information to and from the computer

Transfer between the computer and the display may be carried out serially, parallel by character and parallel by word [24].

Serial transmissions are usually utilized in those applications in which the computer and the display, phisically are very separated, that is, the distance between them is relatively large /in the order of several miles/.

Parallel transfers are employed when the display and computer are co-located. Character transfers are used mainly in alphanumeric displays, where the only information transmitted is the character itself, with position defined according to predetermined formats or with a few special characters /i.e. line feed, carriage return, etc./.

Word tranfers are employed with more complex graphical or situation displays, where vectors as well as characters must be displayed and several types of word formats are needed belonging to the different types of instructions.

According to all systems analyzed up till now, the parallel-by-word form of transmission is most appropriate, taking into account the type of display required and considering that the distance between the computer and display is relatively short. In this case the transmission could be carried out using common shielded cable or any other that yields a good signal-to-noise ratio.

The transmission will consist in synchronous digital /or pulsed/ signals comprising the information to be sent to the display or received from it.

Some kinds of these signals may be:

From each display to computer:

- information calling a new diagram to be displayed
- information ordering actions to be performed on the system being monitored and transmitted through the computer to the system
- information calling values continuously updated by the system, but not displayed on the CRT screen, except when required /ratings, time, etc./.

From the computer to each display:

- Information for updating the refresh list of each display whenever the computer receives information containing the actual state of each component of the system, /but only if that part of the system is displayed/. If this is not so, the updating only occurs in the memory of the computer. These might be measurements from measuring instruments, changes of the states of electromechanical components or networks /when energized, canceled or put out of service/ etc.
- Alarm, or emergency situations in the system to alert the operator.
- The instructions to get the diagram of a specific part of the industrial system being monitored, upon request of the operator.

As a rule, all this information is contained in a "state-instruction", formatted in such a form by the computer that the display is able to interprete it.

j/ <u>Link between the industrial process being monitored and controlled and the display</u>

The link between the display and the industrial process may be very varied depending on the software possibilities of the computer and on the demands required or imposed by the process being monitored and controlled. A good solution, is to include as a part of the entire system, a subsystem formed by a data adquisition station. This station should include a data logger, a signal scanner and a certain number of signal converters. This will be used to convert the measured variables from pneumatical or another type of signal into electrical signals to be accepted by the data logger. The signal scanner would scan the electrical or other type of signal handled, depending on the place where it will be placed. The data logger would digitize the analog electric signals provided by the scanner /or from the converters/ and store them in a buffer to be sent to the computer upon request or when the data logger request an interrupt. The computer can be interrupted at definite time-intervals, or when required by the data logger, thus having a real-time operation. With values received in the computer in digital form, it can solve some operations, determine their validity or if they are not out of range, and finally convert them to an acceptable form for the display units and decide if they must be sent to some display or relegated after storing into its files.

The link between the data acquisition station and the industrial process would be carried out by means of measuring channels, the number of which will be according to the number of variables being monitored and the complexity and size of the plant. We must also consider some additional links required to control the process and to transmit the information of the state of each component, network, equipment, etc. of the system to and from both part: the industrial process and the computer. Thus, these control and "state's" monitor signals, go to and from the industrial process through an interface.

Fig.13 shows in a very general form a controlling and monitoring system.

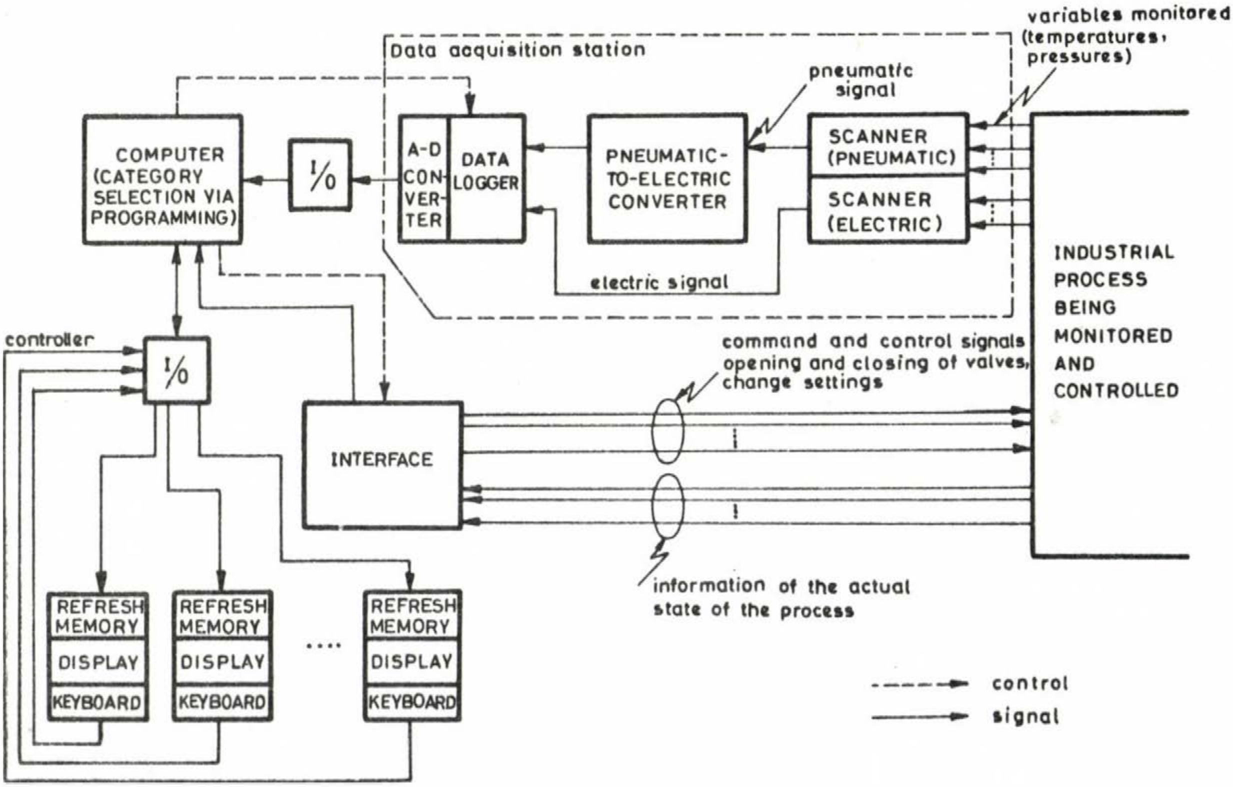


Fig.13 Scheme of the complete controlling and monitoring system /general/

In Fig.13 we suppose two kinds of scanner, one pneumatic and one electric.

This is because of the possibility to get electric signals directly from many processes, for instance, when are used thermocouples in temperature measurements.

The command and control signals from the computer to the process and the information of the actual state of the process sent to the computer, might be voltage levels.

k/ <u>General possibilities which can be included</u>

In process control applications some general possibilities must be included by hardware in the system to enhance in a relatively very simple form, the capability of the color raster-scan graphic display proposed. They could be the following:

- at least two types of lines, i.e. continuous and intermittent lines
- the use of multiplexing in case of cluster operation
- possibility to incorporate video-signals by cable or CATV means in all the stations
- the use of a special type of windowing to permit the operator to analize in a more detailed form, some part of the network being monitored /i.e. tanks, sectors, zones, etc./
- blinking, to be used when required
- more than one intensity level, two probably enough
- make use of PROM memories to change, when required, the symbol set according to the application
- to be modular thus permitting expansion of the system
- for the system to be able, from the software point of view, to use monochromic raster-scan displays, adapting the color information to different type of lines and using more than two different intensity levels, etc.
- tabulation possibilities to facilitate the construction of tables, lists etc.

l/ <u>General criteria to take into account in designing the display</u>

In a process control application some general criteria must be considered when designing the display terminals which are going to be used in the complete system. The most fundamental criteria are:

- Minimum cost per display unit
- High reliability

- Easy-to-use by the operator
- To require minimum training for the personnel
- To be able to be used economically in cluster operation with only one minicomputer handling them all
- Applicable in different types of process by software permitting also a change of the symbol set when required
- To use good technologies when going into production

4. CONCLUSIONS

With the above criteria in mind, we have treated to give a general overview of the most important questions which should be taken into account in designing a process control display. In each part analyzed, the most appropriate propositions were selected considering only general situations and dealing with the fundamental aspects which in our opinion are the most difficult to decide. Unfortunately, there is very little published information on this question, thus we hope this paper will contribute in some measure to facilitate the design of color graphic displays oriented to process control applications.

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