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The Fifth Annual Control Engineering Conference

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Foreword

This is the proceedings of the Fifth Control Engineering Conference, sponsored by Control Engineering magazine and held in Chicago, May 6-8, 1986. The conference was accompanied by CONTROL EXPO/'86, an exhibit of instrumentation and control equipment and systems available from many of the leading suppliers to the field. This volume was distributed at the conference and includes all of the papers which were available at the preprint deadline.

This was a true control engineering meeting in that the sessions dealt with all types of instrumentation and control equipment as it is applied in all types of industries. Equal practical attention was given to process control and to machinery and manufacturing control, and to subjects ranging from local area networks to advanced strategies in process control. There was no overall theme to the conference except that emphasis was placed on areas where rapidly advancing technology is forcing the most radical changes in control engineering practice.

With this conference, the five volumes of proceedings have contributed about 2,100 pages to the control engineering literature. Every effort will be made so that future conferences continue to develop an extensive reservoir of information on the practice of modern industrial control engineering.

Byron K. Ledgerwood
General Program Chairman

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DOES RETROFITTING A PLANT WITH DISTRIBUTED CONTROLS SOLVE YOUR PROCESS CONTROL PROBLEMS?

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ABSTRACT

With the emergence of distributed controls in the chemical industry, many companies have retrofitted their existing pneumatic and electronic controls in order to improve quality, increase production rates, and improve overall plant efficiency. This paper discusses the various stages that Allied phenol plant in Philadelphia underwent in order to have complete conversion from pneumatic controls to the present day distributed digital control system. In addition, the advantages and disadvantages of a distributed control system are discussed.

INTRODUCTION

Allied's Philadelphia phenol plant has deep roots in early industrial United States history. Established in 1884 as the H. W. Jayne Company, the plant is known as one of the earliest coal chemical producers. It was started on four and a half acres of land in the northeast section of Philadelphia. In 1896, it was taken over by Barrett Manufacturing Company, a midwestern coal tar roofing company. At that time, three months were required to produce ten gallons of refined phenol. Over the next several decades, the plant expanded operations to produce chemical intermediates for pharmaceuticals, explosives, dyestuffs, and the first synthetic sulfonation phenol. In 1920, the Barrett Company was incorporated into Allied Chemical & Dye Corporation. The plant's manufacturing was mainly separation and purification of coal chemicals. Over the next three decades, Allied Chemical & Dye Corporation introduced many products derived from coal tar chemicals, including phthalic anhydride and phthalate esters.

In 1954, when Allied Chemical and Dye entered the Nylon fiber business, the first synthetic phenol unit was placed into operation. It was based on the cumene oxidation process and had a capacity of 30 MM lbs/year. The phenol demand grew overwhelmingly in the next two decades as demand for synthetic fibers expanded in this country. Two additional phenol units were built; one in 1960 and a third in 1964. "CP" is the acronym for Cumene-Phenol process. Thus the three phenol units were known as CP #1, 2, and 3. By the early 70's, demand for the coal chemical products, which originally were the backbone of Allied Chemical were now slowing down. Obsolete units which produced xylenes, benzene, phthalic anhydride, naphthalene, cresols, nicotinic acid (Niacin), and quinoline (to mention a few) were shutdown and demolished. Thus, the only process remaining by 1979 was the cumene-phenol process. Phenol capacity was now 600 MM lbs/year, with 360 MM lbs/year of acetone, a co-product in the cumene process. Allied had come to establish itself as a world leader in phenol production. The bulk of the phenol was shipped to its Hopewell, Virginia plant which produces Nylon 6 from the phenol via caprolactam polymerization.

In the early 70's there was a major effort within the plant to develop energy conservation, pollution abatement and efficiency improvements. During the period 1979 to 1981, the plant underwent many changes, including retrofitting of old pneumatic control systems with electronic and digital controls, a far cry from the operator hand control of the 1900's.

The early industrial period in America set the pace for innovation, inventiveness, and mass production. Products were being made not in backyard laboratories or machine shops, but were being mass produced in large factories. Basics for the mass production of materials were lubricating oils and greases, dyes and pigments, leather products, and later on, rubber and plastics. Most of these basic chemicals were derived from coal, plants, oil or animals. These basics were produced crudely; in small, privately owned businesses that tried to keep up with the large mass producing business' demand for the products. All processes were carried out batch-wise, with formulas for many batches being developed by trial and error. Early plants and factories relied on operators to manually run batches. They had to handle liquid, solid and powder reagents and solvents; some of which were quite corrosive and flammable.

Later, semi-continuous processes were developed. Control of liquid, powder and gas flow rates was accomplished by operating valves. To obtain certain conditions for reactions, heat transfer, and separation, operators had to continuously monitor the process (levels, pressures, temperatures, melting/boiling points) and manipulate key hand valves. Product specifications, no matter how crude, still had to be met. Shortly before World War II, pneumatic instrumentation was developed which provided accurate process measurements with remote indication of levels, flows, and pressures. Pneumatic controllers were developed using the already applied "servo mechanism" theory of electronics and their widespread use took off in post-World War II years. Oddly enough, pneumatic controls were being used long before a quantitative technology existed specifically for pneumatics.[1]

The 40's and 50's gave way to electronic instrumentation. Allied's phenol plant had the early electronic controls on compressors and fans. Most of the early electronics were used in relays for switching and alarming. Up until the mid-70's, pneumatic controls dominated, mainly due to their simplicity, reliability and ease of repair. In 1976, a new carbon adsorber vent system was installed at the Philadelphia plant with an electronic sequencer. The sequencer cycled 15 motor-driven valves on the adsorbers. The sequencer panel had a rat's nest of ribbon cable connectors which caused many headaches in tracing down electrical problems. The panel had a lighted display with ability to step through the various sequencing. Programming was done by the manufacturer. Some field problems were encountered with the motor-driven valves not going to their limits and thus throwing off the sequencing.

In 1980, a new caustic soda make-up system was installed with electronic controls. This was the first electronic system in the plant to do multi-loop PID-type control. The low cost and ease of maintenance, accuracy of measurement (electronic transmitters), and no freeze-ups of pneumatic instrument lines were the big pluses of this new system. Later in the same year a larger system was installed on a rebuilt wastewater treatment facility within the plant. The checkout, start-up and operation of this system went very well. Most of the problems encountered were field transmitter freeze-ups and wiring to/from intrinsic safety barrier panels.

In 1981 the plant installed additional sequencers on the CP #2 and CP #3 carbon adsorber vent system. Up until this point, field operators would manually swing valves at prescribed intervals. The new sequencers turned out to be an even more reliable system than the first. The new controller was programmed with a portable programming panel. Sequence programming was easily done by Allied engineers using ladder logic. Problems encountered were with limit switches on the valves due to their "freeze-ups". This problem was resolved by replacing all of the limit switches on the valves with proximity or magnetic types.

Also in 1981, the plant had made the decision to go to a distributed digital control system (DCS) as a trial on a CP #3 distillation column. It had installed a DCS unit which handled up to 16 control loops (8 primary and 8 auxiliary). The existing pneumatic system was retained as a back-up control in the event of failure of the DCS unit. Field switchover of air supply was required to go from pneumatic to digital. The DCS unit could be programmed by a menu-type configuration of control loops. A typical digital computer control loop is shown in Figure 1.[2] Data base was stored on a cassette and loop alarms were logged on a printer. Most of the maintenance was performed by vendor service people. Internal filters and the Mylar keyboard needed replacement. On a semi-regular frequency, the screen would go blank and required controlling on the back-up analog controllers. The reason for the screen blanking out was not determined. However, the system did have to be rebooted in order to restore the digital control.

PLANT ACCIDENT

During the months of January and February of 1982, the phenol business, as well as business in general, was slow. Partial plant shutdowns were contemplated. Then on March 9, 1982 a fire occurred in the CP #1 operating unit. The fire totally engulfed CP #1 and wind carried it into CP #3, causing partial (mostly instrumentation) damage to the unit. CP #2 and the central plant Boilerhouse sustained only minor damage. However, the main process lines and the utilities (250 lb, 50 lb, 10 lb steam, cooling water, fire water, electrical power lines, and instrument air lines) going into and out of these areas were severed, rendering CP #2 and the Boilerhouse inoperable. There was extensive damage to safety systems which included springloaded manheads, relief valves, rupture discs, sprinkler systems, fire alarms, communication systems (phones and public address). Product loss by burning, vaporization and contamination was great.

RECONSTRUCTION

The plant operations came to a dead stop. What was to become of the plant? Could it ever be restarted? Would it ever be restarted? These and many more questions were on the minds of plant employees as well as Allied management. A short term question was asked: what needed to be done in a short time to segregate CP #2 from the damaged areas in order that it may be restarted? The plant was unique in that it had three phenol units all fed by two large reactors, both of which were not damaged. Also, the wastewater treatment facility, the residue handling area, the raw material unloading and finished product loading facilities had sustained little or no damage. Therefore, it was possible to isolate CP #2 from the damaged areas.

The decision was made to restart CP #2. A massive effort was made to isolate the unit to form a "new" plant. Construction of and training on the rebuilt unit was accomplished in record time. By mid-April, 250 lb steam was produced by use of a leased package boiler and CP #2 was restarted.

During the first several months after the fire, the decision to rebuild the partially damaged unit, CP #3, was made. C. E. Lummus was chosen as the design firm which was to provide engineering services to meet Allied's needs. The muscle was provided by the plant maintenance force. The massive decontamination and demolition effort of CP #1 that was required went on side by side with the reconstruction of CP #3. Several criteria were to be met as decided by Allied management. They were 1) the rebuilt units were to have the long range capacity of the pre-fire plant, 2) the rebuilt CP #3 was to have the safest operation possible with adequate automatic shutdown of key equipment, and 3) the rebuilt CP #3 would have state-of-art controls, i.e., a distributed digital control system.

Evaluation of various DDC vendors was made. Foxboro was chosen as the system due to its cost, availability of equipment to start the unit up by November, 1983, and specific features needed by Allied. Some of the features Allied was looking for in the new DDC system were 1) redundant indication and controls required since there was no pneumatic back-up left, 2) redundant power supply to main and back-up controls, 3) redundant processors for viewing the plant through CRT's, 4) intrinsic safety required due to flammable and hazardous chemicals in the plant, 5) programmable control logic needed to handle the complex automatic shutdown of key equipment, 6) a centralized control room from which supervisors can direct almost every operating task, and most importantly 7) a reliable system which would have a high percentage of on-line time so vital to a newly restarted plant.

CP #3 START-UP AND STAGING

During the period of April, 1982 to June, 1983 CP#3 reconstruction was done side by side with demolition of the destroyed CP #1. All the destroyed and damaged equipment had to be accounted for by plant management. This was a tremendous task for those concerned but the most difficult part fell on the unit supervisor's shoulders. Since he knew the unit the best, he had to verify not only all the equipment that was in it but also sample, categorize, and mark each process line for decontamination. At the same time, plant, division, and Lummus people developed a strategy to design, reconstruct, and restart CP #3. At this stage, planning was very important. All control valves and sensors were taken from the unit, cleaned, checked out, rebuilt, reinstalled, or replaced. Process flow diagrams, P&I diagrams, structural, piping and electrical drawings were developed. Piece by piece the unit was reshaped.

The massive wiring and installation of the DDC system was accomplished by electrical contractors, Foxboro service people and plant maintenance people. Installation of the Foxboro SPECTRUM system was begun. The plant was to operate via VIDEOSPECs (CRT display-based microprocessors) interfaced with UCM's (Unit Control Modules - the digital controllers), UFM's (Universal Field Multiplexers - discrete or analog inputs only), and UIO's (Universal Input/Output devices). A redundant system for control and monitoring was installed as shown in Figure 2. Also, a FOX 1/A supervisory computer was installed for the purposes of process graphic display, management reporting, back-up control and monitoring, and potential for "advanced" control. The new DDC system was configured for approximately 150 control loops and 500 indicating loops in the CP #3 operating unit. The UCM's are the heart of the system. Each UCM has the capability of handling up to a maximum of 60 analog inputs and/or outputs, or a maximum of 30 control loops (15 inputs, 15 outputs), or a maximum of 240 discrete inputs and/or outputs. Field signals to the UCM may be 0-20 mA or 4-20 mA (linear or square root), RTD, or thermocouple. In addition, the UCM is capable of having 60 "blocks" configured for control logic. There are 23 different types of blocks and they may be arranged to perform various types of control (see Figure 3). UFM's were installed due to the enormous input capacity; a maximum of 96 inputs per nest with a maximum of 8 nests, or 768 inputs per device. The UIO's can each handle a maximum of 60 analog inputs or outputs, or 60 pulse counters, of 240 digital inputs or outputs, or any combination of the above. The Fox 1/A computer can address almost any parameter on the UCM's and all I/O on the UIO's and inputs on the UFM's. Parameters for which it cannot address directly are pulled in or written to via special FORTRAN programs run on the FOX 1/A.

As it can be seen, it was a huge task to design, configure, document and implement this system. This task fell on the shoulders of only a few people. Foxboro hardware and software experts did aid in setting up the new system. However, there was still much trial and error in configuring the system, and even more in starting it up. From detailed P&I diagrams and flow diagrams came new and rebuilt piping and equipment. Also, from these diagrams came new control logic in the form of capture loop drawings. From experienced managers, engineers, and foremen came new, detailed procedures on equipment start-ups, shutdowns and normal operation.

There was a new outlook on documentation. A new equipment numbering system was instituted. Display and configuration documentation for the SPECTRUM system was well kept. Historical collection and trending of data were to be kept on floppy disk storage for 31 days. Alarm printouts were elaborate highlighting such things as when high and low control limits were reached, when loops were disabled from alarming and when "critical" loops were a problem. Supervisory computer capabilities included monitoring when loops were put in manual from the automatic control mode and monitoring the "health" of SPECTRUM.

With process and computer equipment installation nearing completion, training of foremen and operators was begun. Foxboro conducted both out of and in-plant training courses. The Operations department training group put together a comprehensive program to take operating people wary of a "computer system" to the point of feeling comfortable that the buttons they pushed on the VIDEOSPECs actually caused changes to valves (like the pneumatic systems they had been used to). Training which had started as early as the summer of 1982, was winding down. As equipment was turned over to Operations by construction, various pressure and loop checks had to be performed. As far as instrumentation was concerned, construction had performed the basic loop checks which verified the integrity of sensor to the transmitter, to the I/P, and to the digital I/O device. The final check verified that the VIDEOSPEC was reading the signal and was able to send an output to the field to move the valve to complete the test of the loop. The checkouts of the loops and software continued on into April and May, 1983. Check-outs were made of the redundant controls and indicators, as well as the redundant VIDEOSPECs. Also, preliminary checkouts of the automatic shutdown and interlock systems were performed.

In June, 1983 the control system was nearly complete. The final stage was to introduce water into the processing equipment in order to determine pumping problems, perform some loop tuning, detect leaks, and most of all to get operators familiar with the new distributed digital control system.

Chemicals were first introduced into the rebuilt unit in July, the true test of the new control system. The unit was started up in stages, and DDC system problems were corrected. Hardware problems were minor during this period, but included items such as faulty I/P transducers, out-of-calibration transmitters, incorrect signal conditioning on I/O on the UCMs and VIDEOSPECs, and faulty operator keyboards to name a few. The start-up of CP #3 was successfully accomplished by September, 1983, two months ahead of schedule. The impact of the DDC system on the plant was just starting to be felt. The new control system had greater accuracy of measurement and an ease of tuning of loops which in the past were considered "problems" on the pneumatic system. Figure 4 shows an old pneumatic controller strip chart versus the digital trend of the same control loop. The elaborate safety shutdown system had greatly increased the ease with which the system was shutdown. The unit would shutdown and immediately alert the operators to the occurrence and cause via CRT display and alarm printout. The overall "health" of the DDC system was easily monitored by the systems' engineers and system problems were dealt with in an efficient manner. The time required to analyze and solve a process or control problem was <u>reduced</u>. This was due in large part to the ability to segregate and recombine indicating and/or control loops into a logical display in order to get a better picture as to what was happening with the process. However, the time required to actually manipulate a control loop(s), <u>i.e.</u>, change setpoint or output, or put the controller in manual or automatic mode, is <u>greater</u> for several reasons. One reason is that Foxboro VIDEOSPECs offer only a ramping change in setpoints or outputs. Another reason is that with any DDC system, the operator can access only one loop at a time per CRT, even though he may be able to manipulate more than one loop at a time, as he did with the pneumatic controllers. Figure 5 shows the VIDEOSPEC Area-Group Loop display hierarchy for operator control.[3]

RETROFITTING THE REST OF THE PLANT

In Fall of 1983, the decision was made to retrofit CP #2 and the Boilerhouse with Foxboro SPECTRUM equipment for digital control of the unit. Installing DDC on an operating unit required a different type of strategic planning than did the rebuilt CP #3. The unit had to be staged; initially retrofit two distillation columns (the first two in the train) in the existing CP #2 control room, then retrofit two off-line reactors in the same control room, then retrofit the rest of the reactor section and distillation train, including the wastewater treatment facility with DDC. By April and May, 1984, the two stills and the two reactors were done, respectively, "on the fly". Operations took a short shutdown, retrofitted the equipment, loop checked and restarted with two VIDEOSPEC CRTs located in the existing CP #2 control room. The rest of the unit, including the wastewater facility, was retrofitted during the unit's annual maintenance turnaround in June, 1984. Before the turnaround, the wiring for CP #2 DDC was made to the main control room in order that unit control operations be centralized. By mid-June, the entire CP #2 unit was restarted with the Foxboro SPECTRUM system. One major problem experienced with the retrofit of CP #2 was the relocation of many transmitters and transducers due to space limitations in the unit. A second problem was in integrating the new DDC wiring into the existing (originally installed) electronic controls system wiring of the wastewater facility. Third was the critical coordination of various staging activities between operations, maintenance, project and process engineering, and outside construction groups. A final and difficult task to be accomplished was the training of operators and foremen on the operation of CP #2 on DDC.

In July, 1984, a new VIDEOSPEC system had arrived which was to eventually contain CP #3 controls. These new bays of VIDEOSPECs (type IVs) would have the display and configuration transferred over from the older type VIDEOSPECs (type IIIs) to make room for the Boilerhouse retrofit. By Fall, 1984, through various shutdowns and turnarounds of the three individual boilers, the conversion of the Boilerhouse from pneumatic to an advanced three-level boiler control system was completed. However, not all of the Boilerhouse control and monitoring functions had been transferred to the SPECTRUM system. The boiler safety shutdown system, i.e., flame safeguard, was kept as a series of relays. To monitor the high-speed relays, a sequential events recorder was installed which can monitor and record inputs at a 1 millisecond scan rate. In general, the staging problems of the Boilerhouse operation were similar to those of CP #2. However, one difference was that due to time constraints a large part of the design and implementation of the Boilerhouse DDC configuration was left up to the Foxboro Company. CP #3 and CP #2 configuration was done by Lummus and Allied Fibers Engineering with extensive input from operations and systems engineers. Also, some of the Boilerhouse retrofitting problems were associated with the method to expedite, coordinate and plan which resulted in improper wiring/grounding and incorrect configuration. These caused several "unexplained" boiler shutdowns which were investigated and resolved.

CONTROL SYSTEM MAINTENANCE

From the first day a DDC system is installed, it requires a special kind of maintenance different than that of a pneumatic system. Most of what goes wrong with a DDC system is electronic by virtue of the fact that it is comprised mostly of printed circuit boards, I/O nests and busses, and power supplies. The maintenance group must learn the basic hardware if it is installing the DDC system. However, the more complicated troubleshooting and repair should be left to the hardware vendor or reputable repair service through a service contract. Foxboro service personnel undergo regular training sessions in order to keep up with the latest hardware on the market and software revisions.

At the Allied plant in Philadelphia, the preventive maintenance by Foxboro has been worthwhile. The size of a DDC system dictates the cost of the yearly service contract. Foxboro services run in excess of $100,000 for maintenance on 6 VIDEOSPEC processors with 13 CRTs, 17 UCMs, 8 UIOs, 2 UFMs, the FOX I/A, LINKPORTS, LINK CONTROL STATIONS (LCS), the data highways, and several alarm printers and typers. Other peripherals such as the TEKTRONIX video copiers, the UPS (uninterruptible Power Supply) system, and the KIDDE Halon fire detection and extinguishing system, are maintained by the respective outside service groups. To date, there has not been any unscheduled downtime of the DDC system.

NEW OUTLOOK ON THE CONTROL SYSTEM

Until the beginning of last year only a small portion of time and effort was devoted to making the utmost of the DDC system. At that time, a controls group was organized to begin identifying individual control problems and started developing control schemes to better control the plant. Even prior to the formation of the controls group, a series reactor train level control scheme was developed in order to steady out variations in levels. The steady levels which resulted when the scheme was implemented led to operation of the reactors at higher levels, thus producing higher reaction yields. To date, this one scheme has saved over several million dollars.

Since then, the controls group has designed and implemented advanced control schemes for both distillation trains and has developed a statistical testing of distillation columns to statistical testing of distillation columns to determine their optimum operating conditions. This statistical testing procedure is the topic of another paper to follow.

One other advantage of a DDC system is easy implementation of statistical process/quality control (SPC/SQC). Also, heat (or steam) and material balances may be easily performed. However, these balances are only as good as the accuracy of the metered flows, temperatures, pressures, and analyses. Both balances and statistical calculations may be performed on the supervisory computer with FORTRAN programs.

CONCLUSIONS

In retrospect, a DDC system can definitely monitor and control a plant better than a pneumatic system. In summary, a comparison of a pneumatic and a digital control system is shown in Figure 6. A well designed and installed DDC system can immensely benefit a plant by saving energy, improving yields, and increasing production rates. The better process control, the steadier operation will be the end result with a minimum of downtime.

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2. Deshpande, Pradeep B. and Ash, Raymond H., "Elements of Computer Process Control with Advanced Control Applications:, ISA, 1981.
3. "Display Hierarchy", Fig. 2-1, Foxboro VIDEOSPEC Manual, p. 2-2.

FIGURE 1

TYPICAL COMPUTER CONTROL SYSTEM

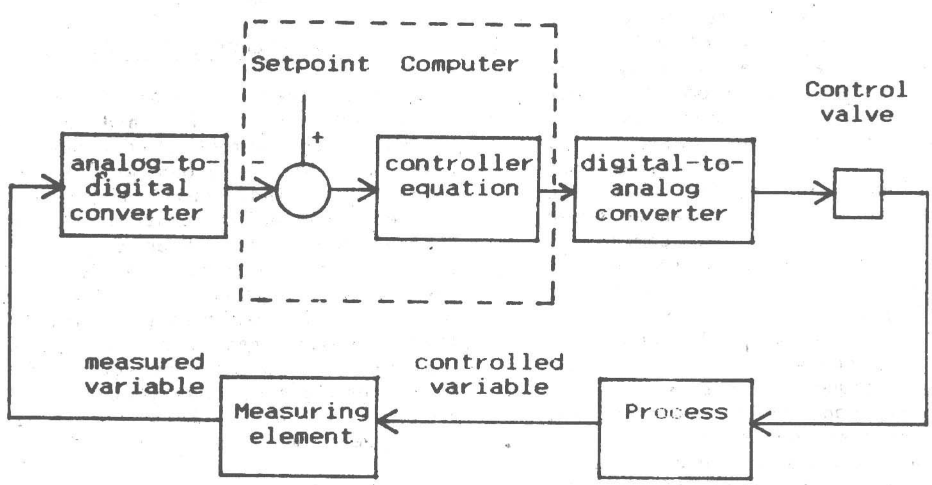

FIGURE 2

FOXBORO SPECTRUM SYSTEM FOR CP#3

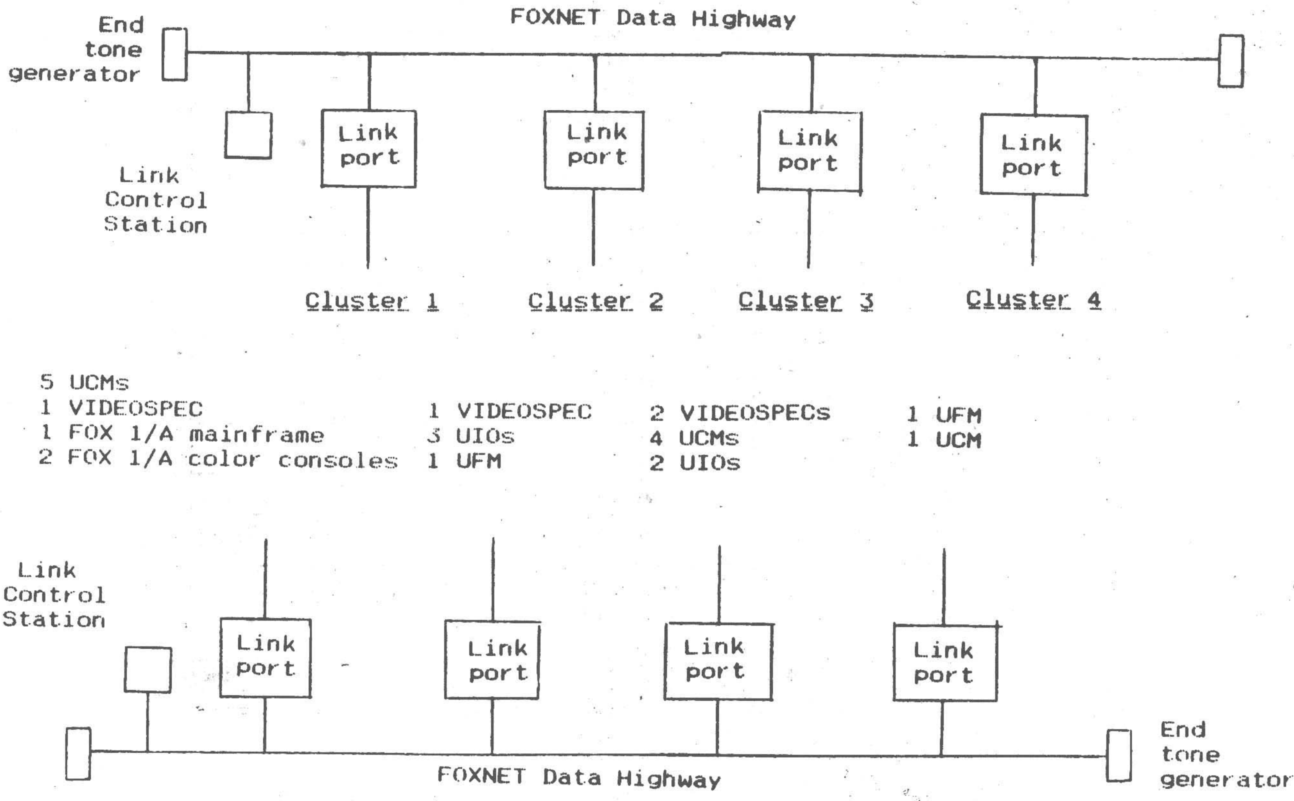

FIGURE 3

UCM BLOCK TYPES

CONTROLLERS

PID	PROPORTIONAL-INTEGRAL-DERIVATIVE
PID-NONL	NON-LINEAR (PID WITH EXTENDER BLOCK)
DGAP	DIFFERENTIAL GAP
INT	INTEGRAL

INPUT AND CONVERSION

AIN	ANALOG INPUT
PCIN	PULSE COUNTER INPUT
AMB	AUTO MANUAL AND BIAS
ACUM	ACCUMULATOR
CHAR	LINEAR CHARACTERIZER
ALRM	ALRM

LOGIC

DIN	DIGITAL INPUT
DOUT	DIGITAL OUTPUT
SEQ	SEQUENCER
GATE	GATE

DYNAMIC COMPENSATION

LLAG	LEAD/LAG
DTIM	DEAD TIME

COMPUTATIONAL

CALC	CALCULATION
SUM	SUMMER
RTIO	RATIO

TIMING AND SELECTION

TIMR	TIMER
SSEL	SIGNAL SELECTOR
SWCH	SWITCH
RAMP	RAMP

FIGURE 4

CUMENE RECOVERY COLUMN OVERHEADS
FLOW - PNEUMATIC STRIP CHART VS.
DIGITAL TREND