THE USE OF COMPUTER GRAPHICS FOR PEPSE ANALYSIS

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ABSTRACT

Computer graphics provides the man-machine interface between human analytical conceptualizing and tedious, repetitive arithmetic. The PEPSE computer graphics of an electrical generating unit thermodynamic cycle is an excellent example of this man-machine interface applied to a practical problem.

This paper describes how graphics capability, in conjunction with the PEPSE code, can provide the power station engineer with a tool to analyze, on a periodic basis, the details of the unit's thermodynamic process. Graphic displays of the simple lumped-component and the more detailed discrete-component models are available via teleprocessing to remote CRT terminals or to remote paper plotters. The relative ease of analysis is accomplished through automated data acquisition and user-friendly software packages, which provide for instructional assistance, performance trending, and interfacing with PEPSE models for diagnostic evaluations. The success in automating the performance programs and the PEPSE graphics is dependent on the availability of sufficient, accurate, and repeatable cycle instrumentation with commensurate computer hardware, software, and technical support.

THE DILEMMA OF TOO MUCH INFORMATION

The power plant engineer is responsible for the planning and engineering of power systems and their smooth and efficient operation. This, along with meeting regulatory commitments, imposes a massive burden of computational requirements that far exceeds his resource of time and support personnel. Greatly improved data base/data communications software has shifted an emphasis to more creative and qualitative utilization of computing/communications/data resources to optimize his productivity.

The electronic digital computer has been integrated in various electric power subsystems and control systems for many years. It performs operations according to stored program logic and has an ever growing capacity for storing information. The computer's data processing capability has assisted the engineer in gathering, storing, sorting, and analyzing a vast quantity of data generated during the operation of an electric power plant. Towards that end, in part, process computers were first introduced into power stations. The data gathered by the process computer is quickly transferred to a main-frame computer for post processing and/or to establish a data base which replicates the plant's operating conditions.

The capture of this data (typically 150-250 pressure, temperature and flow measurements) has enabled the performance engineer to evaluate the thermodynamic/hydraulic cycle of the plant and detect potentially defective components. He compares this data to baseline standards, determines the impact on the plant in terms of safety and economics, and makes timely recommendations to plant managers. Having solved the problems of providing accurate plant instrumentation, and acquiring the performance data needed to characterize the performance of the power plant, the analyst must now perform the unenviable task of reducing and analyzing a potentially overwhelming amount of information.

THE AUTOMATION OF PLANT PERFORMANCE DATA REDUCTION

The Steam Cycle Data Manipulation Program is the main-frame computer program which loads data collected by the process computers into long term storage. Plant data is stored in a direct access data set which may be accessed from both central processing and plant locations. The program allows data to be retrieved selectively for analysis or display purposes.

SAS (Statistical Analysis System) software provides the engineer/analyst with a tool for automated data reduction. Using SAS, large amounts of plant data may be screened without tedious FORTRAN type programming. Standard statistical tests can be performed to identify irregular data and evaluate the relationships between specified data groups. Report writing and trend plotting are accomplished through simple SAS procedures. Trend plots provide a visual cue to the stability of plant data groups without requiring many hours of manual data reduction. However, caution still has to prevail in the interpretation of "trends".

The Steam Cycle Report Program provides another form of automated data reduction. Plant data is screened based on the power level of the plant at the time that the data was collected. Statistics are calculated for each data point using many days or weeks worth of screened data. The results of the calculations are compared to baseline standards to provide a meaningful evaluation of the plant's performance status, again without the requirement of locking the performance engineer into days or weeks of data reduction.

After the plant data has been analyzed as described above, computer simulation models are employed to provide a more detailed performance analysis of plant efficiency and heat rate during suspected off-design power plant operation.

THE USE OF COMPUTER GRAPHICS FOR HEAT BALANCE ANALYSIS

PEPSE (Performance Evaluation of Power System Efficiencies) heat balance simulation models are available for plant performance analysis at various technical and administrative levels. The PEPSE code has not been well received outside of performance engineering groups because it is an engineering tool that requires a depth of understanding and familiarity not normally akin to a casual user.

This heat balance code has a great degree of flexibility and it is this extreme flexibility that can lead the unwary modeler astray. It is also apparent that the potentially voluminous amount of output data generated during a PEPSE analysis can be overwhelming to the PEPSE user.

Humans are challenged by what seems almost within their comprehension and reject or are bored with whatever eludes their grasp. PEPSE graphics is an example of the former and the PEPSE hardcopy printed output can be an example of the latter.

One of the most natural and effective modes of communication is through pictures. Pictures convey information directly through shapes, patterns, shades, and colors. Bela Julesz of the Bell Telephone Laboratories has shown that given a degree of order or redundancy, computer-generated patterns can enhance human communications. This theory has been applied to enhance the performance engineer's comprehension of the voluminous PEPSE output. It also provides a method of supplying power plant personnel with access to extremely detailed and complicated heat balance models.

PEPSE graphics rely on the image of a functional diagram of the power plant to communicate component and piping relationships. This diagram is generated using computer aided design (CAD) software.

The PEPSE Graphics Design Program is an interactive program which uses the Graphical Data Display Manager (GDDM) to create a power plant diagram. GDDM is an IBM software package which consists of a set of subroutines. These subroutines provide the ability to draw the diagram on a color CRT terminal as it is created. The relative positions of PEPSE components and streams are established by moving the terminal cursor to the desired locations. Cursor locations are translated into diagram coordinates, which are then saved in a data set along with other diagram information. This data set allows the diagram to be redrawn whenever necessary.

The PEPSE code is run as a batch job on a main-frame computer. The user of the PEPSE code may submit the job and view the printed output through the Time Sharing Option (TSO) network. The TSO network, which includes the color CRT terminals, is the communication link to the power plants.

Through the use of an output subroutine which has been added to the PEPSE code, a data set(1) (B) containing the results of a calculation is created. This data set is placed on permanent storage and can be recalled at any time without having to rerun the analysis.

The PEPSE Graphics Display Program merges data sets (A) and (B) to produce a power plant diagram with heat balance results printed at specified locations. The program uses GDDM subroutine calls to display the diagram on a color CRT terminal.

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(1) An example of this data set is presented in APPENDIX II.

The user of the PEPSE Graphics Display Program may request a hardcopy print of the analysis, for inclusion in a report or for documentation, by simply pressing a key on the computer keyboard. The program uses Versaplot-07 subroutine calls to produce the hardcopy prints on VERSATEC plotters. Diagram 1 is an example of a typical lumped-component display for a typical nuclear unit. This simple visual presentation of the power plant heat cycle has been well received on technical and administrative levels and has helped bring heat balance models into the plant environment.

The large discrete-component PEPSE models can also be displayed on a color CRT terminal. The entire power plant diagram is first displayed without heat balance results. This analyst then moves the terminal cursor to the desired location on the displayed diagram and specifies a magnification factor. This allows the analyst to "zoom-in" on the plant diagram. At the desired magnification, the heat balance results are written to the diagram. Hardcopy prints corresponding to the terminal displays may be produced as needed. Diagrams 2 and 3 are examples of discrete-component displays for a typical nuclear unit.

The results of the PEPSE calculation are printed next to the stream or component on the diagram to provide the quantitative relationships necessary for any analysis. Hardcopy plotter drawn heat balance diagrams up to 35" X 50" of the plant cycle are available for performance analysis. These models have been used to support the development of the plant training simulators and may be used for personnel training in the future.

THE GENERIC STREAMING AND COMMONALITY WITHIN THE PEPSE MODELS

It has been recognized that as performance programs grow, additional personnel will request access and training in the use of the thermodynamic heat balance models. It is also advantageous to provide for maximum flexibility in the assignment of personnel with varied analytical capabilities, who will be expected to resolve a variety of performance problems in a multi-plant environment. This posed a human engineering problem in the early development of PEPSE models(2). The solution seemed to dictate that the graphical layout and component-stream coding of each model be as visually similar (plant to plant) as possible. The fact that each plant was unique in terms of component and piping configuration and energy/mass flows was a limiting consideration to a "generic layout" approach. The concept did prove to be sound in that lumped-component and discrete-component models are readily utilized by engineers, after plant reassignment, without extensive model refamiliarization. The generic component/stream numbering proves additionally instrumental when it is necessary to model the plant in detail. Discrete models have been developed after detailed analysis of plant performance data proved difficult to reconcile using lumped-component models. Discrete models offer the advantage of allowing individual design mode condensers and feedwater heaters for detail design studies.

The development of the graphics interfaces is time consuming for a computer support group, and should be considered in the PEPSE model development.

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(2) Credit must be given to Dr. Floyd E. Gelhause of EPRI for his assistance to the authors in the development of the generic streaming concept.

To facilitate the ease of model development and implementation of new applications, a generic methodology has been developed and utilized in the following areas:

1. Primary Side Modeling.

   A generic primary side, PWR model, is available and will be made plant specific for each plant as time and personnel permit.

   A generic fossil boiler is available and will be developed as time and personnel permit.

2. Steam Generator Interface.

   A steam generator model has been developed in-house to analyze the effect of tube plugging and sleeving on Millstone Unit II. It may be incorporated into the PEPSE code as time permits.

3. Secondary Side Modeling[3]

   A generic secondary side model has been developed and made plant specific for each nuclear plant.

   The secondary side is divided into Sections A-I.

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(3) To date, the emphasis of model development has been on the secondary side.

The primary flow stream coming from any component will be numbered with its previous upstream components number.

- o Section A "Main Steam Header" streams and components will be numbered 100-199. Even numbers for single stream models.

- o Section B "HP Turbine" streams and components will be numbered 200-299. Even numbers for single stream models.

- o Section C "Moisture Separator Reheater" streams and components will be numbered 300-399. Even numbers for single stream models.

- o Section D "LP Turbine" streams and components will be numbered 400-499. Even numbers for single stream models.

- o Section E "Condenser" streams and components will be numbered 500-599. Even numbers for single stream models.

- o Section F "Initial condensate" streams and components will be numbered 600-699. Even numbers for single stream models.

- o Section G "Low Pressure Feedwater Heaters" streams and components will be numbered 700-799 models. Even numbers for single stream models.

- Section H "Forward Pumped Feedwater Heaters" streams and components will be numbered 800-899 models. Even numbers for single stream models.

- Section I "Output Components" Development of primary side models, numbered 900-999.

The generic numbering and streaming methodology facilitates the rapid development of lumped-component and in particular, the more discrete simulations with multiple feedwater trains and asymmetrical turbine extractions. Calculation results of common systems are grouped together on the printed PEPSE hardcopy output making data comparisons and analysis more convenient. Duplicated components ("A" side stream vs "B" side stream) will be numbered with all even numbers on the "A" side and incremented by 1 into odd numbers on the "B" side. If this seems unnecessarily complicated, consider the ease of developing discrete models by "unfolding" the lumped-component model into a discrete model. A data set representing the lumped-component model can quickly be copied on a computer. The component and stream numbers in the copied data set are incremented by 1 into odd numbers. Missing (new) streams and components are added. The two data sets are merged, producing a discrete model. The generic numbering system has assisted in the development of PEPSE computer graphics.

HEAT BALANCE MODEL ANALYSIS IS ONLY AS GOOD AS THE DATA SUPPLIED

In order to ensure success of a performance program, a utility's top management must commit to fund, support, and sustain a plant wide program dedicated to performance measurement.

The performance program modeling, as described herein, is implemented utilizing an automated on-line computer based methodology directed at acquiring accurate plant performance data from plant process computers on a routine daily basis.

Performance engineers have reaffirmed the necessity of checking and re-checking the calibration of monitored instrumentation. Performance analysis compares daily plant data to "bench marked" or targeted values, which have been established as accepted operating bands (within confidence bounds). The primary problem with this approach is that older power plants have generally not been instrumented specifically for performance monitoring and the present instrumentation does not offer the required absolute accuracy. The best that can be hoped for is acceptable repeatability. Because of the complexity of the regenerative-reheat power plant cycle, the performance engineer has a perpetual task of observation and analysis.

The implementation of any on-line computer-based performance monitoring program will be limited by present plant instrumentation and calibration problems. Statistical analysis software packages have offered a partial solution to analysis problems and when used with graphical displays (graphs, charts, pictorial representations of plant systems) have proven to be an effective communication technique.

The success of this performance program is the result of dedicated central office technical specialists working closely with power plant staffs.

SUMMARY

Northeast Utilities Service Company (NUSCO) is currently using PEPSE to perform heat balance calculations of its three (soon to be four) nuclear plant thermal cycles. Repetitive calculations such as these are impractical to perform by hand because of their long tedious nature.

Plant performance data analysis computer programs have been developed for each of the nuclear plants. The in-house developed computer assisted graphics trending programs provide the capability to identify abnormal step changes or slowly deteriorating performance for major components throughout the turbine cycle. Analysis of the results are available in multi-color graphics displays to enhance comprehension and utilization by engineering and plant personnel. Computer programs allow the use of actual plant parameters to be used as PEPSE input data. The PEPSE Program is used to analyze the data and generate output data. This output data, the results of the data analysis is then available for display via computer generated plots, CRT displays, and hard copy printout. Special graphics are also available for the display of PEPSE results.

The need for accurate plant instrumentation cannot be overstressed. Until utility economics allow for the proper instrumentation of power plants, the performance engineer will have to depend on costly repetitive recalibrations of critical instrumentation presently available within the power plants. By using statistical analysis methods the plant performance engineer has been able to utilize existing instrumentation repeatability in place of absolute instrument accuracy.

By the use of PEPSE and its associated computer generated graphics programs, the power plant engineer has been provided with the tool to analyze, in detail, his unit's thermodynamic cycle. This provides him with the ability to quickly assimilate and interpret massive amounts of plant performance data in order to

diagnose cycle abnormalities or problems and determine whether they are actual or potential. It also allows the plant engineering staff to perform economic analysis on specific plant systems to determine correct maintenance actions in order to optimize plant performance.

APPENDIX I

THE ECS 370/3033 COMPUTER SYSTEM

The Engineering Computer Center located in the Berlin Complex, consists of three main CPU's, about 100 disk drives, ten tape drives, a laser printer, a microfiche card producer, as well as several line printers and graphics (color and non-color) devices. There is also teleprocessing hardware to provide support for both local and remote processing. The CPU's are IBM's 3033MP (two 3033U's with additional multiprocessing hardware enabling them to run completely separate, together as one, or separately, but sharing each other's memory) and IBM's 3083J. Normal operations have the 3033MP running IBM's MVS operating system and the 3083J running IBM's VM operating system (with MVS running as a guest operating system). Most users utilize the TSO interactive processing on the 3033MP MVS system as well as the BATCH facility on both the 3033MP and the 3083J MVS systems. The software development section with Engineering Computer Services has recently started some development on CMS (which is the interactive system for VM). Both the MVS systems communicate with each other, pass data back and forth, and share disk drives. The VM system has limited communication with the MVS system on the 3083J, but does not share any disk drives with it. All remote teleprocessing is handled through the 3033MP MVS system.

This large multi-computer environment has facilitated the development of the performance programs through automated data processing, thus, relieving the engineer from the tedious, time consuming reduction and processing of data.

APPENDIX II

PEPSE OUTPUT DATA SET USED TO PROVIDE GRAPHICS DATA

Millstone Unit II Detailed Model Streaming

A=STREAM NUMBER

B=MASS FLOW

C=START TEMPERATURE

D=END TEMPERATURE

E=START PRESSURE

F-END PRESSURE

G=START ENTHAPLY

H=END ENTHAPLY

A	B	C	D	E	F	G	H
100	11802957.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
102	11802957.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
104	0.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
106	11801457.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
108	1500.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
110	5702038.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
111	5702038.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
112	5702038.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
113	5702038.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
114	5696336.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
115	5696336.	515.092	515.092	778.560	778.560	1196.5000	1196.5000

116	5900729.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
117	5900729.	519.783	519.783	811.000	811.000	1196.5000	1196.5000
118	2821.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
119	2821.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
120	2821.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
121	2821.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
124	198691.	519.783	519.973	811.000	805.323	1196.5000	1196.5000
125	198691.	519.783	519.973	811.000	805.323	1196.5000	1196.5000
126	198691.	518.973	518.973	805.323	805.323	1196.5000	1196.5000
127	198691.	518.973	518.973	805.323	805.323	1196.5000	1196.5000
128	0.	518.973	518.973	805.323	805.323	1196.5000	1196.5000
129	0.	518.973	518.973	805.323	805.323	1196.5000	1196.5000
130	24049.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
131	24049.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
132	12000.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
133	12000.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
134	12049.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
135	12049.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
136	9600.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
137	9600.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
138	2400.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
139	2400.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
142	750.	519.783	519.783	811.000	811.000	1196.4999	1196.4999
143	750.	519.783	519.783	811.000	811.000	1196.4999	1196.4999
144	4800.	396.198	396.198	236.730	236.730	1119.7874	1119.7874
146	5702.	515.092	515.092	778.560	778.560	1196.5000	1196.5000
147	5702.	515.092	515.092	778.560	778.560	1196.5000	1196.5000

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999 944.670 9681.

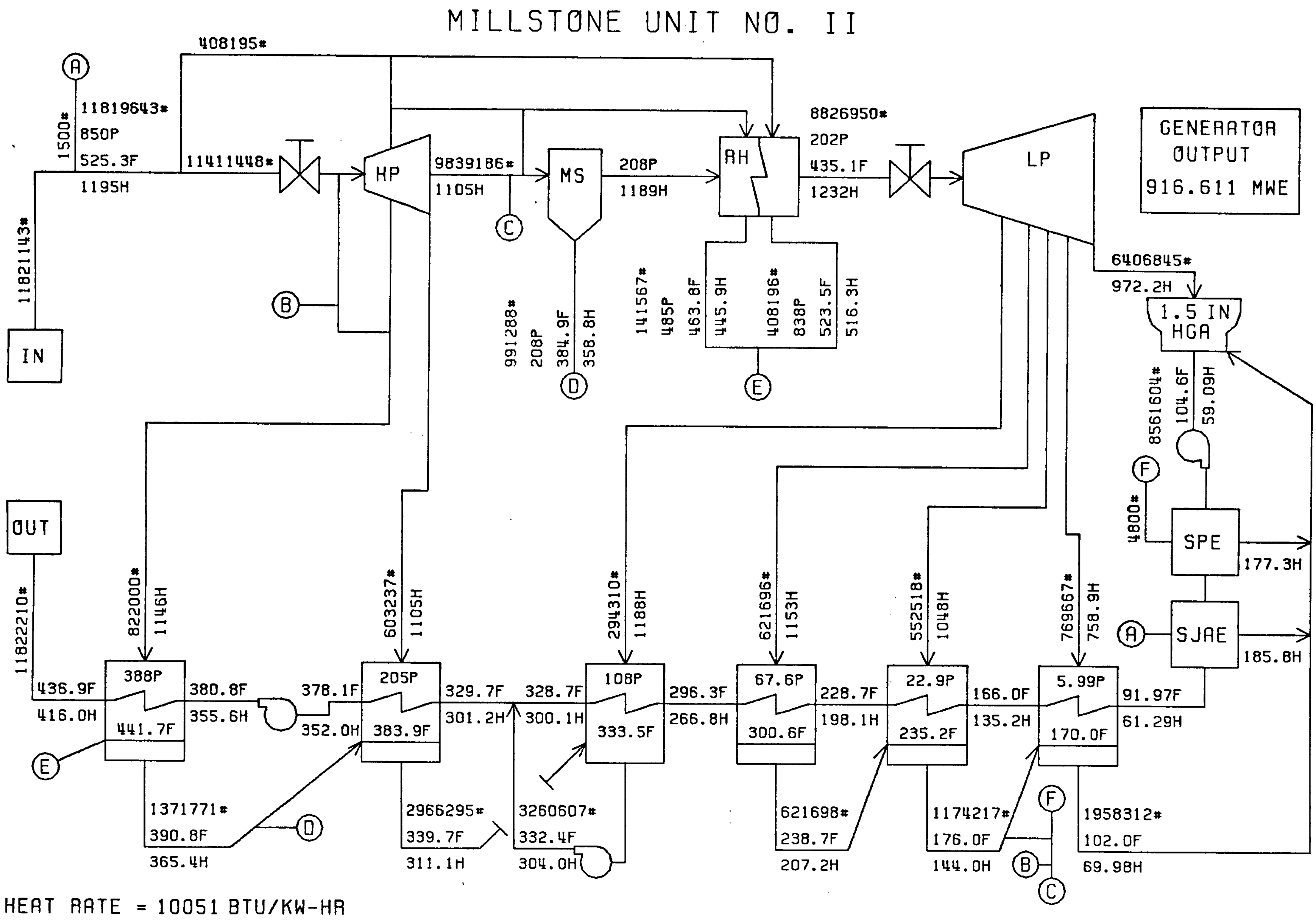

Diagram 1: Lumped-component display for Millstone Unit II

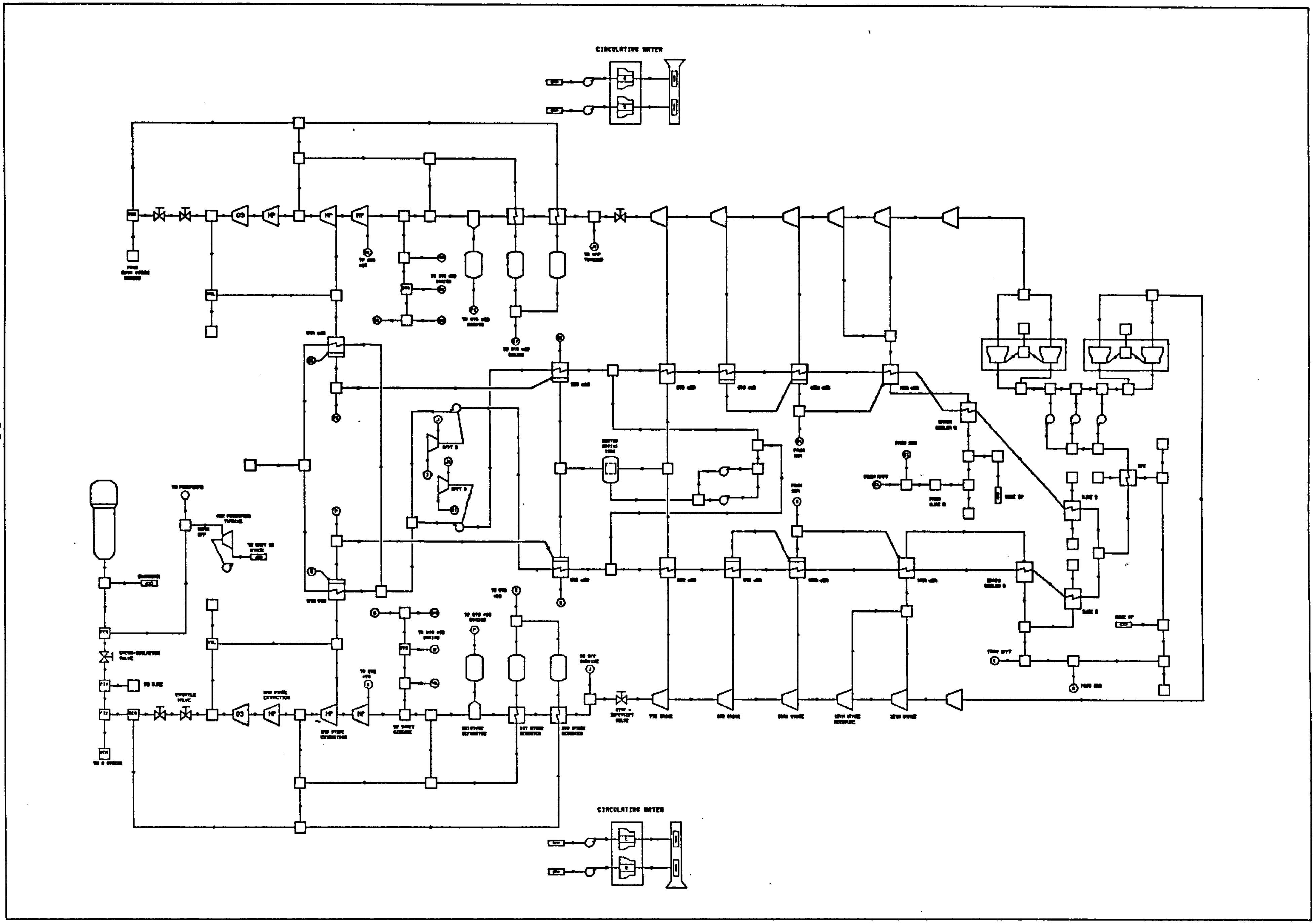

Diagram 2: Discrete-component display for Millstone Unit II, magnification = 1

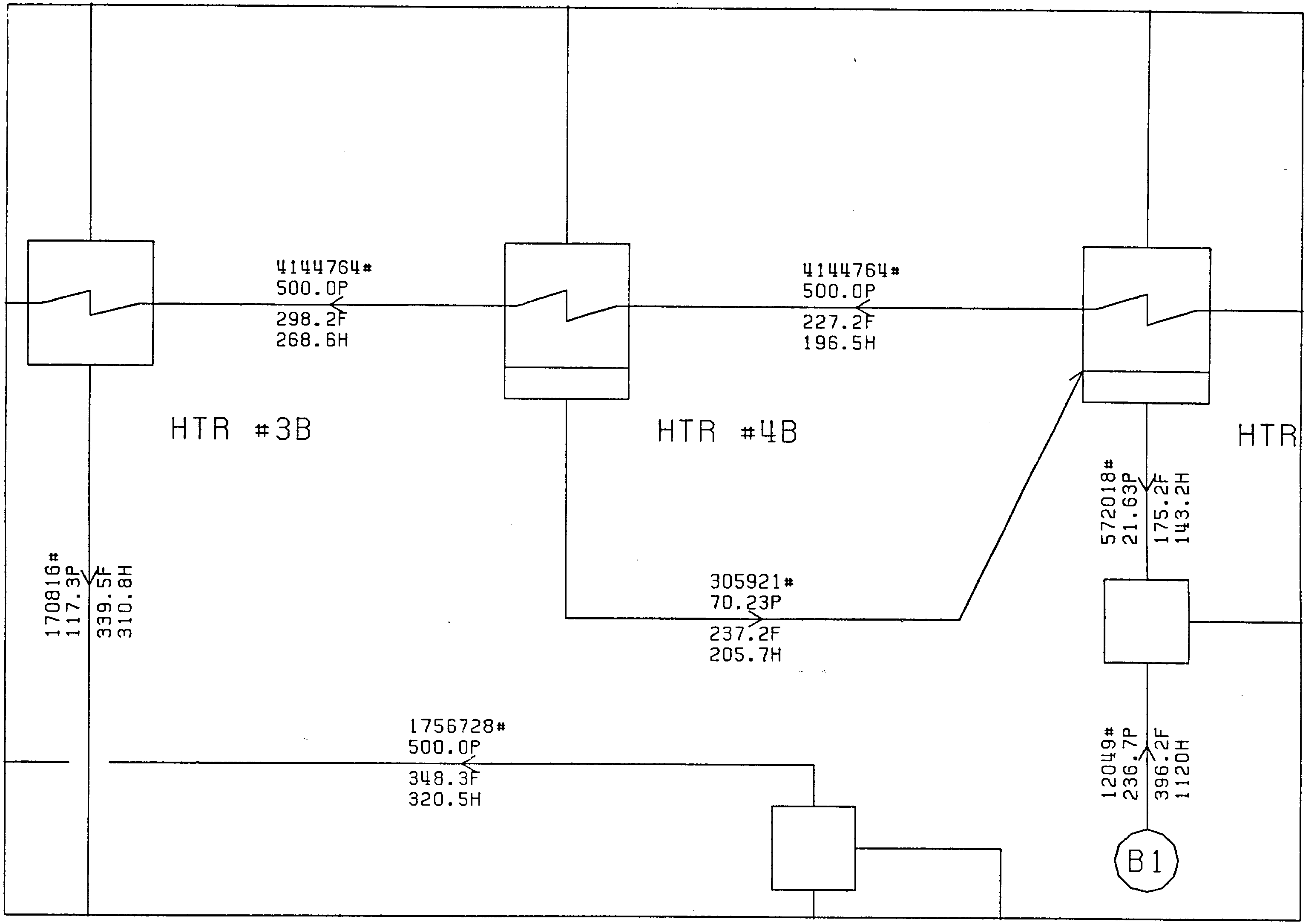

Diagram 3: Discrete-component display for Millstone Unit II, magnification = 8