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FOREWORD

Constrained within the Power Industry is the insurgent technology of instrumentation. The constraints within the Power Industry are those of tradition and conservatism. I believe an expression that is often repeated throughout the Power Industry can best describe this attitude, "Give me a system that applies state of the art techniques, is inexpensive, reliable, and has been operating for 20 years."

Today the world is experiencing a technological revolution, a diminution of natural resources, an ecological renaissance, and an environmental purification as signs of the times. If the Power Industry is to produce power economically while complying with these signs of the times, it must set aside many of the traditional and conservative approaches it has applied in the past. It must, in a bold forth right manner, set priorities and timetables to allow a reasonable blending of these requirements in a most cost effective manner.

The 19th National Power Industry Instrumentation Symposium is intended to provide an arena where persons knowledgeable in the areas of controls and instrumentation in the Power Industry can freely discuss their experiences, challenges, and solutions. The theme for this year's symposium, "Dollars and Sense," furnishes the umbrella under which selected subjects will be presented. Hopefully, it will stimulate meaningful discussions toward the blending of "proven" and "state of the art" controls and instrumentation in a cost effective manner to assist the Power Industry in meeting the requirements for more energy while complying reasonably with the signs of the times. Many of the decisions affecting this blend will be made only on engineering judgment due to long leadtime projects typical to the Power Industry. It is an area where a commitment must be made followed by a thorough analysis of the plant criteria and the integrations of the safest, yet highly flexible control, protection and display, system into the overall designs to optimize the unit's performance. Thus, the theme of this year's symposium:

"DOLLARS AND SENSE"

James V. Rocca
General Chairman

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BOILER CONTROLS - YESTERDAY, TODAY, AND TOMORROW

by S. G. Dukelow
Power Generation Marketing Manager
Bailey Meter Company
Wickliffe, Ohio 44092

ABSTRACT

This paper covers developments and economic reasons for various technological changes in boiler controls which have occurred over the past 50 years. The paper further suggests future potential directions, such as microprocessor, DDC, and use of Modern Control Theory and the potential economic benefits which could result in changes to boiler control systems that come into use before the end of the next decade.

INTRODUCTION

From the early Draft and Feedwater Regulators of 1910, the use of boiler controls has grown and been shaped by factors of economics, technology, and application requirements. Many of these changes were evolutionary and relatively slow, others were explosive or revolutionary. The sequential phases of boiler control development, including 80% or more of the units, and the approximate time periods involved can be identified as follows:

- 1905-1920 Hand Control with Regulator Assistance
- 1920-1940 Analog Boiler Control Systems Acceptance
- 1940-1950 Pneumatic Direct Connected Analog Systems
- 1950-1960 Pneumatic Transmitted Analog Systems
- 1960-1970 Discrete Component Solid State Electric Analog Systems, Burner Control, and Digital Computers
- 1970-1980 Integrated Circuit Digital and Analog Systems
- 1980's Prognostication - The Shift to Digital Controls

1905-1920 HAND CONTROL WITH REGULATOR ASSISTANCE

The first draft regulators and feedwater regulators appeared about 1905. Well known devices in the 1910 time period were the Kitts Hydraulic Damper Regulator and the McLean balanced draft system.[1] Figure 1 is a diagram of the McLean system. In that time period draft regulators received better acceptance, were pilot operated and powered by steam or water pressure. These sensed steam pressure and adjusted the draft of boilers with furnace grates upon which coal was hand-fired. These draft regulators were also used with the early engine driven stokers.

The burning of pulverized coal (called "powdered coal") was also getting started at this time. Unlike the unit systems of today, coal was pulverized and put into a bin system for storing until use. Steam pressure was used to indicate draft requirements since, except for pulverized coal, boilers were operated with a high fuel storage and were not immediately responsive to changes of fuel input. Feedwater was normally regulated by hand in larger boilers since the feedwater regulators of that time were not considered reliable enough for use with utility boilers.[1]

1920-1940 ANALOG CONTROL SYSTEMS ACCEPTANCE

The advance of boiler design and the greater use of stokers and pulverized coal increased the requirements for forced and/or induced draft. With boilers more responsive to changes in both fuel and air, control technology was ready to exploit the primary equipment development by tying the draft and fuel control together into combustion control systems. Initially this consisted of one regulator with individual cables or chains going to fuel and air.[2] This development took place about 1920. A Hagan pneumatic system of the early 1920's is shown in Figure 2. By this time it had been shown that automatic regulation improved fuel efficiency, but it was not until the 1940's that this fact was universally accepted.

In the 1920's three-element feedwater control was added to systems, and pneumatic, electric and hydraulic systems were sold to a growing number of utility leaders. A diagram of such an electric system of the 1920's is shown in Figure 3.[3] During this period boilers were also built for burning pulverized lignite. The City Public Service Board of San Antonio, Comal Station, built in 1924, was equipped with a complete automatic Smoot pneumatic/hydraulic system. A similar system for burning pulverized coke using large Ball Mills with a bin system was installed at the Gulf States Utilities Louisiana Station in Baton Rouge in 1929.

Complete electric combustion control and three-element feedwater control systems with electric damper operators and electrohydraulic feedwater control valves were installed by Bailey Meter Company during the 1920's. Of over 90 units furnished in the 1920's many were on pulverized coal.[3] Typical of these systems were installations at Boston Edison, Cleveland Electric Illuminating Company, Southern California Edison, and Pacific Gas & Electric at Station A (now the Portrero Station). Electric damper operators and electrohydraulic feedwater control valves, as shown in Figure 4, and the three-element feedwater control system, shown in Figure 5, are still in use today – 47 years later – at this plant.

Up to this time there was no real pattern except that the boiler control center was installed at the boiler front and the control systems were direct connected. A typical control center of this period is shown in Figure 6. The application and hardware technology used was determined by the control vendor with Bailey selling electric systems, Hagan pneumatic systems, and Smoot (later Republic Flow Meters) pneumatic-hydraulic systems.

In the early 1930's it became apparent that more than simple mechanical links or electric contacts were necessary to provide control actions, such as those we know now as proportional plus integral, summing, averaging, auctioneering, and limiting. These actions could be secured at reasonable cost by the use of pneumatic techniques, while electric control was either not available or too expensive to compete and provide comparable functions.

In this same period hydraulic systems lost out due partially to economic factors and partially to hazards due to leaks of flammable fluids which could come in contact with hot surfaces. Hydraulic systems also required return lines as well as supply lines

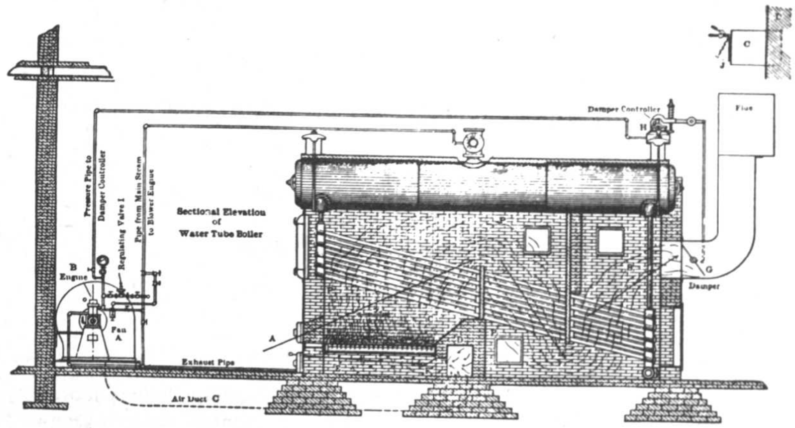
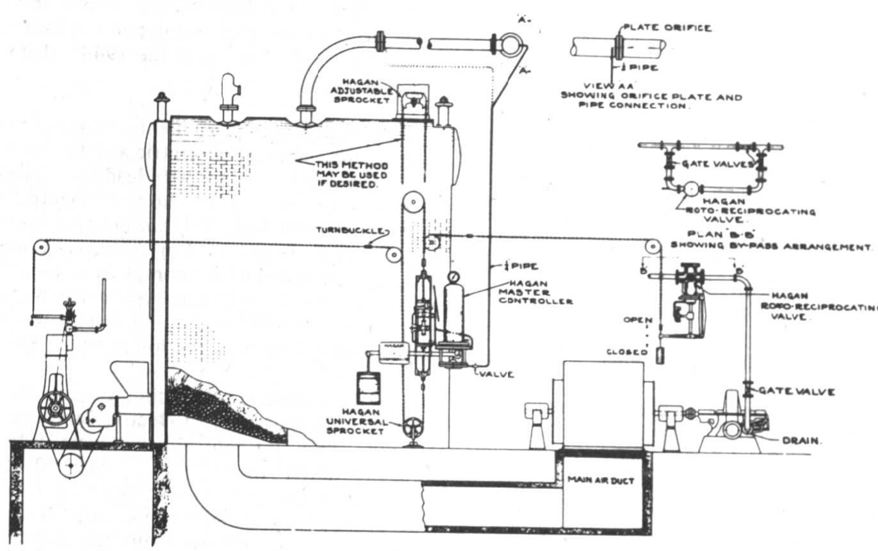


Figure 1



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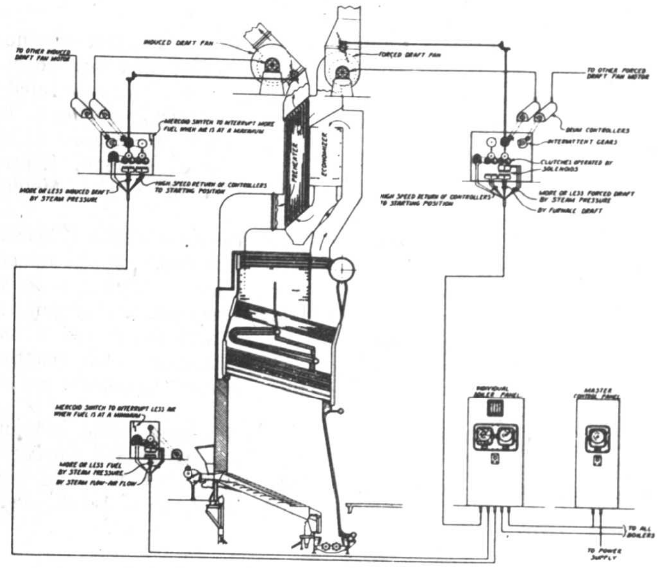

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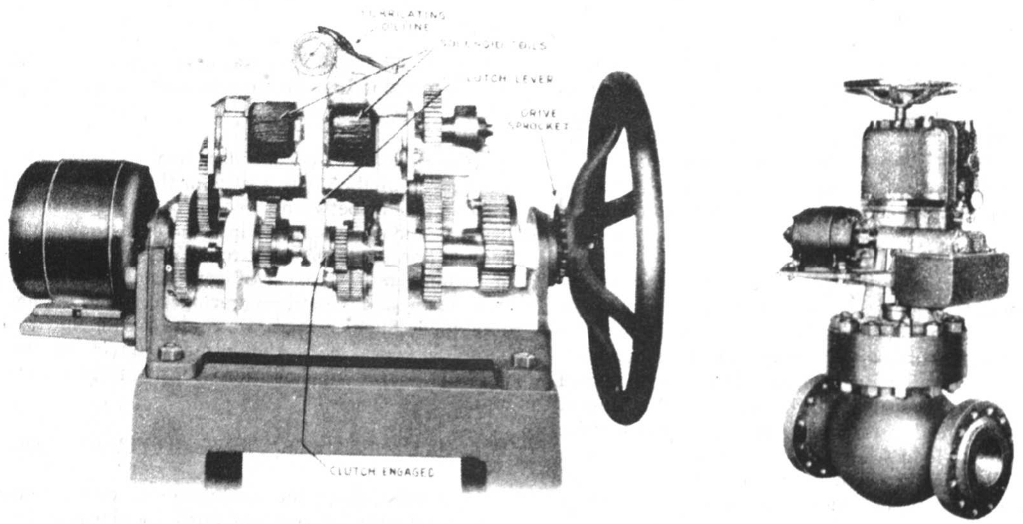

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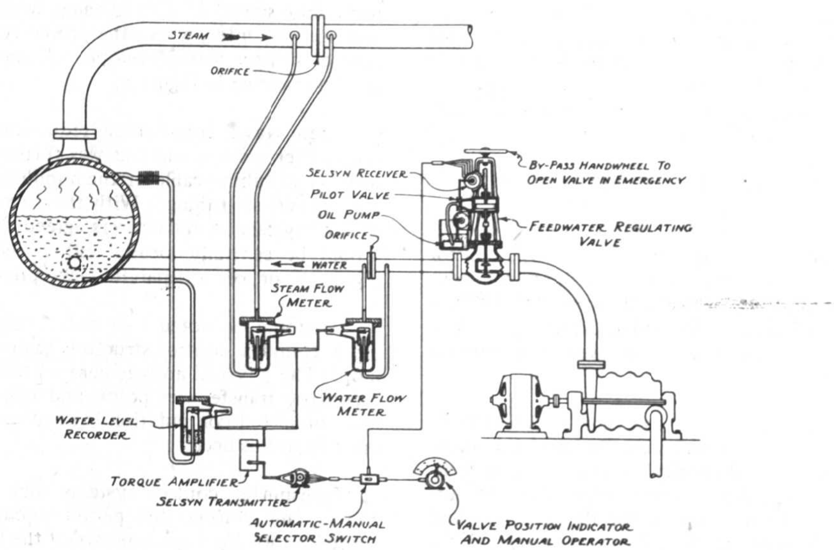

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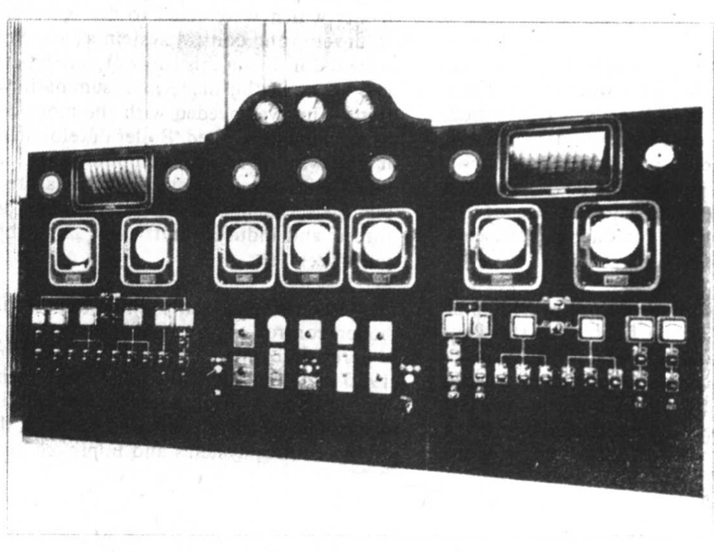


Figure 6

while air was simply exhausted to atmosphere. Power devices became almost universally pneumatic due to low cost and safety as compared to electric-hydraulic. As a result of this and lower installation costs, pneumatic systems captured over 80% of the available market by 1934. The only electric control systems in the late 1930's and 1940's were the Hays electric control and the Leeds and Northrup pneumatic-electric systems. Both used electric control drives.

Boilers also evolved during this period and, in basic design, experienced a revolutionary change with the development of the B&W Integral Furnace and Radiant Boilers about 1935. This development, along with competitive designs of other manufacturers, such as the Combustion Engineering VU Boiler, increased the requirements of control systems. Additional, more stringent control requirements were due to smaller drums, higher furnace heat releases and the fast load swings the new boiler designs were developed to handle. Other factors were greater use of forced and induced draft and more complicated fuel burning equipment as boiler size increased.

To meet these demands control system evolution during this period included greater development of interconnection and more extensive use of feedforward techniques which were already in use.[4] Three-element feedwater control of that period was sufficient to handle the toughest feedwater control jobs. Boiler control had generally become accepted, although in 1940 there were still a significant number of utilities who would accept automatic feedwater and furnace draft control but not steam pressure control, fuel control or fuel-air ratio control.

1940-1950 PNEUMATIC DIRECT-CONNECTED ANALOG

World War II, in the first half of the 1940's, arrested the development of boilers and control systems. Essentially, control system configurations of 1940 were used throughout the next decade. A 1940's system, as shown in Figure 7, normally consisted of a boiler control panel adjacent to the boiler. Controls, whether instrument or regulator type, were direct connected to the process through pressure sensing lines.

During the 1940's flue gas oxygen analyzers (a late 1930's development) came into general use and were first tied into combustion control systems. A large majority of utility boiler feedwater control systems were the three-element type. The first outdoor generating units were being designed for the southern and southwestern parts of the United States. Boilers were getting larger and connecting lines were getting longer. The benefits of the few early central control rooms were being recognized. By the later part of the 1940's, the central control room concept had become thoroughly established.

In the period up to the late 1940's, the major manufacturers of combustion control equipment disagreed on whether the regulating equipment should be field mounted or panel mounted. Some companies panel mounted the control equipment since it centralized the control system, protected it from outside atmosphere or influence, simplified the interconnections, permitted greater use of feedforward techniques and allowed use of the measuring instrument as a sensing device, providing greater sensitivity.[5]

Other companies felt that the regulating equipment should be external from the panel and located in the field since this kept direct connected piping shorter and unhampered by space considerations of the panel, and because larger, heavier, more rugged field equipment could be furnished. Still others took the position that part of the regulators should be on the panel and the rest in the field. Each approach included both positive and negative aspects and the argument was never really settled before a revolution occurred in boiler control systems in the late 1940's and early 1950's.

The advent of the central control room pointed up particular weaknesses of the control systems then being furnished. Distances became greater between the control center and the boiler control devices, and this resulted in high cost, long high pressure connecting lines to the control room. With a trend to outdoor boilers in certain areas, freezing of connecting lines became a problem and steam and electrical tracing for such piping bundles was developed. Such systems were also considered to be somewhat hazardous because of the introduction of all the various high pressure connecting lines into the confined area of the control room.

1950-1960 PNEUMATIC TRANSMITTED ANALOG SYSTEMS

The solution to the weaknesses of direct connected control when used with the central control room was achieved by a major change in boiler control systems. This revolution in boiler control systems, accomplished in two to three years, was the conversion from the direct-connected regulating equipment to transmitting-type systems. In the transmitters, measurements were converted to pneumatic signals of a fixed range which were transmitted to the intelligence center, where the proper control signals to the various control devices were developed. A simplified diagram of such a system is shown in Figure 8.

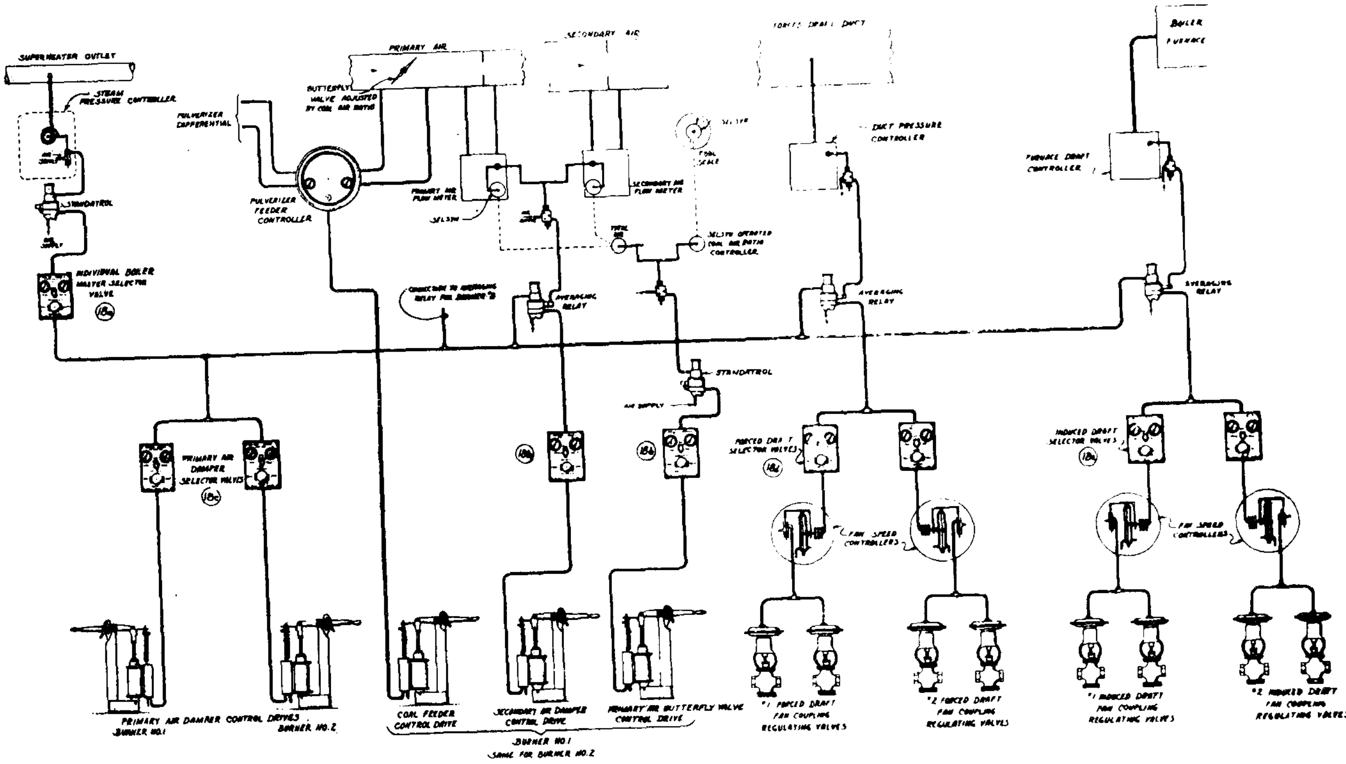
There was a considerable reduction in installation costs for a transmitter system, and this was further emphasized by the development of tubing cable or the bundling-and-cabling of instrument compressed air tubing.[6] With the switch to transmitter systems, control system manufacturers agreed that the system intelligence should be centrally located either inside a cubicle as shown in Figure 9 or on a separate rack, possibly on the floor below.

It should be noted that boiler control has always required a more complex control structure than a group of single element loops. The physical arrangement of the split system, with manual-automatic transfer, set point, and bias at the control panel and interconnected computation logic at a remote location, has developed from this need.

Transmitter control systems met the control needs of the 1950's, and during this period pneumatic transmitter systems accounted for the large majority of the systems sold.

Since all of the intelligence was at a central location and since all of the information began with transmitted signals of measurements which were fixed to the same signal range, it was possible to develop the control system as a computing system rather than a regulator. Using this concept, much better analysis of the control system could be made as a summation of various control functions. This was needed with the more complex boiler units which were being developed. Boiler developments which demanded more in the way of control computations were: gas recirculation combined with spray for steam temperature control, the use of multiple fuels, smaller drums, still higher heat releases, dual sets of forced and induced draft fans, larger boilers, greater number of pulverizers, etc.

Other developments which were to have a profound impact on boiler control of the 1960's evolved during this period. The first supercritical once-through boiler went into operation in the mid-1950's. A transition to forced draft with pressure furnaces rather than balanced draft with forced and induced draft was taking place. This change eliminated some of the most difficult portions of the control systems and improved control stability. Automatic



DIAGRAMMATIC LAYOUT OF SPECIAL BAILEY COMBUSTION CONTROL SYSTEM
FOR
CITY OF LANSING, MICHIGAN

Figure 7

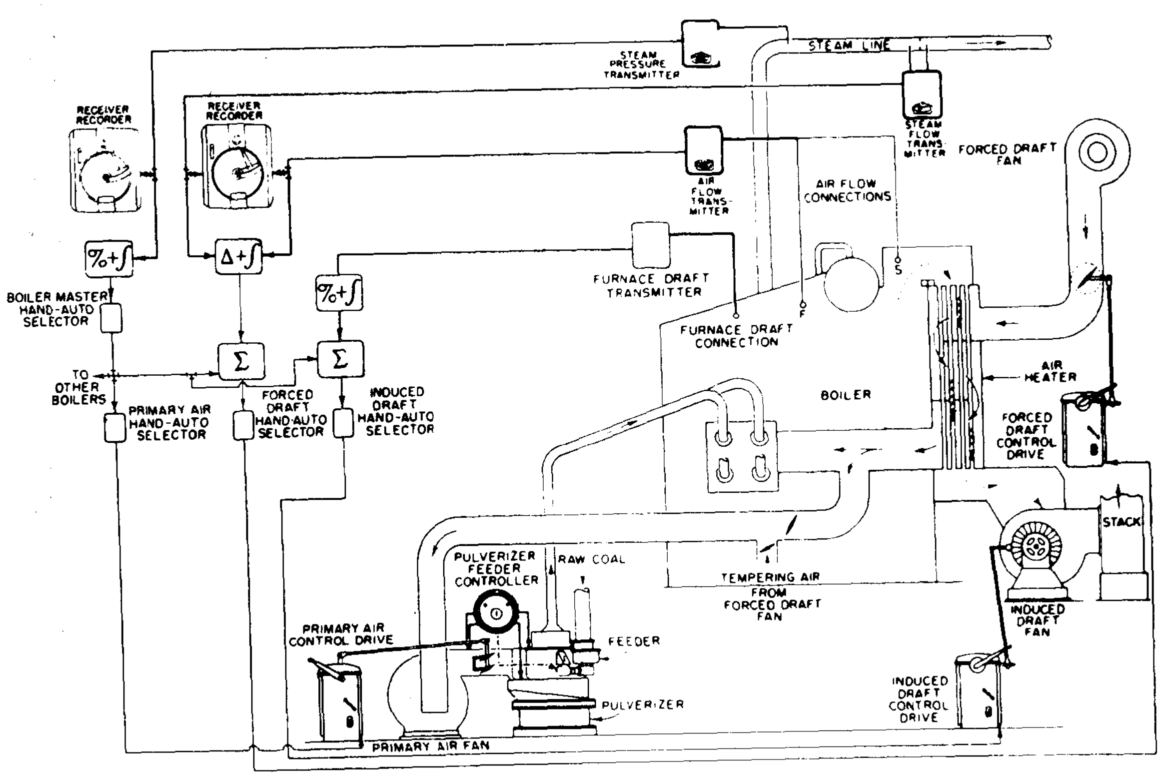


Figure 8

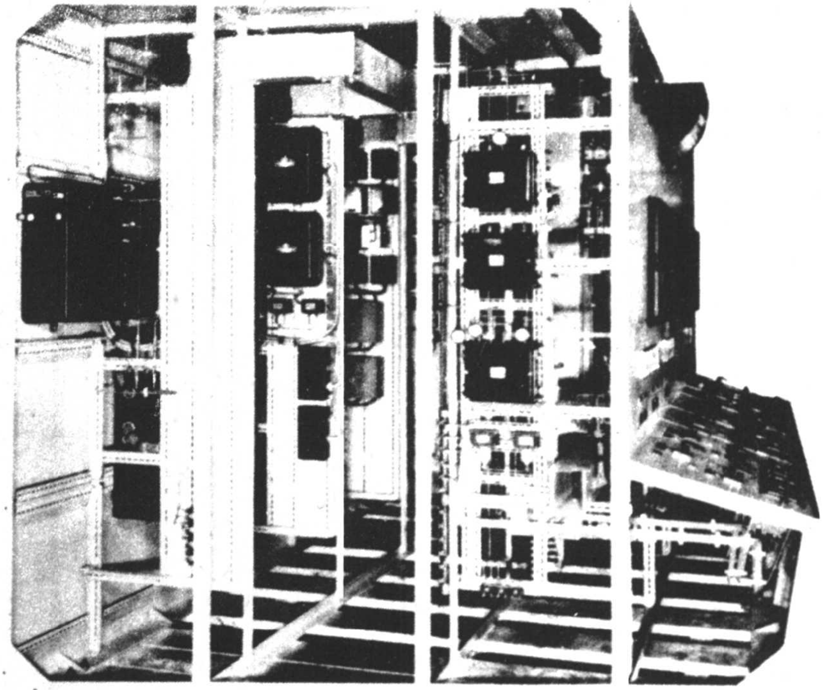


Figure 9

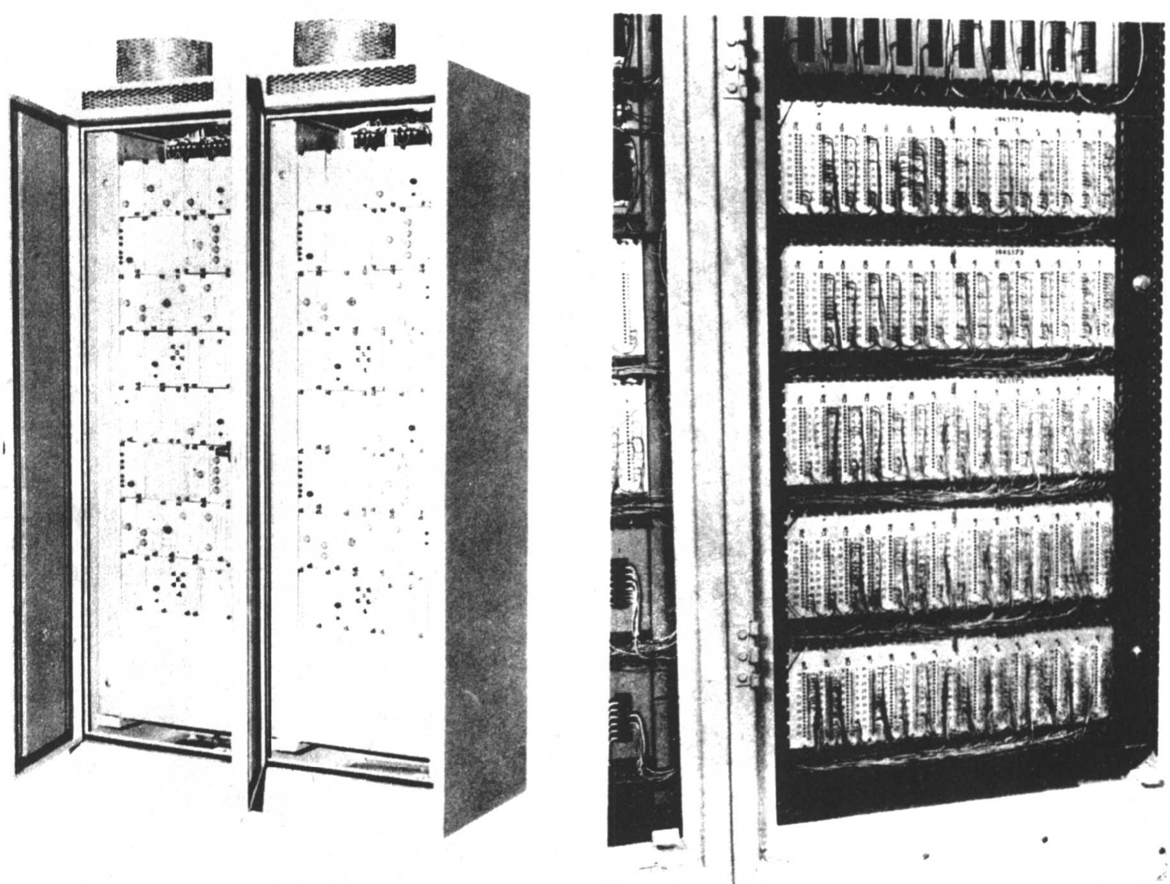


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Figure 10

burner control using relay logic got its start in the latter half of the decade on gas and/or oil pressurized furnace boilers.

Digital data logging in utility plants started in the mid 1950's using vacuum tube amplifiers and stepping switches.[7] In late 1958 the first utility plant installation of a solid state core memory digital computer was made at Sterlington Station of Louisiana Power & Light. Electronic analog boiler control using vacuum tube action units was getting its start in 1955-1960 time period, and more and more boiler control systems were participating in automatic dispatch and economic dispatch control.

These systems were static systems. There were earlier electronic systems which were servo electronic analog systems using amplifiers, balancing motors and potentiometers. Such systems started approximately 1950, did not gain wide acceptance and faded away as solid state static analog systems came along.

1960-1970 DISCRETE COMPONENT SOLID STATE ANALOG SYSTEMS, BURNER CONTROL AND DIGITAL COMPUTERS

In the late 1950's the words "solid state" became magic. As solid state computing and data logging systems gained acceptance in the early 1960's, arguments to change boiler control systems from pneumatic to electronic for overall systems compatibility were more tenable. In addition, some economic factors changed. One of the previous high installation cost factors for electronic control had been the pulling of heavy wire through rigid conduit. Now, the use of multi-conductor cable, laid in open cable trays for carrying the electrical signals around the plant, reduced this cost factor.

In comparing electronic systems to pneumatic in the early 1960's, electronic systems were still not justified unless certain conditions were met. If, for example, a user intended to use data logging and computing systems to simplify the operator's duties and the control center, installing an electronic boiler control system that could use common inputs was desirable. Also, as boiler installations became larger and more complex, the boiler was removed by distance from the control room, resulting in pneumatic time lags that were detrimental to control action.

As it became apparent that a transition was taking place, users wanted to learn as quickly as possible what these new technologies offered. Consequently, a rapid transition from pneumatic analog to electronic analog occurred within two to three years in the early 1960's. As with pneumatic transmitter systems, these were split systems. Transistor and magnetic amplifiers were used for the control action units. The electronics were cabinet mounted, as shown in Figure 10, very similar to systems today with front access for control adjustment and testing and with interconnecting wiring in a rear access wiring plane.

Supercritical once-through boilers gained in popularity because of lower initial investment and improved operational economy. An additional advantage was the lower energy storage and greater responsiveness to load changing requirements of automatic dispatch systems.

The real challenge of the 1960's from a control standpoint was the once-through boiler which got its start in the United States at the AEP Philo Station in 1954. Control systems were required that would automatically start up the boiler, raise the pressure to full pressure as partial load was applied and then raise the load to full load, while simultaneously maintaining steam temperature, reheat temperature, and controlling fuel, air and feedwater in very close balance. Complex control structures were a result of the demands of such applications. Due to the large number of control logic computations and elements that often occurred in a series string, early control action units of 0.5% accuracy were unsatisfactory for the application. As a result, control action units of 0.1% accuracy and better were developed in second generation electronic control systems in the 1963-1964 period.

Also, in the early 1960's, the application of modulating control equipment to a boiler was veiwed as mathematical logic, rather than applying and connecting pieces of hardware. The logic approach freed designers from knowledge of hardware capabilities. A system for showing the logic in symbols free of hardware consideration was proposed by Bailey Meter Company[8] and, after modification, was adopted as standard RC22-11-1966 by SAMA (Scientific Apparatus Makers Association).

Burner control with solid state logic and relay outputs for current capacity was also introduced in the early 1960's. Initial installations were for gas and oil followed by pulverized coal in the mid-60's. Considerable work was done by all companies in improving flame-scanning equipment and the application of this equipment. Systems evolved from comparatively simple monitor and trip systems to complete fuel management systems. By 1970 it was accepted that burner and/or pulverizer control installations should be made on practically all boilers.

During the mid-1960's, concepts were developed for simplification and standardization of operator interface using interposing logic systems for motor control. With these systems, and using combinations of backlighted switch modules and indicators, a total operator interface integrating all types of systems was developed.[9] This concept gained acceptance slowly during the late 1960's. A control center of this type is shown in Figure 11.

Computer systems monitored plant variables and plant performance, and by 1970 they made extensive use of black and white alphanumeric CRT's for message data display and typers for hard copy. In the early part of the 1960's, some very ambitious efforts were made toward complete and automatic start-up and operation. These early installations were very costly and benefits were dubious. Later systems moved away from automatic plant start-up and shutdown due to the many problems identified in these early installations.

1970-1980 INTEGRATED CIRCUIT DIGITAL AND ANALOG

When compared to the developments of the 1960's in once-through boiler control, improved load following systems, extensive application of digital computers, and the evolution of solid state analog systems, the 1970's have been slightly calmer. The decade began with a shift to integrated circuit amplifiers, a change brought about by the availability of lower cost integrated circuit electronics. Side benefits were reduction in cabinet space and reduced heat dissipation.

Except for variable pressure designs, boiler technology has not advanced significantly in the 1970's. There has been a movement back toward subcritical boilers, and average unit capacity is a little smaller. A significant change affecting the control systems of the 1970's has been the move from pressurized furnaces back to balanced draft furnaces as long term maintenance requirements of the pressurized furnaces became a factor. As induced fans were added, an implosion hazard, not previously recognized, has become evident, putting special emphasis on the speed of operation and arrangement of the induced draft control subsystem.[10] The use of induced draft fans has added the difficult furnace draft control to the system. While furnace draft control was largely eliminated in the 1950's and 1960's, its return to use has added complexity and instability to the systems. Since most nuclear units are base loaded, there results more cycling of fossil boilers. The benefits of variable pressure to improve fuel economy brought develop-

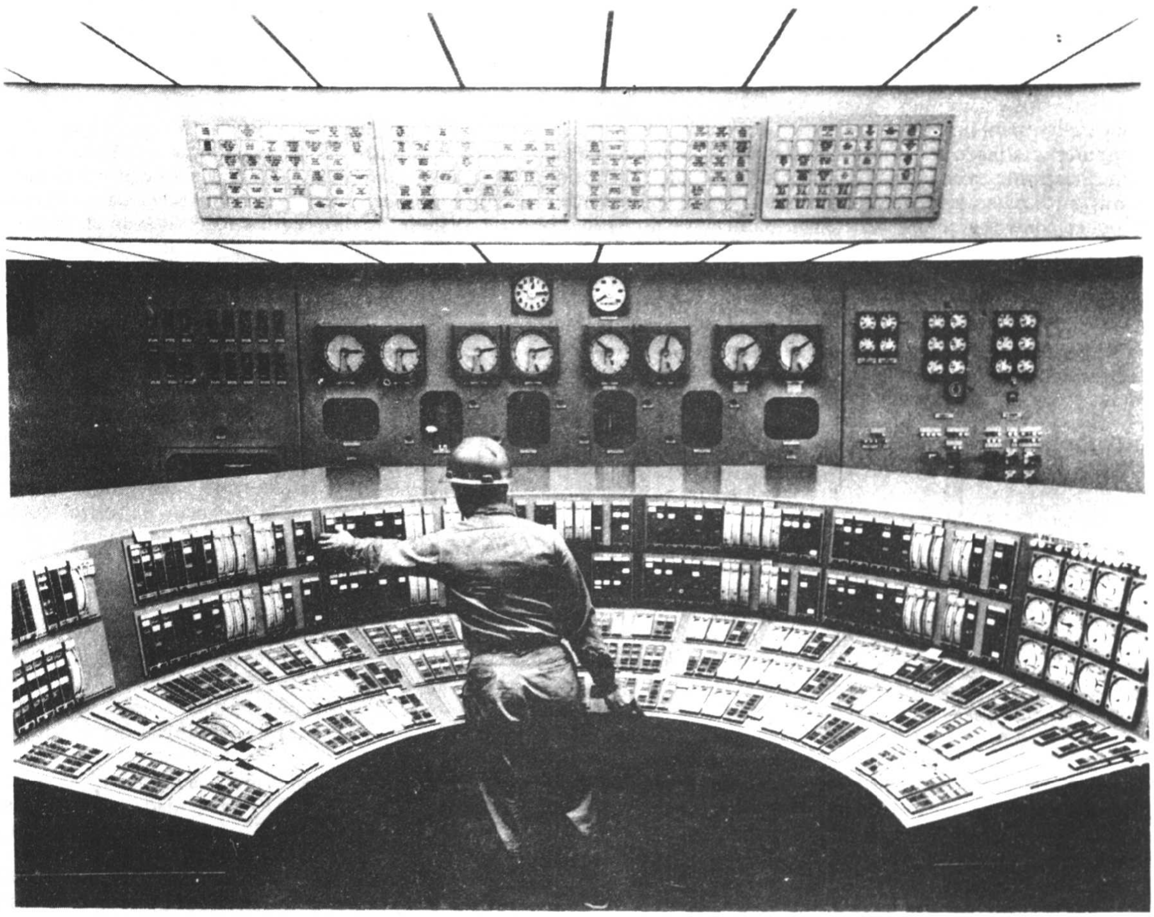

Figure 11

Figure 12

ment of control systems to program pressure with load as required by these units.

However, other control system developments not driven by the advance in boiler technology have occurred. Since 1970 five utility companies have installed Direct Digital Control (DDC) systems on large boiler-turbine-generator units. Some of these include both the modulating and burner or pulverizer control.[11] A control center of one of these is shown in Figure 12. Additional plans are going ahead at this time for units with 1979-1980 startup dates. The computer systems now use extensive color CRT's, with both alphanumeric and graphic capability. Line printers are used instead of typers, and systems may have 2000 to 3000 inputs. High level control software languages have been developed.

With more conventional systems, programmable controllers or microprocessors are being developed for burner/pulverizer control. In analog systems, reduced size operator stations have been developed to reduce control board size and methods of continuously using a battery power supply to improve system availability are being offered.[12]

The shift in 1973 and 1974 from 35% coal to practically 100% coal has put increased emphasis on systems for coal firing. The integration of operator interface on a per-pulverizer basis, combining both analog and digital functions, is being furnished as an improved means of coordinating operator actions relating to both these functions.[13] Figure 13 demonstrates such an operator interface unit for a pulverizer.

1980'S PROGNOSTICATION - THE SHIFT TO DIGITAL CONTROL

Looking at the factors of economics, technology and application requirements, forces today seem to be leading to a new revolution in boiler control which is in the direction of digital control. Digital control to date has identified certain distinct benefits not previously available with conventional analog approaches.[14]

1. Input transducer signals can be tested in many ways before being used to develop a control signal. In an analog system, when an input signal fails, it generally results in an immediate faulty control action.

2. Digital control is capable of diagnosing the majority of its own ills, and can place the control loops on manual or back-up to prevent faulty control action from occurring. This is impossible with analog hardware in which a component failure generally results in a faulty control action.

3. Since the control structure is not hardware based, the control engineer need not worry about cost or time delays when adding additional control operations, such as proportional, integral or function generation or other more advanced forms of control. Care must be taken, however, to provide a sufficiently high priority to the control functions if the system contains other than control functions.

4. Control calculations can duplicate well-known analog actions, or they can be expanded to achieve better control through the creation of specialized software modules. With analog control, the control system designer is limited by the capabilities of the available hardware modules.

5. Digital control has the capability of providing pure delay in its control calculations. With pure delay, control action can be delayed any desired length of time to duplicate identifiable pure delay in the process.

6. Because digital calculations are error and drift free, digital control settings are exact and reproducible. Initial settings do not deteriorate as on analog systems where the analog elements may deteriorate with time.

7. A high degree of reliability is obtained because of the relatively few components involved. Integrated boiler and burner control systems presently furnished may represent 30 to 40 cabinets of analog and digital components. This may be reduced to 10-20 cabinets for digital control, resulting in potential for considerable economic savings.

8. A properly designed digital system permits control engineers and maintenance personnel to readily and continually monitor the status within the system, thus simplifying troubleshooting. Inherent is the flexibility that could be duplicated in an analog system only by having a digital voltmeter on every wire.

9. With digital control all calibration, tuning, and testing work is performed in the presence of the unit operator at the BTG board. Using the continuous dialog between the control engineer and operators, smoother, better coordinated commissioning occurs. The participation of the operator in this process speeds up training, and increases confidence in the system.

10. The merging of control and information systems can result in a symbiosis that provides access to complete information on the status of the control system (permissives, times, transfers. and logic action) through CRT messages, alarms, and status summaries. These programs provide printed records that automatically document the progress and state of the control system throughout the tuning and calibration period. Also, diagnostic programs, trend recording, logging, and CRT displays provide powerful debugging tools not previously available. Aligned with the need for digital control is a 1980's requirement for documentation to support historical plant operations. Indications are that this is coming and will be mandatory.

The specific manner in which digital control will be applied is not so clear. There seems to be two paths that will be followed, each of which has its adherents. One of these, or some compromise between them, will eventually win out.

One path is DDC in a large central plant computer system. An economic reason for such a step is to maximize the return on investment of the plant computer by doing control while eliminating a separate modulating/sequence system. Such a system is capable of the most sophisticated control structure.

In control structure sophistication, we have come a very long way. We may have reached close to the ultimate required unless a major change occurs in boiler types or fuel burning. We have limited ourselves to the conventional control algorithms and functions available in analog modules. Whether this is carried further into the very sophisticated alogorithms and Modern Control Theory will depend on the need. If we can control temperature now within 10°, as shown in the DDC Charts in Figure 14, what is the economic benefit of control within 5°? What is the economic benefit of self-adaptive control on a utility boiler? Such a technical advance in utility boiler control is not inexpensive, and it will not be done for the sheer joy of advancing the technology.

Following the DDC path, the Plant Computer System should consist of two or more CPU's with capability for automatic switching to improve control system availability through redundancy. This system will require some linkage with dedicated subsystems which may be microprocessor or minicomputer based.

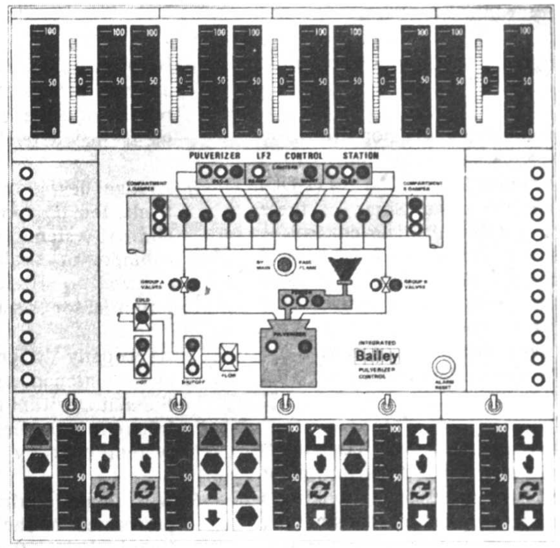

Figure 13

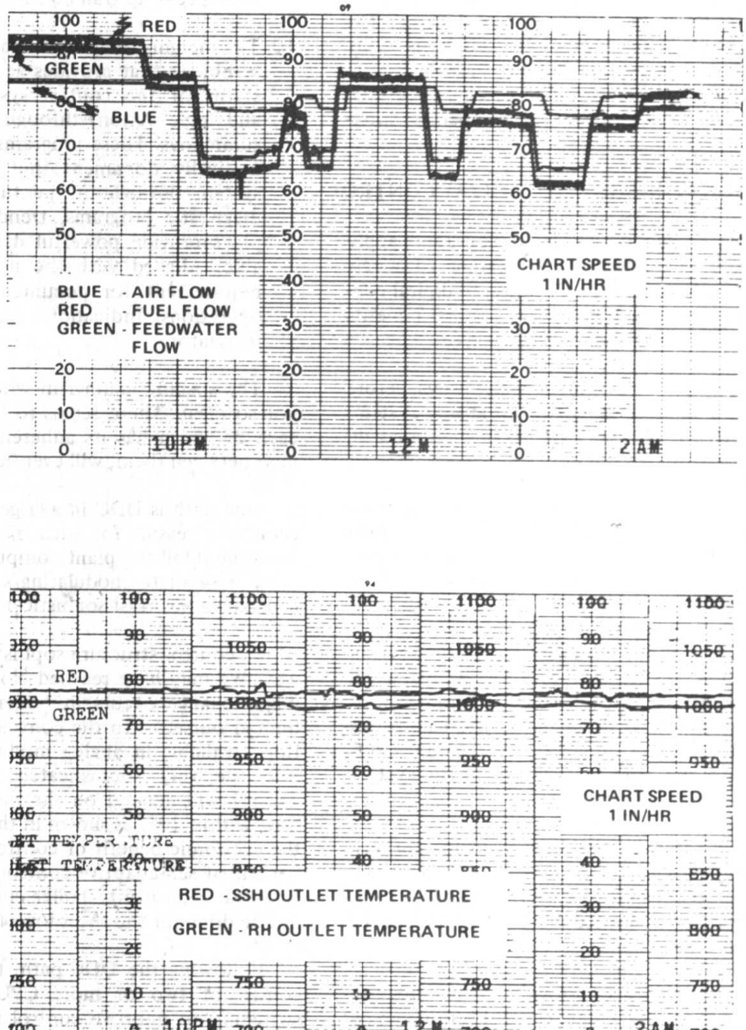

Figure 14

Potentially such linkage will be required or desired for DEH governor systems, coal handling and management systems, cooling tower packages etc. Techniques for such linkages exist. Backup control will consist of the redundant CPU's referred to above, manual, and possibly some hard wired, override systems where protection integrity are very critical e.g. furnace implosion circuitry.

Experience on such DDC Plant Computer Systems, including both the digital burner control and the modulating operation control, is being gained in the 1970's. The lead-time of plant construction and the feedback of good operation experience by pioneer companies will probably delay any large switch from analog until at least 1980.

The other route for digital control is in the use of microprocessors in a distributed system. In such a system a group of microprocessor subsystems with a communication network and with linkages to other subsystems described above will provide a complete system. It is probable that a functional block will control a subsystem rather than performing a single control function as with today's analog modules. In part, economic benefit will come from the reduction of wiring between the modules which make up the system, reduction of cabinet space, and software control implementation. Such a system may be similar to the distributed control systems that are coming for process plants. There will, however, be a basic difference. In distributed process control, clusters of control are connected to a data highway and via the highway to a control center. The concept is of a control heirarchy, and if the highway is not in service, the control cluster can continue to operate without the central control. A utility boiler system differs since the various elements of the total system are so entwined and interacting that, except for certain subsystems, a failure of one part of the system quite often destroys the automatic function of the system.

Microprocessor based systems can be configured to have all the advantages of digital control enumerated above. In the use of "Modern Control Theory" algorithms, however, a communications link with the plant computer would probably be required for storing and updating the necessary model and for any additional "number crunching" that may be required.

Either way, the control for the future shapes up as digital control. The method that wins out, whether it be one of the two described or a compromise, will be determined by the successful applications, the economic benefit and the comparative reliability.

From a control standpoint, this should carry us to Solar Power, and what a job that is going to be tilting all those mirrors.

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