BROWN BOVERI

REVIEW

7

July 1986
Volume 73

A new oscilloscope prints out curves in seconds

How our supervisory network control systems manage energy

Planning pipework packages for power plants

When are district heating power plants really cost-effective?

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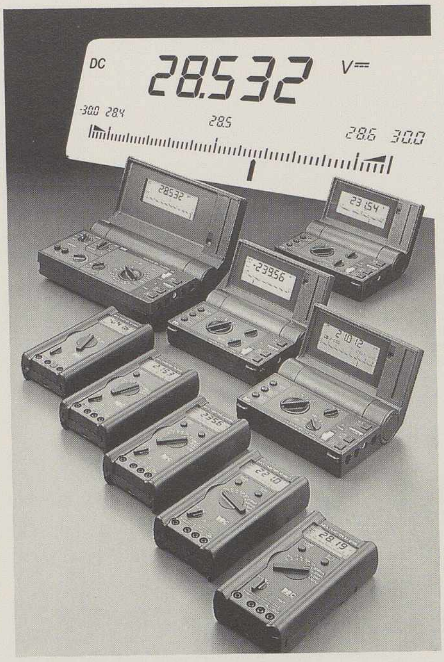

Cover:
A precise digital display and high-resolution analog scale—dominant features of a new series of 5 hand-held and 4 bench-top multimeters from Metrawatt. On-the-job requirements such as exact measurement of fluctuations in measured values in addition to absolute values are satisfied by these meters.
The inertialess pointer on the LCD scale is free of parallax and is unaffected by the circumstances of the meter's use and by shocks.

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Brown Boveri Review, July 1986, Volume 73

Editorial

The advent of LSI circuits, and of microprocessors in particular, has given enormous impetus to measurement and control technology.

Brown Boveri were quick to recognize these components' extraordinary ability to endow measurement and control equipment with new attributes. It is therefore not surprising that microprocessors are found in practically all new products brought onto the market by our Group companies Metrawatt and Goerz. Introduction of the new digital technology was speeded up by the professionalism of our engineers, who soon came to look upon work with these systems as daily routine. Our vast experience with analog systems also stood us in good stead, ensuring that equipment with outstanding qualities would evolve.

How, though, is our equipment's performance improved by LSI circuits?

- Its functionality is significantly increased; whereas in the past every additional function required its own analog circuit(s)—and these were often complex—most can be implemented today with software.
- It is considerably easier to operate than before.
- Digital technology offers increased measurement precision. Digital multimeters, for example, feature better data than the earlier, more complex analog precision instruments.
- The potential for rationalization is greater. Measurements, evaluation and documentation are all completed sooner. And manufacturers benefit from a reduced number of hardware variants, particularly for built-in equipment for industry.

The digital storage oscilloscope SE 571 is a prime example of how these improvements can be effectively implemented.

And our multi-transducer GTU 0500 and the modular control system GTR 800 offer qualities which are highly appreciated wherever built-in equipment is required.

The new flatbed laboratory recorder SE 780 also has features made possible by digital technology; attributes such as print-out of measured data and automatic paper transport have considerably rationalized recording in laboratories.

Another outstanding example of the benefits to be gained from technological advances is the new series of multimeters shown on the front cover. These combine the qualities of digital *and* analog precision instruments, whilst also guaranteeing a high level of user-friendliness.

Brown Boveri's commitment to high-tech measurement and control has secured us a leading position in this sector. Scientists and engineers in many countries hold state-of-the-art instruments from Brown Boveri in high regard. And our proven performance and vast experience, as well as the broad spectrum of applications for which our products fit the bill, underline our successful activity in countries the world over.

H. Freiländer
Member of the Managing committee of
Brown, Boveri & Cie. Aktiengesellschaft
Mannheim

Oscilloscope and Oscillograph – A New Concept

Measurement and documentation are the twin features offered by new digital recording instruments from BBC-Goerz/Metrawatt. The company introduced a multichannel transient recorder system with built-in graphics printer already a year ago. In the meantime, their Digitalscope SE 571 (Fig. 1), also with a built-in graphics printer, has arrived on the scene. At the press of a button, this instrument prints out hard copies of the screen image quickly, quietly, cleanly and at minimum cost.

Dr. ***J. Hemetsberger*** *is in charge of marketing of digital recording instruments at BBC-Goerz-Metrawatt. Vienna, Austria*

Signal Displays Past and Present

From time immemorial man has tried to understand nature and put it to use. Fundamental research was accompanied at all stages by ever-improving measurement techniques. Given the simple, mostly mechanical or optical measuring devices available in the past, it is not surprising that only a few quantities could be measured at a time, and then only with limited precision. A major breakthrough came with the advent of electrical measurement. By using sensors which convert non-electrical quantities into electrical signals, it is possible today to measure practically all conceivable quantities with the help of electrical or electronic instruments.

Often, information is required about a physical quantity at a certain instant. Since all processes change with time, the measurement of quantities as a function of time has always occupied a position of great importance in electrical measurement systems.

A variety of measurement principles have been applied over the course of the last century or so. The first instruments used to record signals were basically electro-mechanical, and the urgent need to display and measure rapidly changing processes ultimately led to some truly incredible feats of precision engineering.

Slower processes were recorded using electro-dynamic ink recorders, while more rapid processes could be followed with electro-mechanical oscillographs [1] *(Fig. 2)*. In these, the current to be measured flows through a measuring coil situated in the magnetic field of a strong permanent magnet and carrying a tiny mirror, causing the coil to move as the current changes. The beam of an arc lamp is directed by a simple lens system onto the moving mirror and is reflected from the mirror onto a film moving at constant speed. In this way the film is exposed in accordance with the signal variations. Coil oscillographs were used to record signals up to the kilohertz range.

In 1897 the German physicist Karl Ferdinand Braun published his fundamental work on a method of demonstrating and studying the behaviour of variable current with time. In this work he describes cathode-ray tubes named after him as Braun tubes and their application for recording high-frequency signals [2].

Cathode-ray tubes have undergone numerous modifications over the years. For example, expensive electro-optical systems were developed which had several lenses and tubes with two electron beams for the simultaneous measurement of two signals. The first instruments with electrostatic image-storing tubes became available in the early 1970s, enabling a signal trace to be stored temporarily on a screen without the need for auxiliaries.

Tremendous advances in microelectronics, and particularly in digital technology, have had a fundamental influence on the development of oscillographs. The completely new method of digital signal acquisition, in which a signal is sampled at equal time intervals, began to gain acceptance. A fast analog/digital converter transforms the instantaneous values of the signals sampled into binary data words and stores them serially in a data memory (shift register).

The discrete points on the signal trace so acquired are shifted via the memory *(Fig. 3)*. And the signal is stored in the digital memory in that the trigger system stops the flow of data through the memory. The screen shows the signal trace based on the stored data.

In the so-called 'refresh operation', this procedure is run through cyclically; i.e. a series of single images is displayed.

The Digital Approach

Most of the digital oscilloscopes available on the market today are in effect analog oscilloscopes which have been converted for digital operation. After short intermediate digital stor-

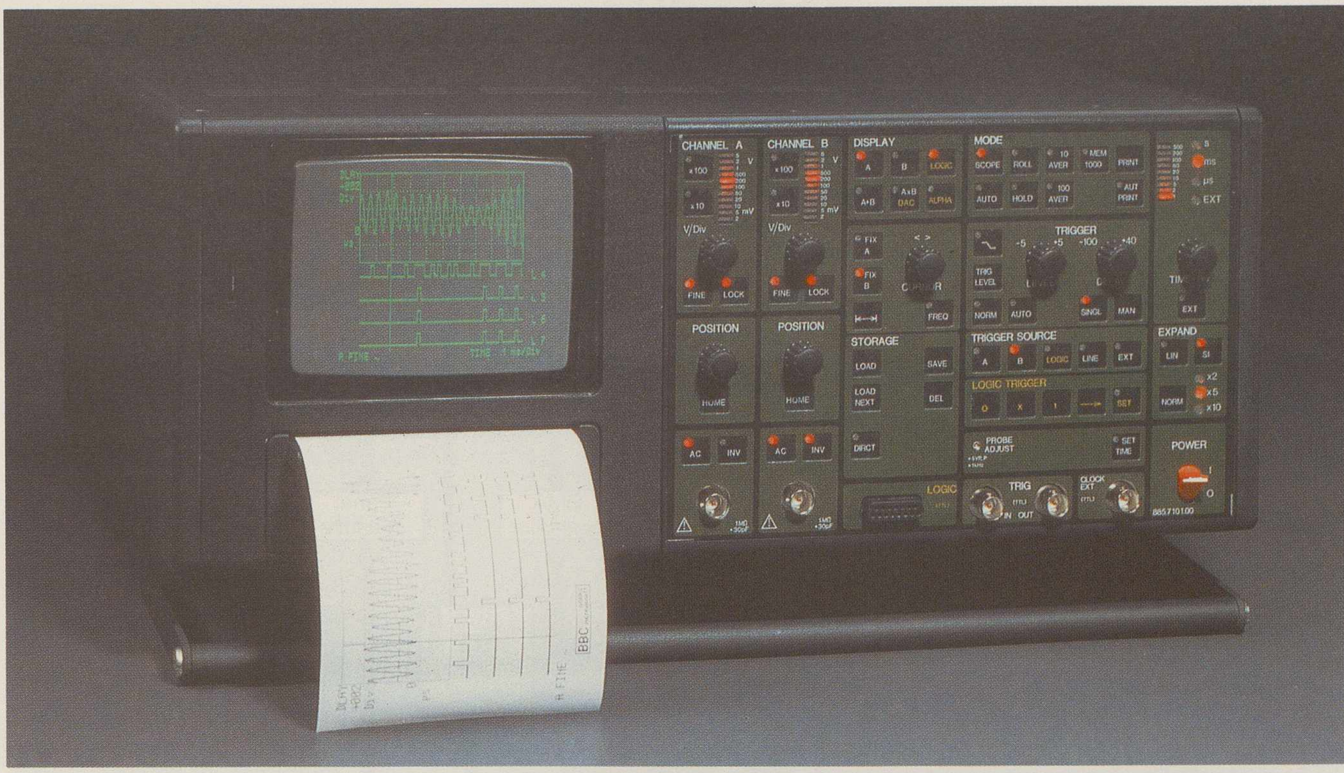


Fig. 1 - Digitalscope SE 571 featuring a built-in graphics printer, autoranging and 8 logic channels

Fig. 2 - Oscillograph with three measuring coils from the early 20th century

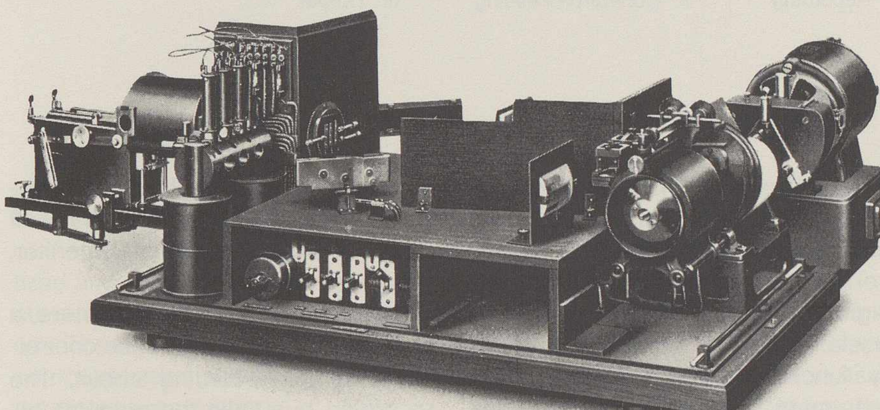
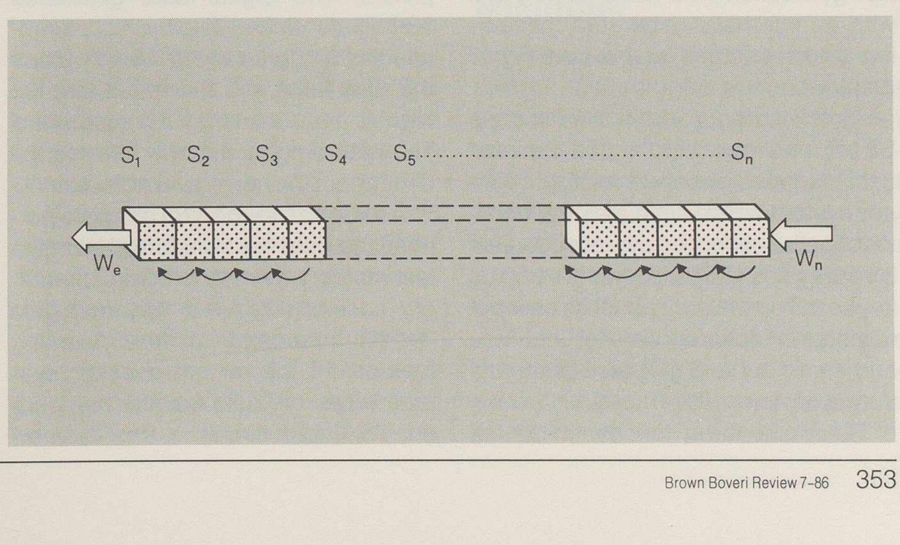


Fig. 3 - Principle of digital signal acquisition with the Digitalscope SE 571

S_n = Memory locations
W_n = Arriving values
W_e = Eliminated values



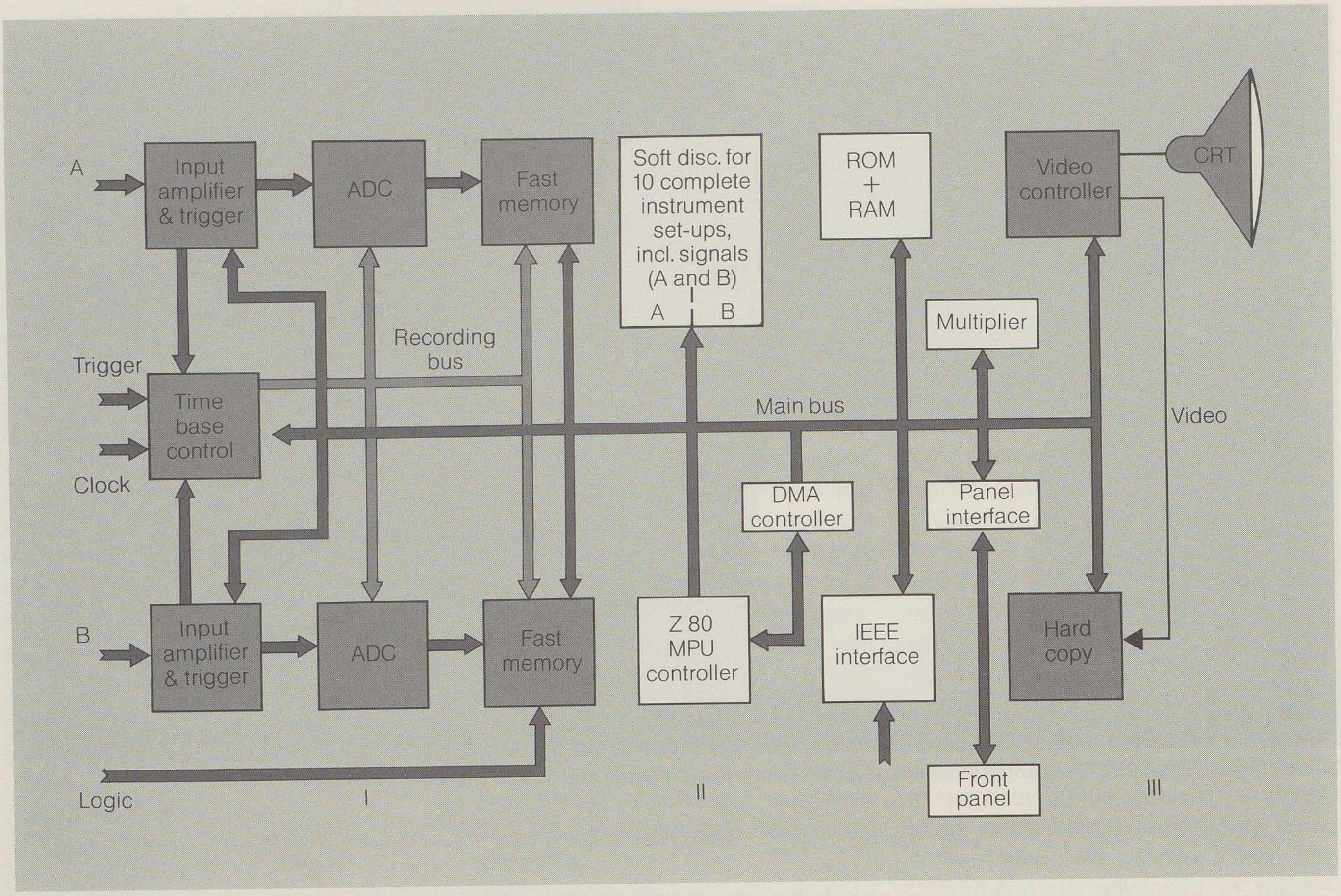


Fig. 4 – Block diagram of the Digitalscope SE571 showing interconnections

I: Recording II: Control/processing III: Output

age, the signals are transformed back into analog signals and processing continues in a conventional way.

The new BBC-Goerz/Metrawatt Digitalscope SE571 presented in this article adopts a different approach by functioning as a purely digital instrument. After conversion, further processing of the input signals is exclusively digital. Functions possible with this concept include numerical averaging, addition, multiplication, interpolation and so on. The digital image generation on a video display unit with an internally generated measuring raster ensures a drift-free signal display.

As shown in *Fig. 4*, the Digitalscope SE571 has replaced the conventional oscilloscope circuit by a microprocessor system which simulates the oscilloscope function. The system consists basically of analog and digital inputs, a keyboard on the front panel as an input device, an optional parallel interface and a monitor and graphics printer as output device.

There are three function modules which work together: the recording circuit, the control and processing unit (CPU) and the output units (monitor, graphics printer).

Input amplifiers, A/D converters, a fast memory and a time-base controller form the recording circuit. The recording bus links the modules together. Except when determining the measurement parameters, the recording process functions independently of the CPU. The signals pass to the A/D converters by way of the input amplifiers. The digital data generated therein are 'shifted' into the fast memory until the trigger system finally stops the data flow, with the result that the signals are 'frozen' in the memories. The recording circuit now informs the CPU about the newly available data.

As soon as the control program permits, the data are transferred from the fast memory by means of direct memory access (DMA)–a very fast data transfer process–to the working memory of the microprocessor system. When the data transfer has ended, the input circuit is free for new signal acquisition. Recording and processing can therefore take place in parallel.

Further processing of the data and their preparation for display is carried out by the CPU (microprocessor system). When the processing has ended, the data are transferred (also by means of DMA) to the video controller during the image flyback. The video controller operates autonomously, i.e. it displays stored signals cyclically until it receives new signals from the control unit. When hard copies are required, the video signal is diverted temporarily to the graphics printer.

Hard Copies for Short-Term Use or Documentation

Although the conventional 'transient' oscilloscope image offers many advantages, it is frequently required to record the signals on paper.

Notwithstanding man's mental ability to store images more or less precisely for a certain length of time, when signal variations are involved he quickly reaches his limits. And in the case of measured signals, it is not only the characteristic variation which is important, but also, for example, the scaling in the two coordinate axes.

Traditionally, images have been recorded by photographing them with the oscilloscope camera. Although the instantaneous developing camera reduced the difficulty of photographing to an acceptable level, the cost per exposure is still relatively high. A more recent trend has been to document the signals on external printers. However, such printers are unwieldy and print-out takes longer.

It is here that the Digitalscope SE571 comes to the fore: its recording device is integrated—there is a very flat graphics printer below the screen *(Fig. 5)*.

The printer, which operates quietly and quickly, is in a constant state of readiness. Output of an image takes about 10 s.

The high cost per image obtained with conventional copying processes and the time they require to produce the images can usually only be justified when the pictures are required for long-term documentation.

Hard copies produced with the Digitalscope SE571, however, cost very little and the graphics printer is so easy to use that the print-out of interim signal traces can be justified as an aid to working. The 'interim images' can be compared repeatedly with values obtained from measurements currently in progress. Although some copies may become superfluous on completion of a measurement, the important function of short-term documentation will have been fulfilled.

The hard copies are, of course, also suitable for long-term documentation, being scaled and containing the date and time of the actual measurement.

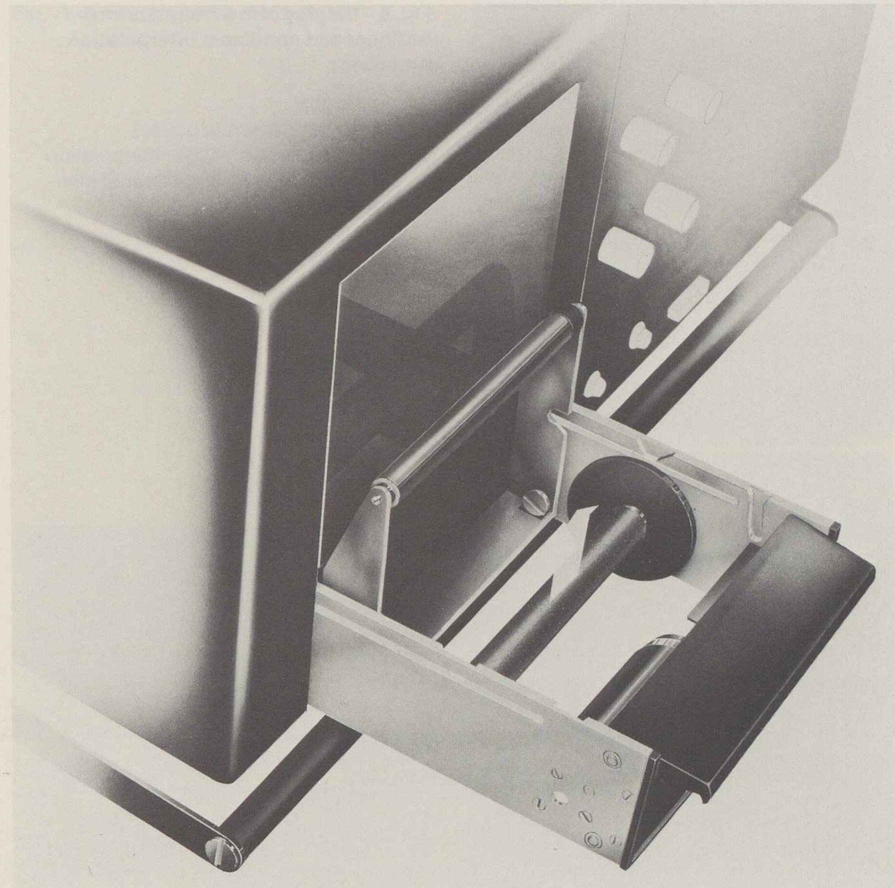

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Fig. 5 - Graphics printer (extended)

'Real-Time Measurement'—The Digital Way

In contrast to the conventional analog oscilloscope where signals are processed by analog means from their input to the diversion of the electron beam in the cathode-ray tube, analog methods are not used beyond the input amplifier in the Digitalscope SE571. The signal is periodically sampled at intervals predetermined by the time base. The instantaneous values of the signal thus recorded are digitized and then stored in an intermediate memory before processing continues. The signals are displayed, as on a computer video screen, by means of the raster-scan method.

Extremely fast image processing leads to the 'live effect' obtained with conventional analog oscilloscopes; continuously changing signals appear to move on the screen, giving the impression of a live image.

What, then, is the advantage of the purely digital architecture of the Digitalscope SE571? The answer is that everything that can be seen on the screen can also be stored, printed or processed.

Many an oscilloscope user has been deterred from employing digital signal acquisition because of the complicated equipment involved.

This hesitation can no longer be justified considering the ease with which the Digitalscope SE571 can be operated. In fact, its operation is so closely allied to that of the familiar analog oscilloscope that special training is unnecessary. And its designers have come up with simple and practically self-explanatory controls for the additional digital oscilloscope functions. Simple operation is not only an end in itself, but also reduces user irritation and costs.

Operation Reduced to a Minimum

When measurements are being carried out, the problems of measurement should be in the foreground, and not the measuring equipment. An instrument is, after all, no more than a tool. It should not burden users with lengthy adjustment procedures, but should provide the required information clearly and rapidly.

The Digitalscope SE571 achieves precisely this: The 'autoranging' function minimizes the effort involved in its operation. At the press of the 'Auto'

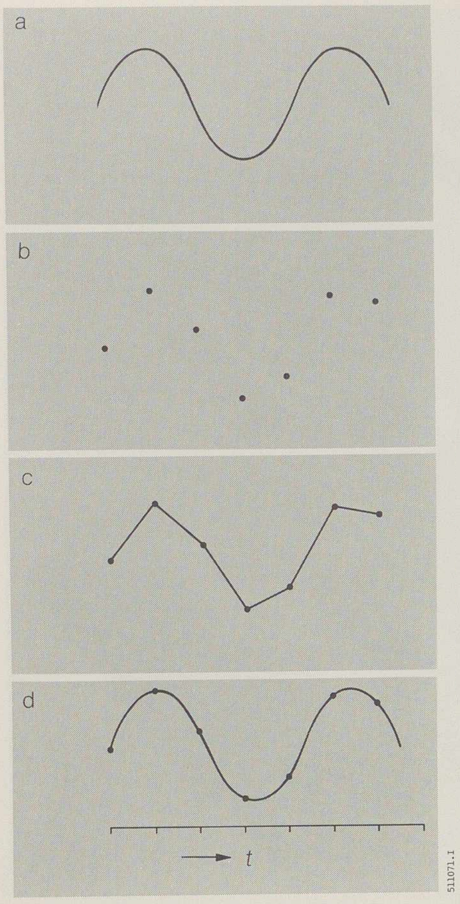


Fig. 6 – Display of input signals based on linear and non-linear interpolation processes

a: Input signal
b: Stored data (discrete points)
c: Signal display with linear interpolation
d: Signal display with non-linear SI interpolation

t = Time

button, the ranges and time base are automatically adjusted to the input signal. Manual adjustment is also possible.

In the ideal case, measurement with hard-copy output proceeds in three steps:

- Connect input signals
- Press 'Auto' button
- Press 'Print' button

SI Interpolation of Effective Storage Utilization

The Digitalscope SE571 does more with the stored data than conventional digital-storage oscilloscopes. Appropriate numerical evaluation of these data not only raises the upper frequency limit of the signal, but also permits storage of longer signal segments.

This statement sounds paradoxical since, according to it, the measured data must contain more than is shown by their simple graphical display—and this is also the case.

With digital signal acquisition, the signal is sampled periodically, with relatively long 'measurement gaps' between the individual sampling points. The stored data thus represent discrete points passed through by the measured signal.

The question now is how to reconstruct the signal trace between these points and to find out the real variation of the signal.

The answer can be found in the adjacent values. The sampling theorem of C. Shannon (1949) [3] provides the basis for calculation of the curve between the discrete points. Providing the signal has a limited bandwidth and the sample rate is at least double the highest frequency contained in the signal, this procedure, which is designated 'non-linear SI interpolation', yields the most reliable curve between the points. The digitizing effects require, in contrast to theory, that the sample rate be set to about 2·5 times the highest signal frequency.

If, when using the Digitalscope SE571, the signals are extended along the time axis, the discrete points of the measured signal will be displayed further apart. The Digitalscope SE571 interpolates the signal shape between these points. Two methods of interpolation are possible:

- Linear interpolation
- Non-linear SI interpolation

In the case of linear interpolation, a straight line connects adjacent discrete points *(Fig. 6)*. Linear interpolation is the simplest method of interpolation and is recommended for use with signals which change abruptly (e.g. square-wave signals).

For sinusoidal signals, the non-linear SI interpolation yields better results. Here, the original signal shape between the discrete points is determined numerically. And non-linear SI interpolation makes far better use of the memory content: reconstruction of a sine curve with linear interpolation requires about ten points per cycle, whereas the non-linear SI interpolation yields the same result for only about 2·5 points per cycle. As less memory is required per signal cycle, longer signal segments can be stored. Put differently, linear interpolation requires ten sampling points for the acquisition of one signal cycle, while non-linear SI interpolation requires the same number of sampling points for the acquisition of about four cycles. In other words, the 'bandwidth' has been increased.

The two types of interpolation possible with the Digitalscope SE571 are not limited to 'frozen' signals, but may also be used by the instrument for 'live' signal display.

Convenience of Two Cursors

To use an oscilloscope for measurement means to follow signals visually. And although a qualitative evaluation of the signals is often sufficient, more precise information is sometimes needed.

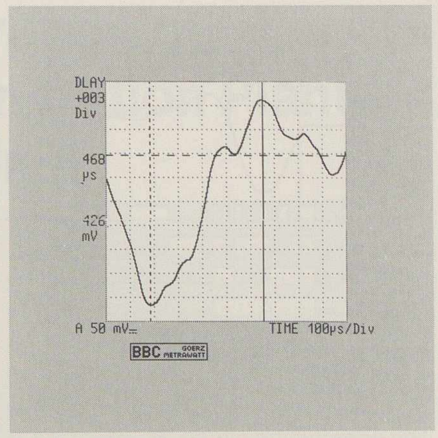
The cursors of the SE571 permit simple and effective measurement of signal parameters. The cursor is moved along the shape of the curve and a point is selected as reference for the measurement. The cursor can be fixed at this point by pressing a button. If the main cursor is moved further, a 'reference cursor' remains at the original point.

The evaluation of a signal with these cursors *(Fig. 7)* yields the following results:

- Time difference between the cursors (or frequency)
- Voltage difference between the points where the reference cursor and the main cursor intersect the curve
- Value of the voltage at the point where the signal intersects with the main cursor referred to zero time

These values are shown alphanumerically on the left edge of the screen.

Fig. 7 - Evaluation with the cursors



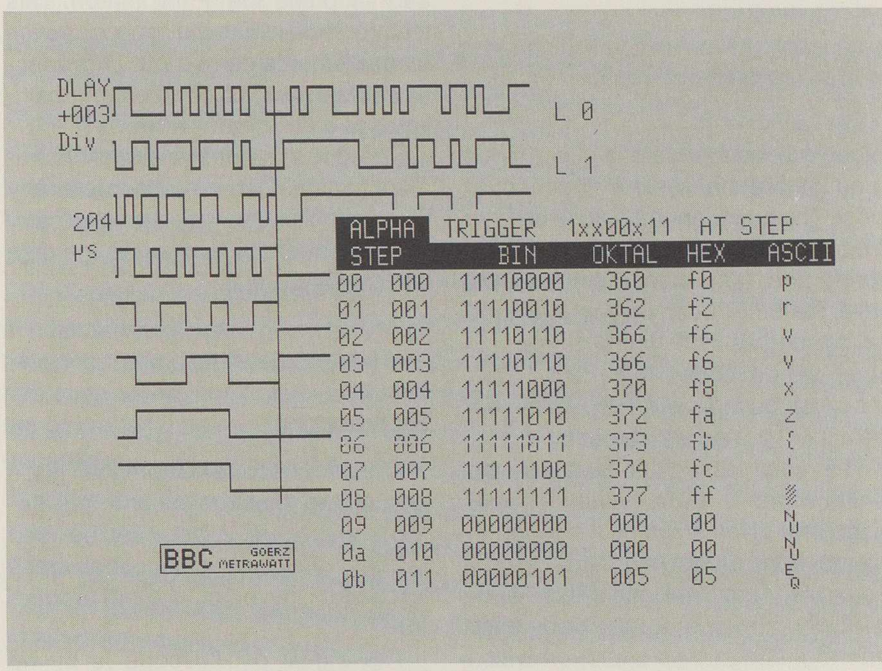


Fig. 8 - Timing diagram and data list of logic signals

Eight-Channel Logic Analyzer

Use of digital signal processing for electronics systems is rapidly gaining in popularity. Digital signals occur everywhere—from consumer electronics to industrial process control. In digital systems, interest is usually focussed on the interaction of several logic signals as a function of time; the precise variation of the individual signals tends to remain in the background.

The capabilities of the Digitalscope SE571 are not limited to the acquisition of analog signals; the instrument is also an eight-channel logic analyzer with a sample rate of 25 MHz. Triggering can be initiated by a sequence of logical states of the digital data in the logic channels. The triggering word is programmable.

The measured data can be presented in different display modes or printed out: The timing diagram *(Fig. 8)*, for example, shows eight square-wave signals. As with the analog signals, the user can extend logic signals on the time axis with this instrument. The cursor considerably simplifies the arrangement of the individual signals as a function of time.

Alphanumeric output of the logic signals is also possible *(Fig. 8)*. The data list contains binary, octal, hexadecimal and ASCII formats.

Also possible is the analog display of logic data. This can be useful for functionally related data, e.g. when testing analog/digital converters.

Analog and Digital on the Same Image

In the logic mode, channel A can be used to measure an analog signal in parallel with the logic measurement. This feature is particularly suitable for investigating the interaction of analog signals and digital processes. A simple example could be the investigation of the effect of supply voltage disturbances on a digital circuit.

Parallel sampling in the analog channel A and in the logic channel ensures the correct time relationship between the measured signals. Either channel A or the logic input may be selected as the trigger source. The Digitalscope SE571 therefore permits logic triggering of analog signals and vice versa.

Once the measured signals have been stored, the user can choose between several modes for their display. One possibility is a mixed display of the analog signal from channel A and four logic signals *(Fig. 9)*.

Automatic Disturbance Monitoring—with Hard Copy

The Digitalscope SE 571 also helps to solve a problem frequently encountered in measurements, namely the un-

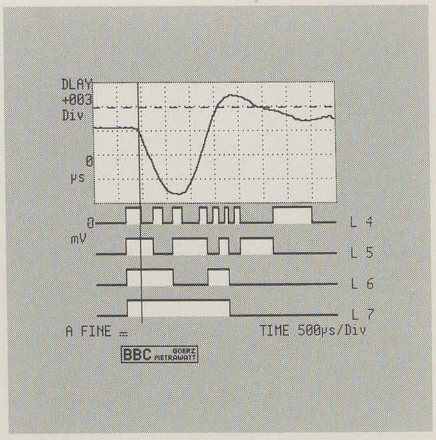


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Fig. 9 – Simultaneous display of analog and logic values

expected occurrence of a disturbance in an installation, system or an instrument. The question to be answered is: What is the cause and what happens during the disturbance? In such a case, the SE 571 can be used to monitor the analog and digital signals; in other words states (e.g. relay positions) can be monitored in parallel with the actual signal mesurement.

The graphics printer built into the digital scope is always ready for operation and gives significant support to the monitoring functions. In the operating mode 'Auto Print', the printer automatically prints out a hard copy each time triggering takes place, on which are included the date and time of triggering.

Monitoring does not require extensive programming; the device is ready for operation simply at the press of a button. Operation of the instrument is automatic. When a measurement has been completed, the instrument is automatically reset and made ready for operation again.

Soft-Disc Storage for Instrument Settings and Input Signals

The Digitalscope SE 571 has a non-volatile data memory. If it is switched off and subsequently switched on again some time later, the instrument settings will be same as when it was switched off. Similarly, stored signals are also preserved when the instrument is switched off.

The instrument also features a large reference memory—the 'soft disc'. This is another non-volatile memory, but with a capacity of ten complete instrument settings. The measured data are also stored.

A standard instrument setting can be activated at the push of a single button. The soft disc is particularly suitable for comparison of the reference and actual values of the input signals. The required instrument settings for the measuring points are loaded sequentially with the reference signal from the soft disc. If the measurement is to be documented, it is only necessary to press the 'Print' button. This feature is ideal for the type of series measurements carried out in production processes, quality control, maintenance and research work.

The directory of the stored instrument settings can be called up at any time on the screen. The data files carry serial numbers in addition to the date and time of storage.

Summary

The oscilloscope is more than just a tool of the electronics and maintenance engineers. In fact, it can be used to observe signals in almost all areas of research, development and production.

The digital oscilloscope is by no means limited to displaying signals, but offers additional functions which significantly expand its area of application. For example, it is possible to store signals in the long term and to process them numerically, as well as to display the pre-history and post-history of an event, etc.

Until now, oscilloscopes were renowned for their lack of documentation capability. BBC-Goerz/Metrawatt have satisfied this need by equipping the Digitalscope SE571 with a built-in graphics printer. A button has only to be pressed and the screen contents are printed out on paper within a few seconds. Measuring with the SE571 means 'copying' instead of 'remembering'. The 'Print' button can be pressed whenever interim print-outs are required due to the low cost of each image.

The Digitalscope SE571 was developed with easy operation in mind: There are no tedious menu commands, no multiple functions, but instead a clear, easily understood operating concept. The user sits down in front of the instrument and operates it in the same way as he would a traditional analog oscilloscope.

By taking over the measuring function, the SE 571 enables the user to concentrate on the measurement problem at hand. One press of the 'Auto' button and the input signals are displayed; one press of the 'Print' button and the signals are available in black and white.

Measurement systems are becoming increasingly automated—a trend which the Digitalscope SE571 takes full account of; an optional IEEE 488 interface can be used for remote control of the instrument and for data transfer.

The Digitalscope SE571 is a future-oriented, multi-purpose measuring instrument offering performance characteristics beyond the ordinary.

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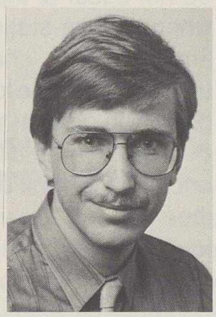
Optimum Design and Operation of District Heating Systems in Cogeneration Plants with Condensing Turbines

Notwithstanding the fact that it improves environmental conditions and saves on primary energy, the full benefit of combined heat and power generation only comes to the fore when all components and systems of the cogeneration power plant are of optimum design, and when optimum process control is assured during operation. The article considers important design parameters, such as the heat-load variation and its duration, which influence the elements of district heating systems, feedwater heating and condensation.

The authors discuss the influence of measures affecting the efficiency, the operational advantages and drawbacks of some thermal cycles, possible and preferred modes of operation as well as some general aspects of optimum heat-output control.



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Introduction

The tasks facing the heat engineer planning a district heating power plant are similar to those he faces when designing a condensing power plant. For example:

- He must design reliable, economically feasible thermal equipment, in this case including the district heaters (DH).
- He must devise a concept for the entire feedwater heating (FH) system and the steam and heater drain systems as a whole.

In addition, he must take account of differences in concept and operation which result from the extreme variation in heat demand over a given period of time *(Fig. 1)*. And he must consider factors such as economic feasibility and the operational safety of both the cogeneration power plant and the district heating system.

In the following, a close look will be taken at the most important relationships and their effects. As the highly flexible plants with extraction/condensing turbines have prevailed, particularly where high heat outputs are required, the article will concentrate mainly on this type of plant. Nevertheless, all significant statements made in connection with these apply equally to plants with backpressure turbines.

District-Heating Turbine Arrangements

The criteria upon which the choice of turbine arrangement, number of DH stages and optimal division of the water-temperature rise between the stages are based have been described elsewhere [1].

Many different district-heating cycles are possible. In addition to the extraction steam from the main turbine, exhaust steam from auxiliary turbines such as the feedwater pump turbines can also be used to heat the district water. Brown Boveri have employed a number of different solutions [2, 3, 4, 5].

Of the numerous possible arrangements, three with extraction/condensing turbines with two DH stages *(Fig. 2)* have been chosen for a discussion of the optimum design of DHs and FH systems. Only a brief look will be taken at the thermodynamic advantages and drawbacks of the actual turbine arrangements. R1, R2 and R3 designate the valves used to control the outgoing temperature of the heating water for a given live-steam flow and given heat load.

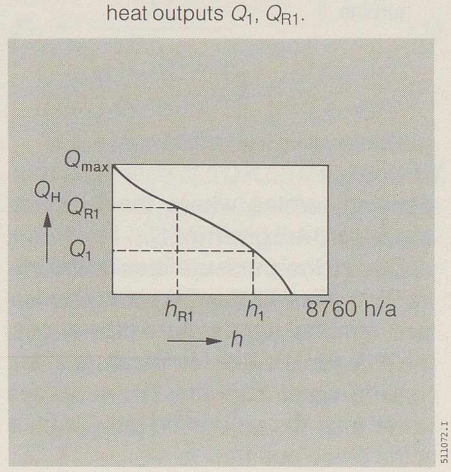
Irreversibility Losses, Loss-Free Points, Definitions

Examples of the natural behaviour of the extraction pressure (ellipse law) at the points on the extraction/con-

Fig. 1 – Classified heat output curve for one year

Operating ranges of a cogeneration power plant, definitions (see also Fig. 2)

Q_{max}	=	Maximum heat output
Q_1	=	Heat output, with lower district heater (DH) no longer bypassed on water-side or throttled on steam-side. When DH stage is not fitted with control valves R2 or R3, point (h_1, Q_1) is omitted.
Q_{R1}	=	Heat output, with higher DH no longer bypassed on water-side or throttled on the steam-side.
$h_{1,\,R1}$	=	Number of hours per year during which plant is operated at least at heat outputs Q_1, Q_{R1}.



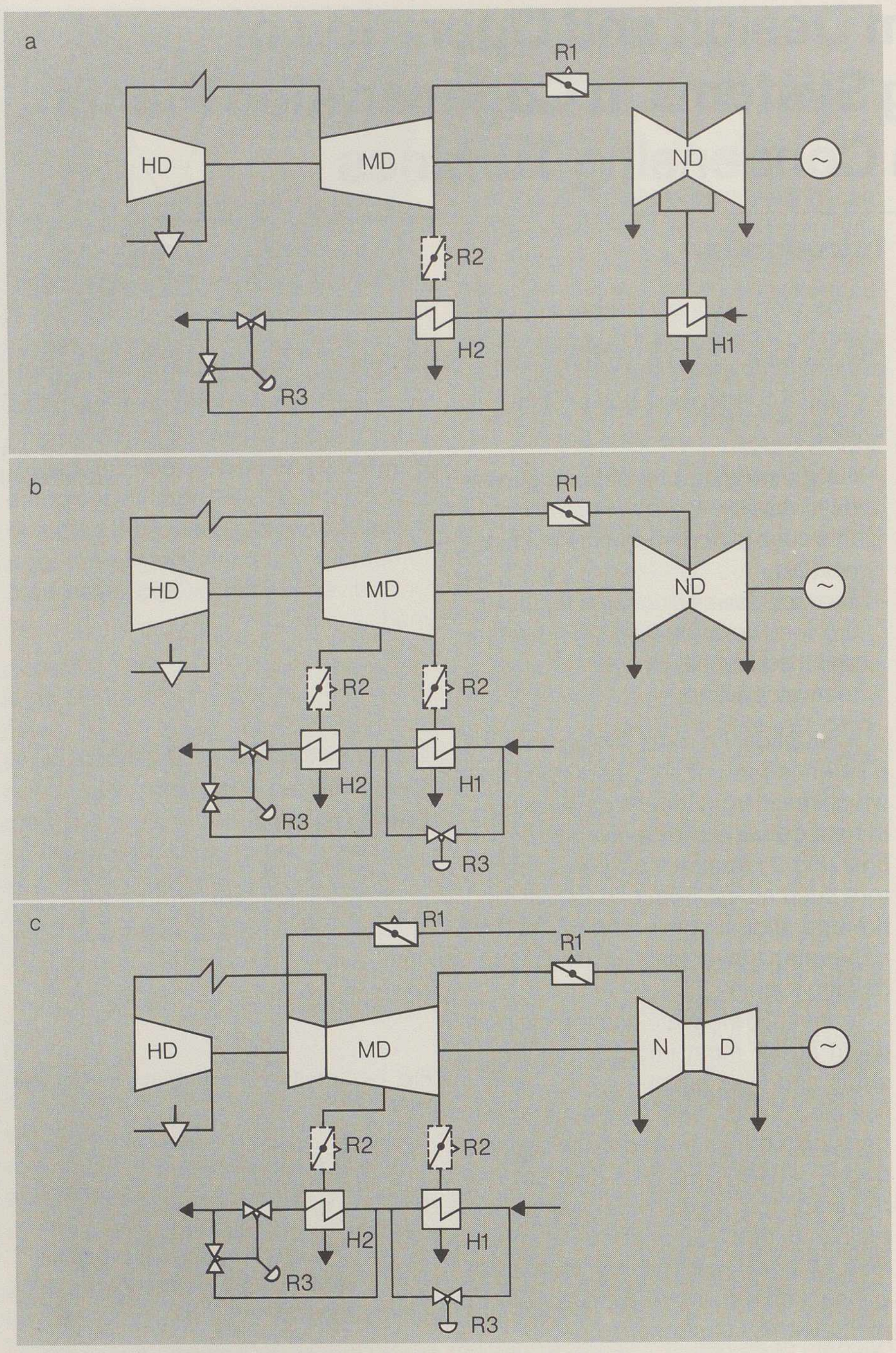


Fig. 2 – Arrangements for extraction/condensing turbines

a: Two-stage heating with extraction from the l.p. turbine
b: Two-stage heating with extraction from the i.p. turbine
c: Two-stage heating with a double-flow i.p. turbine

HD = High-pressure turbine
MD = Intermediate-pressure turbine
ND = Low-pressure turbine
H1, H2 = District heaters 1, 2
R1 = Crossover control valve
R2 = Throttle valve (alternative)
R3 = Control bypass (alternative)

densing turbine where the DHs are connected are given in [1].

Due to the pressure loss in the extraction lines to the DHs and the latters' terminal temperature differences, the attainable outlet temperature of the heating water from any DH is always lower than the saturation temperature at the bleed point.

Irreversibility Losses Caused by Control Actions

Only at particular load points, and these depend upon the turbine design, does the natural extraction pressure result in the heating water at the outlet of the first or last DH having precisely the temperature required for district heating. When heat loads are down and electrical loads are up, this temperature may be too high, in which case it must be reduced to the required value (Fig. 2) either by throttling in R2 or by admixture of cold return water in R3. The loss in electrical output is the same whichever type of control is chosen. In multi-stage DHs, only the lower DH stages remain in operation when the heat load is low; the higher stages are, as a rule, taken into operation (in succession) only at the higher heat loads. The valve R2 or R3 of the DH stage to be connected last controls the temperature, which results in a loss in electrical output; operation of the lower DH stages is not controlled, and is therefore 'loss-free'. When the highest DH stage has reached its 'loss-free' point, the heat output can only be increased by artificially increasing the pressure at the extraction point. (The pressure increase must be slightly higher in arrangements with valve R2 than in arrangements with R3.) The steam continuing to flow suffers throttling and irreversibility losses in the crossover valve R1. It should be noted that the operating ranges which are loss-free and those with output losses do not occur at the same heat output when the live-steam flow and the operating mode change. The criteria used to select the loss-free points for a plant with district-heating turbines are described in detail in [1], so that only brief mention will be made of these in the following.

Irreversibility Losses Due to Heat Transfer

Further irreversibility losses are caused, in a similar way to those arising with FHs [6], by the finite number of DH stages and the finite temperature differences existing between the condensing steam and the heating water.

The number of DH stages is found by optimizing for maximum economy. When large extraction/condensing turbines with a high fuel price are used, three-stage or multi-stage district heating may be economical. Two-stage district heating is a solution which meets practically all economic requirements today.

When the number of DH stages is fixed, the irreversibility losses caused by the temperature difference can be influenced by the choice of heating surface or by the design terminal temperature difference.

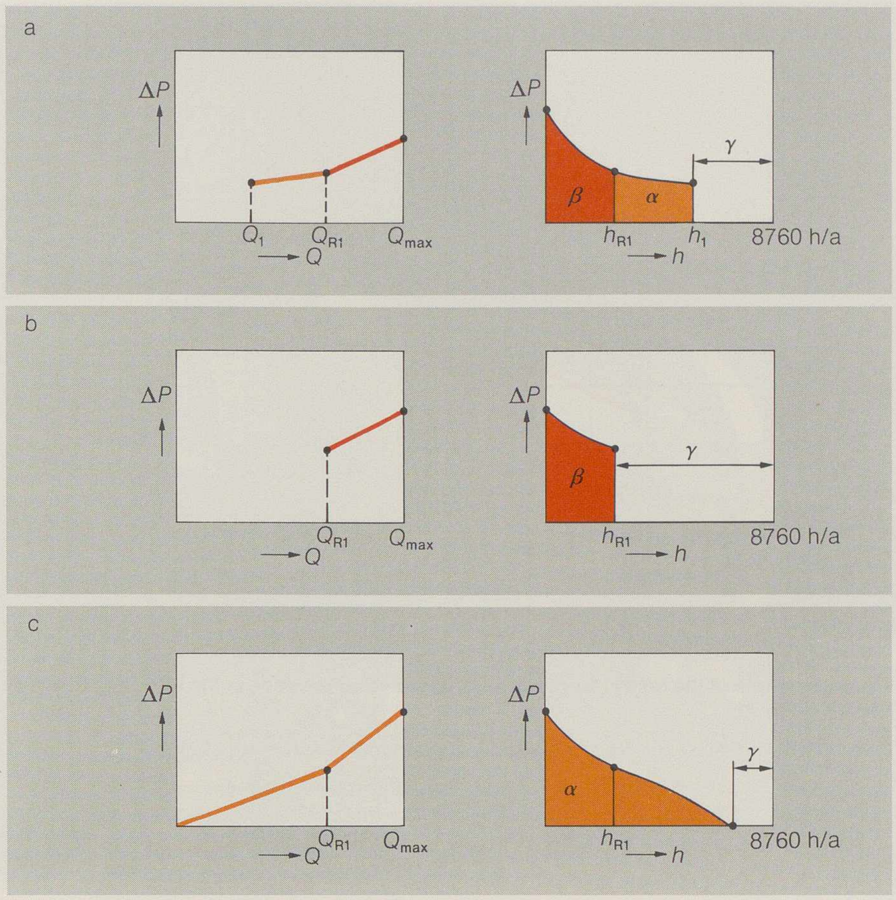
Fig. 3 – Schematic representation of the losses in electrical output of individual district heaters (DH) for a change in the design terminal temperature difference

a: E.g. H1 for arrangement in Figs. 2b and 2c
b: E.g. H2 for arrangement in Figs. 2a, 2b and 2c
c: E.g. H1 for arrangement in Fig. 2a

α = Range in which DH operates loss-free with regard to control actions
β = Range in which pressure is built up in R1
γ = Range in which DH is bypassed on water-side, pressure in extraction line is throttled or DH is no longer in operation

Left: $\Delta P(\Delta\Gamma) = f(Q)$
Right: $\Delta P(\Delta\Gamma) = f(h)$ with reference to heat output curve in Fig. 1

Coloured areas: Energy losses over one year



Discussion of Irreversibility Losses for Turbine Arrangements in Fig. 2

When the number of DH stages is given, the rise in temperature of the heating water in each of the stages depends upon the turbine arrangement and the operating point. Reference is made to Fig. 2 in the following discussion of the different turbine arrangements:

In the arrangement shown in Fig. 2a, the extraction pressure of the DH2 can be controlled via valve R1. The extraction pressure of DH1, however, changes in accordance with the ellipse law for turbines. As the heat demand increases, the heat load therefore shifts increasingly towards DH2. And as more steam is extracted at a higher extraction pressure, the turbine output decreases. The cycle in Fig. 2b behaves in a similar manner: DH2 must be compared here with DH1 in the cycle shown in Fig. 2a. As the heat demand increases, so too does the heat output of DH1. The irreversibility losses caused by throttling in valve R1 continue to rise.

Figure 2c shows a turbine arrangement for low irreversibility losses in the upper heat load range which ensures optimum control of both extraction pressures. This is also one of the reasons why the double-flow, asymmetrical i.p. section is particularly well suited for two-stage district-water heating in large plants [1].

Effect of Terminal Temperature Difference of District Heaters on Electrical Output Losses

The irreversibility losses in the DHs are influenced by the terminal temperature differences chosen for them.

The terminal temperature differences affect the electrical output losses under the following operating conditions:

- At loads in which the pressure in the crossover pipe is increased by throttling with valve R1 (Fig. 1 – range Q_{R1}–Q_{max}).
- In ranges in which the DH operates without control actions by R2 or R3.

The terminal temperature difference affects the limit at which the next-highest DH must be taken into operation or valve R1 must begin increasing the extraction pressure.

To obtain clearly defined conditions for the turbine design, the terminal temperature differences are normally chosen for a loss-free point, e.g. at Q_{R1} (Fig. 1) and at the design live-steam flow of the turbine.

Once a DH has been designed, its terminal temperature difference changes as a function of, among other things, the instantaneous heat load:

$$\Gamma_{TL} = \frac{\Delta t_w}{e^{\frac{k.A}{\dot{M}_w . c_w}} - 1} \qquad (1)$$

The effect of the terminal temperature difference of a DH on the electrical output for a given heat load can be found out quickly with a slightly modified version of the formula derived for feedheaters given in [6]:

$$\Delta P = -\varphi \;.\; \dot{M}_w \;.\; \Delta\Gamma \;.\; T_c \;.\; c_w \;.\; \eta_G \;.\; \left(\frac{\Delta t_w}{T_s^2}\right) \qquad (2)$$

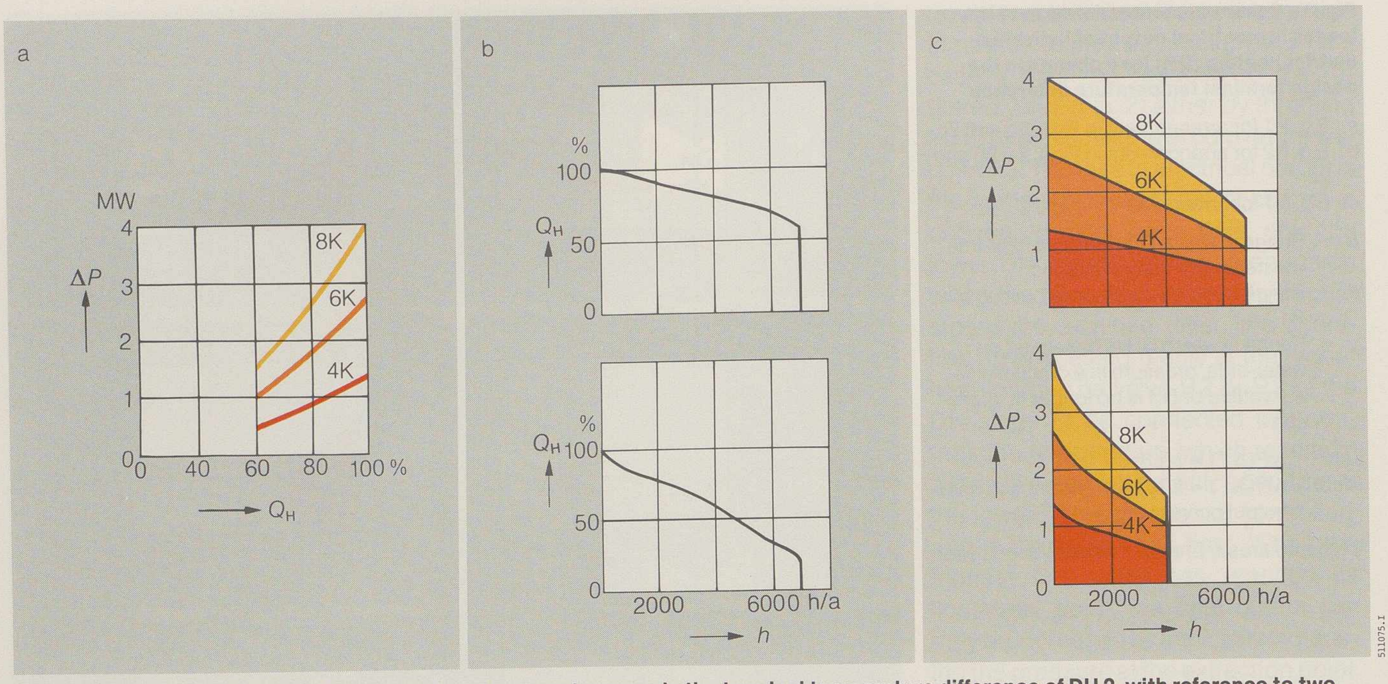


Fig. 4 – Example of the loss in electrical output due to an increase in the terminal temperature difference of DH 2, with reference to two DHs as in Fig. 2c

Maximum electrical output 375 MW, maximum heat output 484 MJ/s; $Q_{R1}/Q_{max} = 0{\cdot}6$

a: $\Delta P(\Delta\Gamma) = f(Q)$ for an increase in terminal temperature difference of DH 2, on the basis of $\Gamma = 2$ K

b: Two examples of classified curves of heat output of a cogeneration plant

c: $\Delta P(\Delta\Gamma) = f(h)$ with reference to heat output curve in b

The area below these curves corresponds to the energy losses over one year.

Figure 3 shows, for the turbine arrangements in Fig. 2, the ranges and curves of the losses in electrical output resulting from a change in the design terminal temperature difference of individual DHs.

As an example, *Fig. 4* shows the actual loss in electrical output when the design terminal temperature difference of DH 2 *(Fig. 5)* in a plant with a double-flow, asymmetrical i.p. turbine (Fig. 2c) is increased. The loss-free point in this case is at $Q_{R1}/Q_{max} = 0{\cdot}6$. If the loss-free point Q_{R1} is chosen such that the relationship Q_{R1}/Q_{max} is, for example, 0·5 or 0·7 other output losses result over the new range of Q_{R1} to Q_{max}.

Criteria for Economically Feasible Cogeneration Plants

When the criteria determining the economical feasibility of a power plant are known, the effects on the heat rate ΔW or on the electrical output ΔP of measures taken to change the efficiency can be capitalized, i.e. converted into a present value ΔK. Thus, the question can be answered as to how fast additional investment ΔI will be amortized. Both the fuel parity a (eqn. 3) [7] and the capital parity KP (eqn. 4) have proved their worth as criteria for the economic feasibility. The fuel parity is the capitalized difference in fuel saving due to improved efficiency, referred to the unit of electrical output, and relates to the differences in investment costs permitted at the time of industrial commissioning:

$$a = \frac{h_{KP} \cdot p_{Br} \cdot W_0}{\psi} \tag{3}$$

The capital parity takes account of the supplementary costs (which the plant utility has to bear) arising during the construction phase, i.e. between signing of the contract and commissioning of the plant:

$$KP = \frac{a}{1 + \xi} \tag{4}$$

If the differences in output ΔP achieved by adopting the chosen measures are correctly determined (a constant fuel input is presumed), the value of ΔK for a given capital parity KP is:

$$\Delta K = KP \cdot \Delta P \tag{5}$$

To ensure that the additional expenditure ΔI is economically feasible, the following condition must be fulfilled:

$$\Delta I_{zul} < \Delta K \tag{6}$$

Various procedures are known for evaluating the economic feasibility of measures changing the efficiency of cogeneration power plants [8, 9].

It may be assumed that the difference in investment cost will influence either the cost of electricity (COE) or the price of the generated unit of heat.

A simple and yet practicable evaluation is possible when the following is considered:

- For the same fuel input to the process and for the same given heat output, each measure affecting the efficiency of a cogeneration plant results in a change in the electrical output.

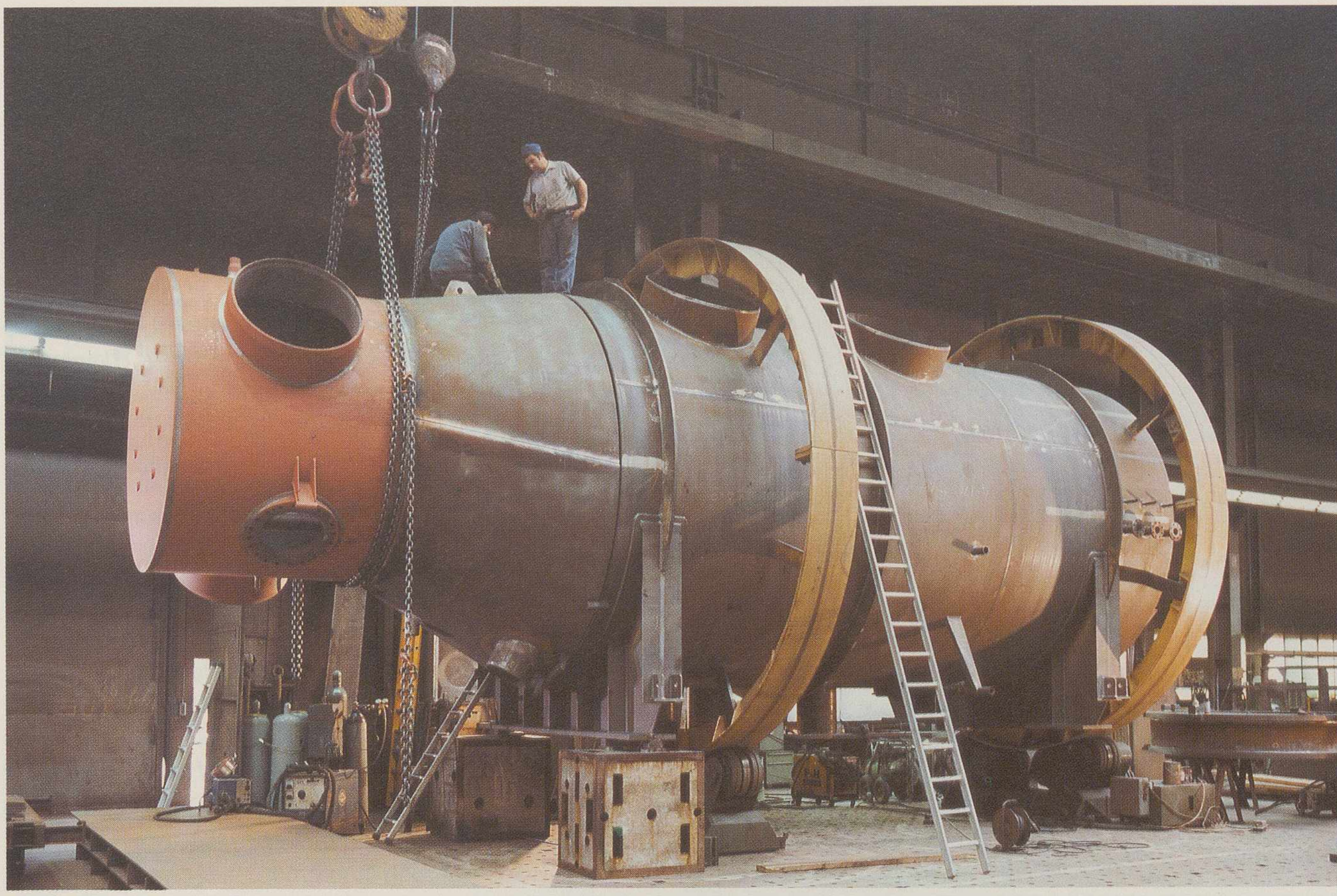


Fig. 5 - A district heater being assembled; maximum thermal output 242 MJ/s

- This difference in electrical output reduces or increases the demand made on a 'normal' reference condensing plant operating with the same fuel, annuity factor and equivalent process conditions (live-steam and reheat parameters, feedheating) as the cogeneration plant.

As in [9], it is assumed that the product 'electricity' is generated in the cogeneration plant with the same amount of primary energy as in the reference condensing plant. This means that the efficiency of the cogeneration plant is the same as that of the reference power plant.

To determine the capital parity, the values h_{KP}, p_{Br} and W_0 of the reference power plant have to be entered in formulas (3) and (4). This is usually a base load power plant with h_{KP} equal to 5000 to 6000 h/a.

The load duration of the individual components and systems of a cogeneration plant depends on the heat-load and electrical-load diagram. Every measure affecting the efficiency therefore does not have the same effect on the annual electrical energy production and the annual fuel costs considered in eqns. (3) and (4), even when the change in electrical output ΔP is the same.

Figure 6 shows examples of load duration curves for various components and systems for a constant live-steam flow and a known classified heat load curve.

Optimum Design of Equipment and Systems

Given the principles specified above for calculating the economic feasibility and the described duration of the changes in electrical output ΔP (which depend upon the heat output and result from measures changing the efficiency), eqn. (5) takes the general form:

$$\Delta K = KP \cdot \frac{1}{h_{KP}} \cdot \int \Delta P \cdot dh \qquad (7)$$

Equation (7) has practical use as simplified formulas, such as those listed in the *Table*.

The changes in output ΔP are determined numerically at certain operating points (Fig. 3), as with eqn. (8), or are formed into mean values of $\overline{\Delta P}$ using eqn. (9). In the latter case, a reduced

Equation (No.)	Formula	Example of application
(8)	$\Delta K = KP \cdot \frac{1}{h_{KP}} \cdot \Sigma \Delta P \cdot \Delta h$	Optimization of DHs and cold end
(9)	$\Delta K = KP_{red} \cdot \Delta P$	Extraction piping LP-FH Pumps
(10)	$KP_{red} = KP \cdot \frac{h_{red}}{h_{KP}}$	
(11)	$h_{red} = \frac{\Sigma Q \cdot \Delta h}{Q_{max}}$	

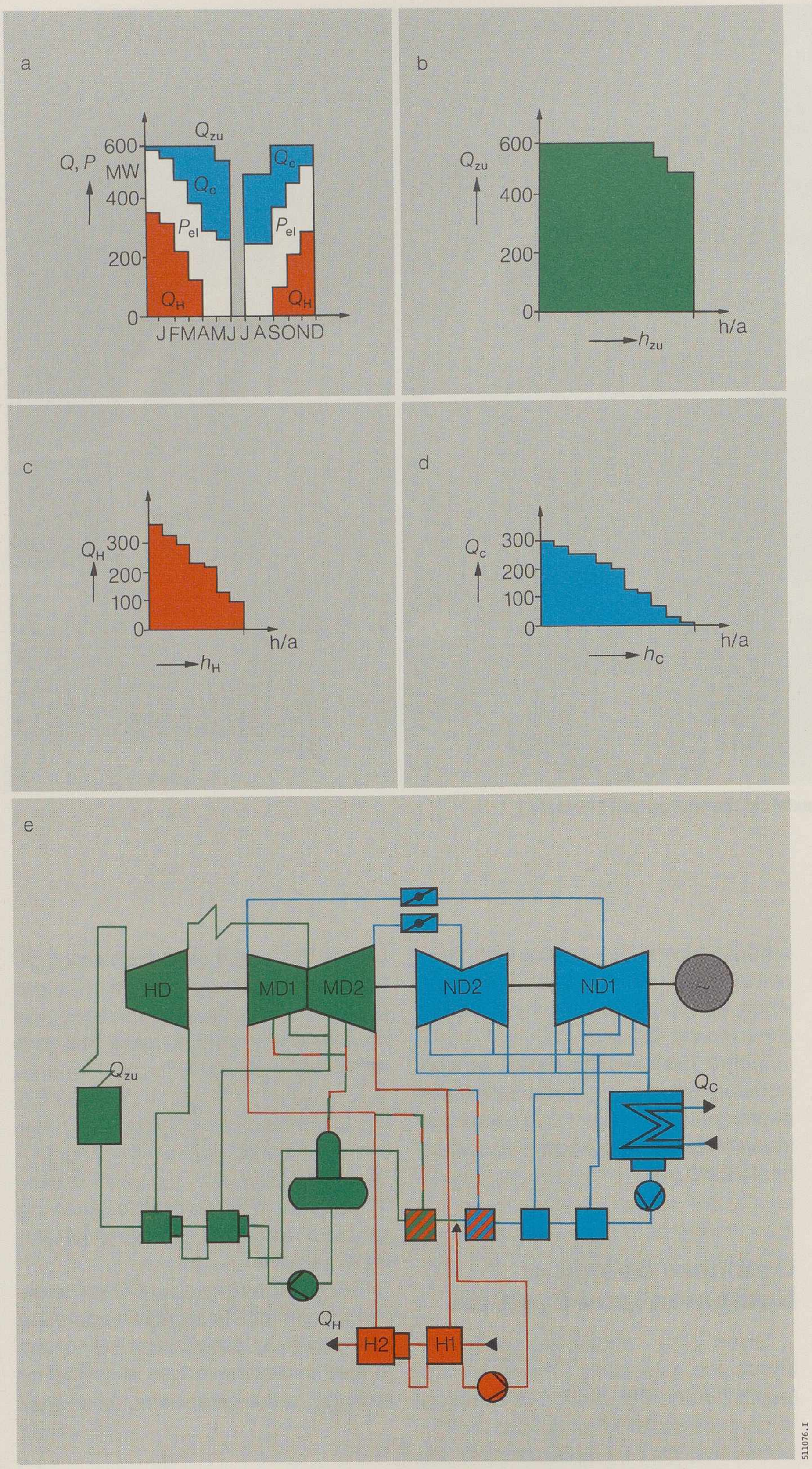


Fig. 6 – Example of load duration curves for a condensing power plant and thermal loading of the individual systems

a: Heat output, electrical output and heat rejected in condenser in one year of operation
b: Classified diagram of heat input Q_{zu}
c: Classified diagram of heat output Q_H
d: Classified diagram of heat Q_C rejected in the condenser
e: Thermal loading of individual systems

Green: Referred to heat input Q_{zu}
Red: Referred to heat output Q_H
Blue: Referred to heat rejected Q_C in condenser

HD = High-pressure turbine
MD1, MD2 = Intermediate-pressure turbine 1, 2
ND1, ND2 = Low-pressure turbine 1, 2
H1, H2 = District heater 1, 2
J–D = Months

capital parity KP_{red} and a reduced time duration h_{red} are used for the calculation. The second of these is referred, according to the different loads *(Fig. 6)*, to the relevant maximum heat flow $(Q_C)_{max}$ or $(Q_H)_{max}$.

In district heating plants, as in all other plants, thermodynamic improvements can only be turned into full economic gain when the availability of the element concerned is not impaired.

Optimum Terminal Temperature Difference of District Heaters and Feedheaters

In [6] an analytical formula was derived with which the optimum terminal temperature difference of FHs in power plants with condensing turbines can be determined. This formula can also be used for FHs in cogeneration plants. Depending upon the FH stage, it may be necessary to carry out the calculation with a reduced capital parity according to eqn. (10). The optimum terminal temperature differences of the first l.p. feedheaters in cogeneration plants are usually larger than in the condensing power plants.

Brown Boveri have developed programs and design tools for determining the optimum design terminal temperature differences (or the sizes of the heating surfaces) for DHs and their drain coolers. Account is taken of all the above-mentioned thermodynamic and economical relationships, as well as the turbine arrangement (Fig. 2), the classified heat-load curve (Fig. 1) and intended mode of operation (see below).

Optimum Water Velocity in the Heat-Exchanger Tubes

The chosen water velocity dictates on the one hand the geometrical data of the FH, the size of the heating surface and the investment costs and, on the other, because of the pressure losses, the power rating of the pumps.

Since the h.p. FH load is more or less constant (Fig. 6), the optimum feedwater velocities in these FHs are the same as in condensing power plants. Erosion at the tube inlet is prevented when the chosen velocity is lower than the maximum permitted value, which depends on the design and flow pattern of the water inlet zone. This maximum often lies below the optimum value. Development work carried out over the years and experience with very high water velocities (up to 4·5 m/s for tubesheet-type h.p. feedheaters designed by Brown Boveri [10, 11]), however, enable us to choose the optimum values for each particular case, and particularly for these types.

Numerous optimizations based on equation (9) have shown that in cogeneration plants (Fig. 6) higher optimum water velocities result for both l.p. feedheaters and for DHs with a variable heating water flow rate than for l.p. feedheaters in condensing power plants.

Optimum Velocity in the Extraction Lines

Here, the aim is to find the optimum number and diameter of the extraction lines, including the associated valves. The pressure loss in the extraction line reduces the saturation temperature in the FH or DH and can be compared with a change $\Delta\Gamma$ in the terminal temperature difference as regards its effect on the electrical output.

Figure 7 shows, as an example, the curve of the losses in electrical output in extraction lines to DHs. Optimization can be carried out with the aid of eqns. (9) and (2), as well as by referring to Figs. 6 and 7. The variation in load with time often results in relatively high optimum velocities, particularly in the extraction lines to the DHs and l.p. feedheaters. When making the final decision on the diameter, care should be taken to ensure that, for the steam conditions and chosen pipe material, certain velocity limits are not exceeded. This will prevent unnecessary noise and the risk of erosion, etc.

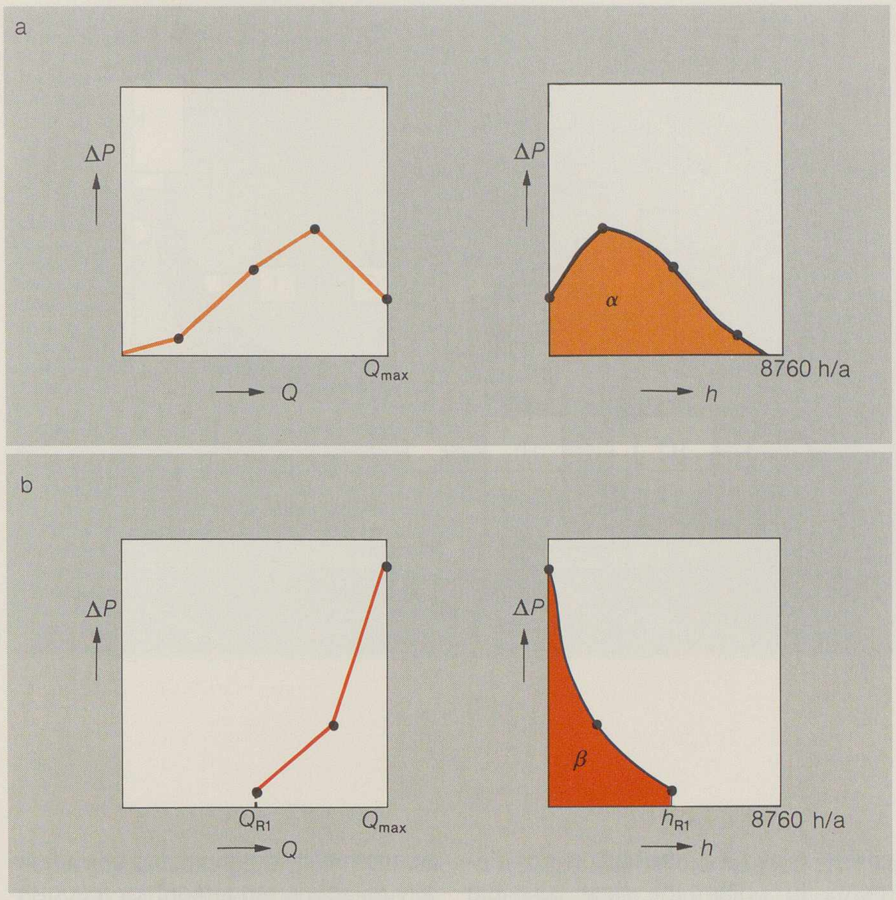


Fig. 7 – Schematic representation of losses in electrical output due to a drop in pressure in the DH extraction lines

a: E.g. H1 for arrangement in Fig. 2a
b: E.g. H2 for arrangement in Fig. 2a

Hatched areas: Energy losses over one year

α and β, see Fig. 3

Cold-End Optimization

The investment costs for the cold end of a cogeneration plant with extraction condensing turbines vary according to the type of cooling used and the chosen design, and can be quite considerable. What is more, the cold-end load varies widely with time (Fig. 6). In plants with turbine arrangements as shown in Figs. 2b and 2c, it is possible that only cooling steam is admitted to the l.p. turbine at maximum heat output, while the full condensing steam flow is admitted when there is no demand for district heat. The condenser pressure and the output of a given l.p. turbine for various operating conditions can be influenced to comply with given environmental conditions (cooling-water temperature for once-through cooling, etc. or air temperature and humidity in the case of a cooling tower). This is done by choosing appropriate sizes for the cooling tower and the heating surface of the condenser and for the mass flow of the cooling water. The net output fed into the network is also influenced by the rating of the cooling-water pumps (and possibly by the rating of the cooling-tower fans). Here, optimization in-

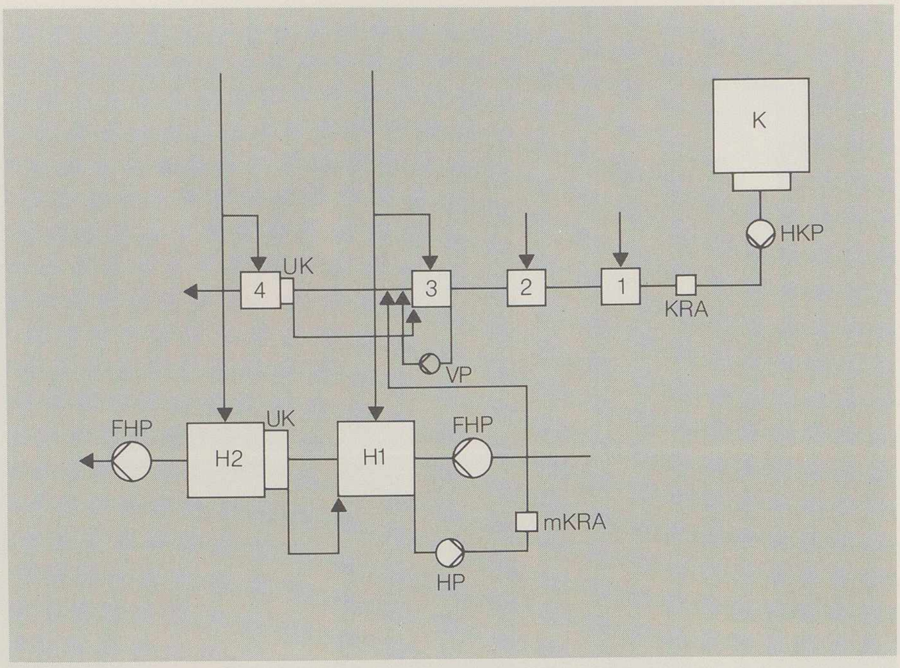


Fig. 8 – Arrangement on condensate side

HKP = Main condensate pump
Capacity and number chosen for economic feasibility in operation
HP = Hot condensate pump
Capacity and number chosen for economic feasibility in operation
VP = Drain pump
FHP = District-heating water pump
UK = Drain cooler
KRA = Condensate polishing plant
mKRA = Mechanical condensate polishing plant
1–4 = LP feedheaters
H1, H2 = District heater 1, 2
K = Condenser

volves matching the following elements to obtain the best possible economic results:

- Size of the l.p. turbine, particularly its annular exhaust area. Account is also taken here of any effect this might have on the size of the machine hall.
- Size of the heating surface of the condenser
- Cooling-water mass flow, together with the entire cooling-water supply system, heeding any conditions attached by authorities with regard to the permitted amount of water which may be diverted, its permitted temperature rise, etc.
- The size and type of cooling tower used in a closed-cycle cooling system

The influence of any measure affecting efficiency on the present value is determined for a cogeneration plant using eqn. (8). Brown Boveri have computer programs with which a comprehensive cold-end optimization can be carried out numerically.

District Heater and LP-FH Arrangement

The effect of drain coolers and drain pumps on the heat rate of conventional and nuclear condensing power plants and on their economy was looked at in detail on a previous occasion [12]. An economically optimum and operationally reliable arrangement for a cogeneration plant with a double-flow i.p. turbine as in Fig. 2c is shown in *Fig. 8.* The main features of this arrangement are discussed in the following.

Draining the Condensate from the Lowest DH

The condensate from the lowest DH is pumped back to a point in the main condensate system which is at approximately the same temperature; this is also the best thermodynamic solution. The point is downstream of the FH receiving steam from the same extraction point.

When selecting the pump for this, Brown Boveri abide by the principle that such drain pumps have to satisfy the same availability requirements, in terms of quality and redundancy, as the main condensate pumps in a condensing power plant.

As a result of the drainage, the main condensate pumps have usually to discharge only a small amount of condensate during the heating period, and only a fraction of the feedwater is cleaned in the condensate polishing plant.

Better use can be made of the poorly utilized main condensate pumps by:

- Choosing a low-loss drive
- Choosing pumps with different delivery rates, so that economy is assured both in condensing and district heating operation.

To achieve the desired feedwater quality in this cycle, it is usually sufficient to provide a mechanical filter which polishes some or all of the condensate drained from the DH.

Draining the Condensate from a Higher DH Stage

The solution with drain cooler shown in Fig. 8 has proved in most cases to be economically and operationally sound.

Use of a drain pump may be considered in plants with very high capital parities which are operated for long periods with a high heat load. What is more a drain pump enables high operational flexibility to be achieved. Here too, as with the lower DH stage, the drained condensate is returned to the main condensate system downstream of the feedheater connected to the same extraction point.

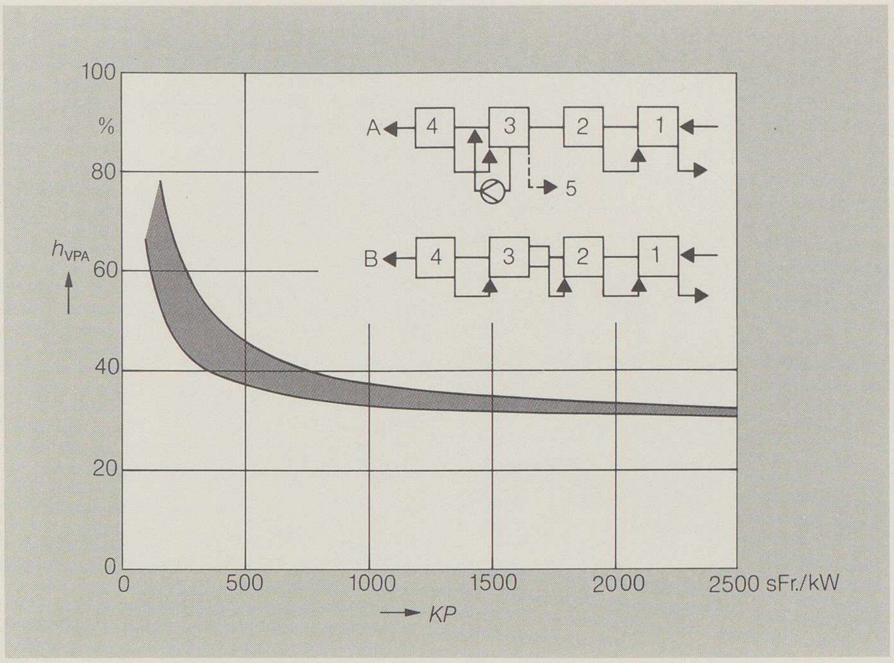
LP-FH Arrangement

Different pressure conditions are possible at the l.p. feedheaters, depending upon the operating mode and the position of the control valves R1. Some operational advantages are offered by the solution with a drain pump

Fig. 9 – Permitted outage time h_{VPA} of the drain pump at feedheater 3, for which arrangement A is still more economical than arrangement B

1–4: LP feedheaters
5: to condenser
Arrangement A: Drain pump at feedheater 3
Arrangement B: Drain cooler at feedheater 3

KP = Capital parity



at the last FH of the i.p. turbine MDZ (FH3 in Figs. 6 and 8). At maximum heat output, with the plant operating in backpressure mode and the l.p. turbine practically isolated (only cooling steam is required), this pump ensures that the isolation also applies to the drain-side of the l.p. heaters so that there is no extreme, unwanted flashing of the cascaded drains when heat demand is high.

The arrangement with a drain pump at FH3 exhibits a better heat rate and generally lower total investment costs than the version with a drain cooler in place of the pump. In a comparison of the two cycles, the permitted outage time for the pump can also be taken into account:

$$\frac{h_{red}}{h_{KP}} . KP . [\Delta P_{VP\text{-}UK} - (\Delta P . h)_{VPA}] > \Delta I_{VP-UK} \quad (12)$$

Figure 9 plots the permitted outage times h_{VPA} of the drain pump at FH3 as a function of the capital parity.

A drain cooler at FH4 permits a thermodynamic gain which is usually economical when rises in the temperature of the main condensate are greater than 25 K.

FH1 and FH2 loads are greatest during condensing operation, while their steam sides are practically out of operation at maximum heat output. Whether or not a drain cooler is economically advantageous at FH1 or FH2 mainly depends upon the load diagram (Fig. 6).

Operating Modes for the District Heating System; Optimum Process Control

When several plants are connected to a district heating network, those with the smallest impact on the environment and which feature the highest utilization of primary energy [13] are usually chosen for delivery of the demanded heat. Another important factor with respect to the pump's energy requirements, is the power plant's distance from the heat consumers. It is also advantageous when a cogeneration plant's commitment at each new stage of an extending district heating system is known already during the planning phase.

It has been assumed in the above that, for a given live-steam flow and electrical output, the required heat output is obtained by controlling the outgoing temperature of the heating water with valves R1, R2 and R3. In actual fact, the heating water flow rate can also be varied to meet the demand for the particular heat load, which is why variable-speed pumps are usually installed. The economical and operational advantages of a variable-speed drive, and especially those offered by state-of-the-art frequency converters, are known [14]. The principles embraced in eqns. (6) and (8) support the final choice of district heating pumps.

A distinction is made between three possible operating modes:

- Intensity control:
  Variation of the heat output by variation of the outgoing temperature for a constant flow of heating water
- Flow rate control:
  Variation of the heat output by variation of the heating water flow rate for a constant outgoing temperature of the heating water
- Combined control:
  A combination of the two abovementioned modes: e.g. intensity control in the upper heat output range and flow-rate control in the lower range

Seen as a whole, an optimum operating mode can be achieved by minimizing the total electrical losses and the power rating of the district heating pumps.

Optimum Process Control

The ultimate aim of optimizing the process is to supply the consumer with the amount of heat required when it is required, whilst minimizing fuel consumption; at the same time, the demand for electrical output has to be

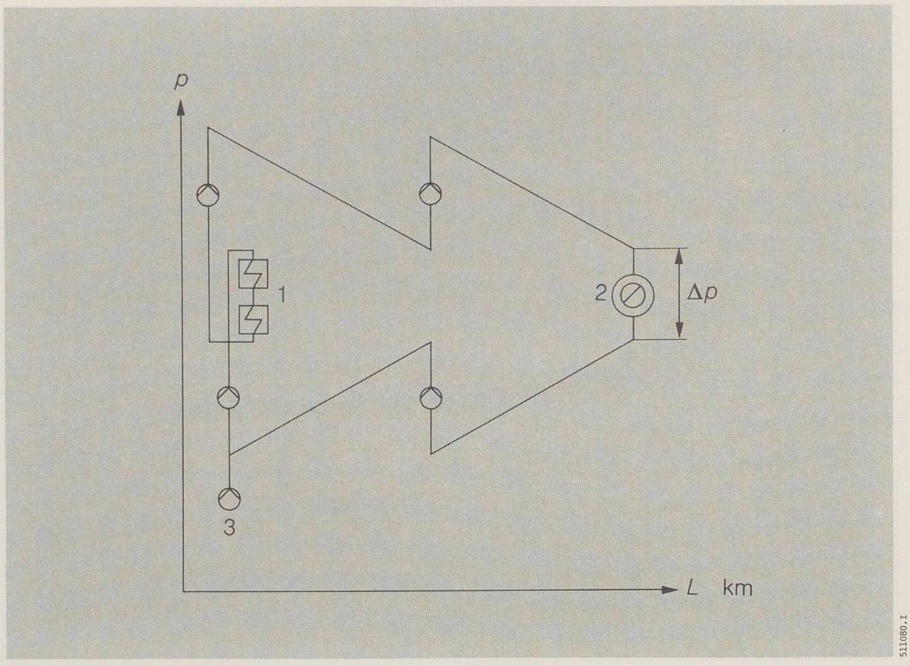


Fig. 10 – Pressure characteristic *p* for a simple district-heating network

1 = District heater
2 = Heat consumers
3 = Pressure-holding systems
L = Length of network

met and all safety requirements satisfied.

To ensure that all the control duties are also performed as the district heating network grows, certain values must be continually optimized during operation. These include the:

- Live-steam flow
- Outgoing temperature for the known (or predicted) ambient temperature and the given inertia of the district heating system
- Heating water flow rate
- Number of pumps in operation

It would go beyond the scope of this article to discuss the method of process optimization which should be chosen. However, it should be noted that this optimization, and also the control and protection of all associated systems, can be integrated in the conceptual planning of Brown Boveri's process control and automation systems [15]. Comprehensive analyses and verifications of the attainable electrical outputs for a known live-steam flow rate and diverse heat outputs are undertaken by Brown Boveri already during the design work for the turbine and DH plant. The range in which operational reliability is assured is therefore clearly defined.

From the explanations which have been given, it is clear that the lowest possible outgoing temperature which can be obtained without control via R1, R2 or R3 (Fig. 2) assures the lowest losses. This mode of operation is therefore to be preferred providing the outgoing temperatures also come up to the expectations of the heat consumers. It is also an advantage when operation of the higher DH stages is kept as short as possible.

If, for a certain outgoing temperature, the required heat output can be achieved by placing an additional pump in operation so as to increase the mass flow slightly, the higher output losses resulting must be taken into consideration, as must the duration of the heat load. Under certain circumstances it may even be necessary to change over to higher outgoing temperatures for a short time.

The required pressure difference Δp *(Fig. 10)* must be ensured under all operating conditions. The pressure downstream of the pumps remains variable as it depends on the flow conditions and pressure losses. It goes without saying that the entire system must always be protected by a pressure-holding system against evaporation.

A more detailed analysis of the system can show whether the number of series-connected pressure-raising pumps may be reduced during partial heat-load operation.

Process control can only be said to be optimum when auxiliaries such as the cooling-water supply system and the condensate pumping system are also taken into account.

Summary

The optimization and design of cogeneration plants depends on, among other things, the economic assessment of the change in output resulting from measures taken to improve the efficiency. A proven means by which this aspect can be considered is to refer the change in electrical output for a given heat output to a reference condensing power plant.

Measures affecting the efficiency have an influence on the electrical output which varies with time, and which depends upon the duration curve of the heat output. The thermal loading of the individual systems of a cogeneration plant differs according to the heat output. This has to be considered when designing optimal equipment and systems.

Another factor which has an important bearing on the design is the planned mode of operation. Optimization of the overall process (including the district-heating system itself) must take place with the plant in operation.

Brown Boveri have both the necessary experience and the documenta-

tion and programs, to ensure the optimum design of all systems installed in a combined heat and power plant. Several plants of this type have been built by Brown Boveri and are now in operation, while others are currently under construction.

Subscripts

H	=	District heater
TL	=	Partial load
VP-UK	=	Drain pump compared with drain cooler
VPA	=	Drain pump failure
c	=	Condensation
max	=	Maximum
red	=	Reduced
s	=	Saturation
w	=	Water
zul	=	Permitted

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Nomenclature

A	m^2	Heating surface
ΔI	SFr	Difference in investment costs at the time of signing of the contract
ΔK	SFr	Present value of the changed fuel costs following a change in efficiency
L	km	Length of district heating network
KP	SFr/kW	Capital parity
$\dot{M}$	kg/s	Mass flow
$P, \Delta P, \overline{\Delta P}$	kW	Electrical power, power difference, mean power difference
Q, Q_1, Q_{R1}, Q_{max}	kJ/s	Heat output (see Fig. 1)
T, t	K, °C	Temperature
$\Delta T, \Delta t$	K	Temperature difference
W_0	kJ/kWh	Specific net heat rate of reference plant averaged over one year
ΔW	kJ/kWh	Difference in heat rate
a	SFr/kW	Fuel parity
c	kW/(kg K)	Specific heat capacity
h, h_1, h_{R1}	Ms/a, h/a	Operating period per year
h_{KP}	Ms/a, h/a	Annual equivalent utilization period of reference plant
k	$kW/(m^2 K)$	Heat transfer coefficient
Δp	bars	Pressure difference (pressure losses)
p_{Br}	SFr/GJ	Specific fuel costs at time of commissioning
$\Gamma, \Delta\Gamma$	K	Condensing terminal temperature difference, difference in same
φ	–	Power factor
η_G	–	Generator efficiency
ξ	–	Supplementary costs
ψ	per year	Annuity factor for specified return on investment

Energy Management and Load Control with Supervisory Network Control Systems

Brown Boveri's supervisory network control system BECOS® includes among its important functional assets software packages for energy management and load control. The article reports on the high-performance, modular program system BELAS, which is based on BECOS 28. It is being used for the first time with the BECONTROL® supervisory control system in an electric utility in the Federal Republic of Germany, where it takes advantage of BECONTROL's general capabilities in performing the functions of energy management and load control in the power system.

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Municipal and regional electric utilities, industrial plants and commercial enterprises obtain certain amounts of their electrical energy from basic supply companies. The total cost of the energy supplied is based on the 'energy charge' and the 'demand charge' laid down in energy supply contracts.

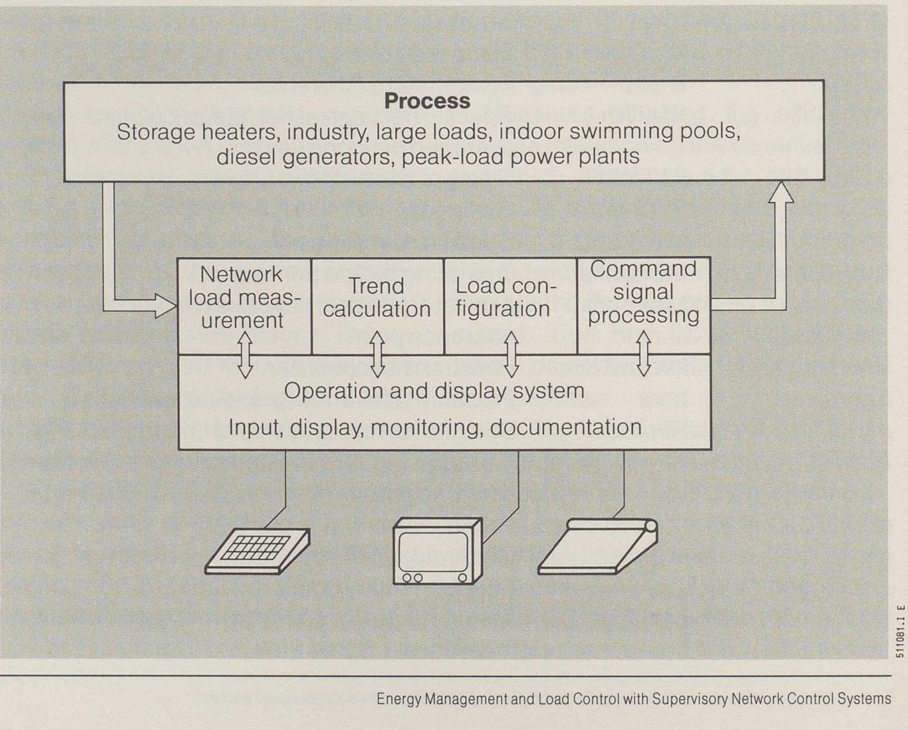
The price which has to be paid to these companies for the electrical energy (the energy charge) is given by the total electrical energy (measured in kilowatt hours) supplied multiplied by the respective price per kilowatt hour. The demand charge is calculated on the basis of the billed power, which is determined from the maximum energy demands over several demand periods. And it is the demand charge which serves as a basis for the proportionate payment made to the original suppliers who provide the electrical energy.

Since the consumers do not make constant use of the energy over any given period, but use it instead according to climate and temperature, the time of day and season, etc., the average power supply fluctuates over a demand period. Electric utilities usually work with demand periods lasting 15 or 30 minutes.

The billed period is the length of time over which the chargeable demand is determined and for which it is valid. The period used most often for this is the month or the year, in which case we refer to monthly and yearly chargeable demand. The monthly or yearly chargeable demand is often an arithmetical mean formed from the two, or at the most three, mean demands over different demand periods. In the case of the monthly chargeable demand, these maximum mean demands must refer to different days, while for the yearly chargeable demand they must refer to different months.

The maximum energy supplied over only a few demand periods in the billed period therefore determines the demand charge. If the electric utility manages to significantly reduce the peak load during the demand periods used for billing, the result will be a considerably lower demand charge. In the yearly contracts, this tariff is fixed at

Fig. 1 – Basic structure of the BELAS program system for energy management and load control



about 250 DM per kW and year up to the average, contractually agreed demand (depending upon the contract and demand period), increasing by about 50% per kW when the agreed mean demand is exceeded.

As the economic success of a supply utility depends to a great extent upon the demand charge, it is in the interest of the utilities to keep it as low as possible and to do this without endangering the power supply to the customers. This is achieved with the BELAS program system, which shifts load peaks by demand-related control of the generation systems and load/consumers, and compensates wherever possible for low-demand periods.

Basic Structure

The basic structure of the BELAS program system for energy management and load control comprises the following function groups:

- Network load measurement
- Trend calculation
- Load configuration
- Command signal processing
- Operation and display

These function groups are run through in cycles, as shown in *Fig. 1*.

Network Load Measurement

The task of this function group is to determine the instantaneous energy supply situation and to place this information at the disposal of the 'Trend calculation' module. To this end it makes use of the telecontrol equipment in the substations, etc. The working values, which are available in the form of meter pulses, are totalized in a one-minute basic meter reading cycle with incremental input, moved to another data area (synchronized with respect to time) and transmitted via the telecontrol equipment to the load dispatching centre. The computer in this centre weights the individual values according to their pulse valency and generates a total for use by the 'Trend calculation' module.

Trend Calculation

This module uses a mathematical model to cyclically forecast values up to the end of the demand period being measured. The result of the forecast is a positive or negative corrective power P_{CORR}, indicating to what extent the instantaneous total power supply has to be changed to obtain an average supply at the end of the demand period which corresponds precisely to the maximum value permitted by the contract.

Load Configuration

This program module, which is activated at one-minute intervals following the trend forecast, is responsible for all logic decisions and operations required for load control.

The effect of switching a load group is determined on the basis of parameters such as system-related dead times (starting times of diesel generators), the remaining duration of the demand period, the installed rating of a generator or load, and the load factor specifying the instantaneous proportion of the installed power to be reckoned with. The load configuration program determines separately the effect of switching each generator or load group.

This 'switching effect' indicates how much the calculated corrective power would change at a particular instant as a result of the respective load group being switched. The object of all calculations and system reactions is to make the corrective power precisely zero towards the end of the demand period, so as not to exceed the mean demand specified for this period.

Subprocesses can be integrated in the load configuration to adapt it precisely to any given application. Those most widely used are:

- Load groups (for example storage heaters) switched by ripple control systems, or special consumers in the industrial and business sectors (e.g. operators of smelting furnaces or other large electrical loads). Usually, it is possible for the electric utility to shed and reconnect such loads within a short time via ripple control or telecontrol systems.
- In-plant generating systems and stations such as diesel generators, hydro-generators, unit district heating plants, refuse incineration plants and similar. These are operated by the electric utilities themselves or are installed on customers' premises. When power supply contracts between the supplier and customer exist, such plants can be switched by the electric utilities as required, or at the very least their actual generating capacity influenced.

The user decides on the sequence of sub-processes to be used for load control. If required, load groups and special loads/consumers with with appropriate contracts have been drawn up can be shed as a first step. When this possibility has been fully exploited, in-plant generating systems/stations may be switched into the network in a specified sequence. In such cases, however, the load configuration program first checks, as with the load groups, whether contractual conditions, etc., place any restrictions on their availability for such use.

Load groups are selected according to their most suitable 'switching effect' or on account of their priority. As a rule, none of the available load groups will provide exactly the desired power correction so that, reverting to the method of the most suitable 'switching effect', the load group selected for control is that for which the 'switching effect' comes closest to providing the required power correction. This approximation is permitted as the corrective power always approaches infinity towards the end of the demand period, except when $P_{CORR} = 0$. Fundamentally, the switching effect is the reverse of the course followed by the power correction. As the demand period advances, it approaches zero, reaching this value when the system-related dead time of a load group is equal to the remaining duration of the demand period measured. The point at which the two curves intersect corresponds to the moment at which the respective load group must be switched.

When switching according to priority, BELAS delays a control command until the corrective power corresponds to the effect of switching the load group intended for control. This procedure avoids frequent switching as a result of changing energy supply situations, as a load group is only switched when the curve of the calculated corrective power makes switching necessary. This is referred to as 'selective load switching'.

If all of these functions incorporated in BELAS do not suffice to make the corrective power zero or to give it a positive value, a system alarm is released.

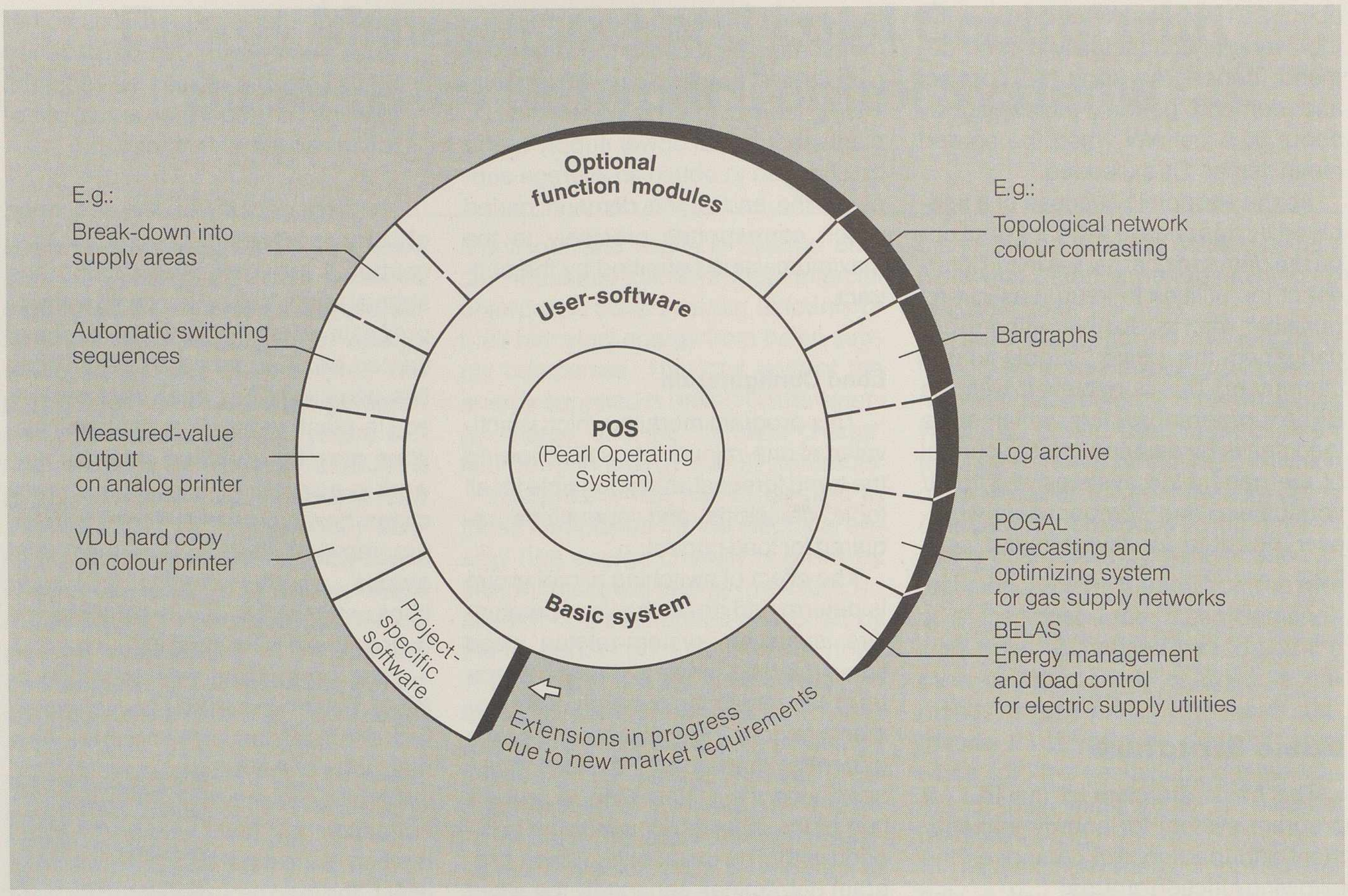


Fig. 2 – Software structure of the BECOS 28 supervisory network control system

Command Signal Processing

On the basis of the load configuration, this program section establishes a link to the address of the equipment to be controlled. The telegram interface via which the telecontrol units are connected represents the processing limit for the program system.

When Brown Boveri's telecontrol systems are used, the hardware involved is a microprocessor-based line coupler in the telecontrol link. Time-division multiplex telecontrol systems from other companies are related to the same, internal telegram interface via a multi-purpose line coupler, a processing program ensuring adaptation to the telecontrol telegram structure in the multi-purpose line coupler. With the defined interface ('multi-purpose line coupler'), practically every time-division multiplex telecontrol system available on the market can be operated without users having to exert influence on the program system of the process computer.

The method used to generate the hardware address corresponds to the method used to process commands in BECOS 28 [1, 2]. To this end, the user enters the required descriptive data in interactive mode. The control commands are received as signal pulses in the respective telecontrol outstation, so that external inputs of the ripple control unit can also be used to send ripple control telegrams.

Operation and Display

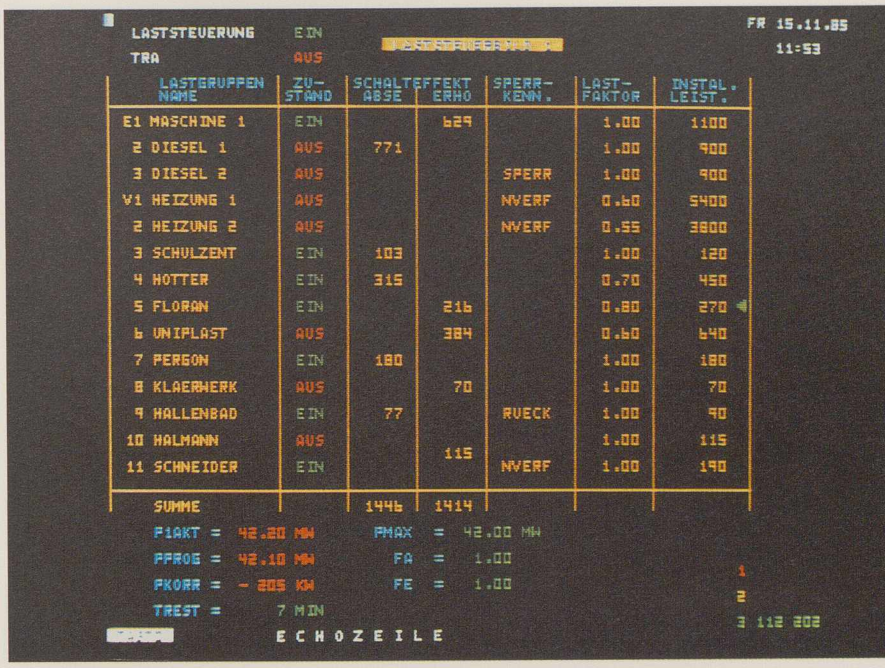
When choosing a supervisory network control system, users will often base their decision on the ease with which the program system can be used. The individual system capabilities of BECOS 28 *(Fig. 2)* are designed to ensure maximum flexibility and adaptability of the system to the process. This feature ensures that even operators unfamiliar with computer systems will have no trouble using the BECOS supervisory control system.

The same assets are also required of the energy management and load control functions. Operation and display functions are included which cover the following fields:

- Displays on semigraphic and alphanumeric VDUs
- Outputs logged on printers at the terminals
- Filing (including logs)
- On-line modification of important system parameters for fast adaptation to process reactions
- System behaviour response to disturbances in the process computer system and process peripherals. This also includes the system's behaviour during cold and hot starts, for example after a drop in voltage.

As many of the listed functions are also basic capabilities of the BECOS 28 supervisory control system, a close look will only be taken at those capabilities which apply particularly to BELAS. These mainly feature CRT displays and special log outputs.

Fig. 3 – BELAS load control display with generation and load-group data entered in interactive mode, and switching states, switching effects, blocking codes, load factors, installed power ratings and actual energy supply situations entered by the program system in cyclic mode



Displays

Users of the BECOS 28 supervisory network control system have a great deal of freedom in their configuration of pictures on the colour VDUs. Experience gained in the field has shown that additional, preprepared monitor tables with static and dynamic picture areas offer users advantages when dealing with complex functions. The BELAS load control display in *Fig. 3*, is such a screen mask. The dynamic picture area comprises, among other things, the data of the generation and load groups, these being entered in interactive mode. The remaining dynamic picture components are updated in cycles by means of the various program sections.

Since the load control display is also one of the central items of the operation and display system, a closer look will be taken at its different sections in the following. The upper section of the display contains, besides the date and time, a note indicating whether or not the automatic load control is in action and whether the ripple control system is sending a telegram at that particular time. The entries in the columns of the load control display have the following meaning:

- 1st column: LOAD GROUP NAME
  The generation system or load group name is taken from the data store and shown on the colour VDU. In front of the name appears either an E (in-plant generation) or a V (load groups).
- 2nd column: STATE
  This column shows the current switching state of the generator and load groups. It can also be used to manually switch the individual groups or update the switching state when return signals have not been received from the process (cursor control).
- 3rd and 4th columns: SWITCHING EFFECT
  The user can refer to this column to obtain important information about his remaining options for increasing or reducing the energy demand in the rest of the demand period left to him.
  An entry in the first of these columns means that when this load group is switched (account being taken of the power demand), the demand is reduced by the given amount for the rest of the demand period. The values entered decrease as the demand period expires. When the time remaining in the demand period is equal to the system-related dead time of the load group, the switching effect will be zero. This means that the average power supplied during the actual demand period is no longer influenced by switching of the load group.
  An entry in the second of these columns causes the energy demand to be increased by the given value when a load group is connected. Since the switching effect continues to approach zero as the demand period progresses, an additional program routine ensures that not all load groups are connected in quick succession towards the end of the demand period when the corrective power is positive.
  The above applies equally to the generator groups, although with reversed signs; connection results in a lower and disconnection a higher energy demand.
- 5th column: BLOCKING CODE
  This column lists notes entered by the system which relate to the generator and load groups and provide information about instantaneous availability for automatic load configuration.
  The German word SPERR for 'block' entered in this column means that the operator has applied a manual blocking code to this group for the load configuration. Only the operator himself is able to cancel this code, providing users with a simple means of excluding individual in-plant generation units or special customers from the load configuration for a certain length of time, for example during overhauls or repairs.
  The word RUECK for 'return' indicates that the reswitching time for this load group has not yet elapsed.

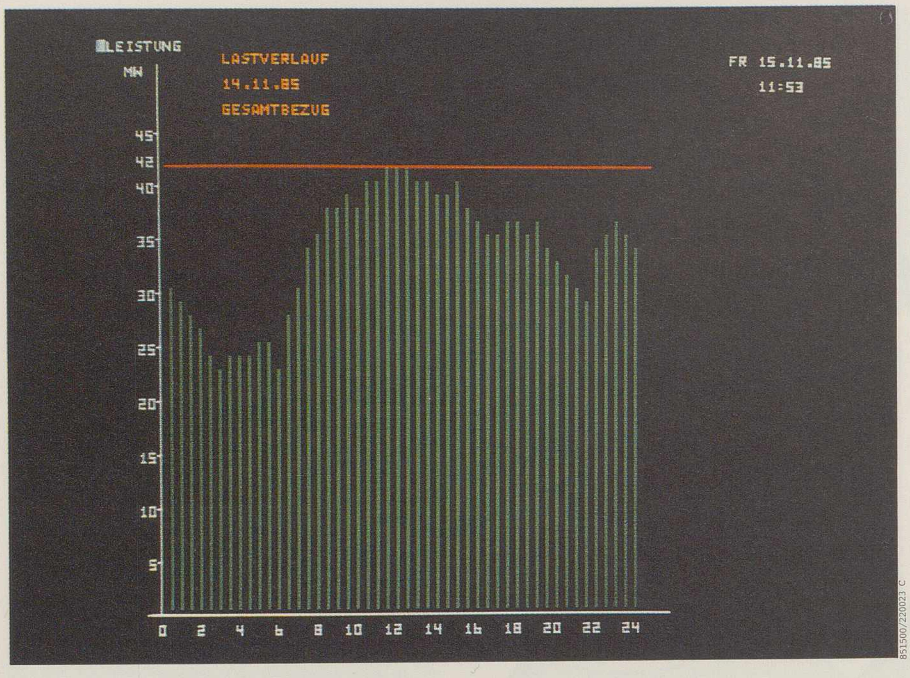


Fig. 4 – Daily load curve: 48 mean energy values in a green bargraph display, plotted at 30 min intervals. The red line shows the permitted maximum value of the mean energy.

In the case of in-plant generators, this time implies, for example, the minimum time a diesel-generator set may be switched on (as specified by the manufacturer) if its service life is not to be impaired.

A load, however, can feature a minimum 'on' time and a maximum 'off' time, in which case the word RUECK remains in this column as long as the minimum 'on' time has not expired. This means that this group may not be switched in the load configuration. A load with a maximum 'off' time must be automatically reconnected by the system before its maximum 'off' time has expired.

The abbreviation NVERF means that special contractual agreements prevent the generators or the load group from being used in the load configuration at the moment.

- 6th column: LOAD FACTOR
  The indicated load factor shows the value by which the installed power has to be multiplied to calculate the switchable power. The operator can vary the load factor from 0 to 1 on the function keyboard to adapt the installed power to the actual switchable power.
- 7th column: INSTALLED POWER
  This column lists the total power rating of the generator and load groups in kilowatts.

The triangular pointer shows the last generator group or load group to be switched by the command-signal processing section of the program.

The following values are listed below the table in the load control diagram:

P1AKT	=	Actual mean one-minute energy
PPROG	=	Forecast mean energy for the actual demand period
PMAX	=	Mean energy of the demand period which may not be exceeded
PKORR	=	Corrective power required to achieve PMAX at the end of the demand period
TREST	=	Time remaining to the end of the actual demand period
FA/FE	=	Hysteresis factors of the minute in question. These are necessary in order to calculate the weighted corrective power.

At the bottom, on the right of the load control display is an area containing notes for the text output of assigned alarms. Below this area are the identification numbers of plant displays containing messages that must be acknowledged. These identification codes are entered in the appropriate zone, sorted according to three priority classes.

The bottom line of the load control diagram serves as the echo line for all operator inputs.

Bargraph Displays

The semigraphic displays on the colour VDUs provide the operator with the following information:

- Load characteristic of the actual demand period, in which the one-minute mean energy values (P1AKT) are shown as coloured bars.
- Actual daily load bargraph. 48 daily mean energy values are displayed as coloured bars *(Fig. 4)*, based on demand periods of 30 minutes. The diagram shows the permitted maximum value (P_{MAX}) of the mean energy in the form of a line. The 96 daily values for 15-minute demand periods are divided between two display pictures: The load characteristic is displayed as a function of time from 0 hours to 15.00 hours in the first picture and, with an overlap, from 09.00 hours to 24.00 hours in the second picture.
- Daily load characteristics of the seven previous days. The load charac-

teristics of the seven previous days can be called up from the file and displayed on the colour VDU as described above.

Logs and Archive

With the BECOS 28 control system, event, measurand and meter-status logs, etc. can be printed out or displayed on alphanumeric VDUs.

Data filed in the archive via the BELAS system find their way into logs such as the event log.

The operator can use different search and selection criteria to generate his own logs with the aid of the 'Event log archive selection' function.

Special logs which the operator can request are a load control log and a load group table. The load control log shows the time at which each load group last changed its state. The load group table lists all characteristic data of the in-plant generators and load groups, i.e. load group names, installed ratings, telecontrol identification codes, switching priorities, minimum 'on' times, maximum 'off' times, control codes and systematic dead times. The operator can call up these logs at any time to obtain an overview of the load control values which have been entered.

Additional Program Functions

Since the determination of the demand charge has a significant bearing on the tariff and contract, many users prefer not to specify a fixed permitted maximum value for the mean energy (P_{MAX}) over the billed period.

In such cases it is possible to use a 'sliding' maximum. After a start value has been given, BELAS stores in the data file all P_{MAX} values important for determining the chargeable demand. As a rule, two or three values are involved, depending upon the supply contract and the billed period. The program system controls connection/disconnection of the in-plant generators and load groups as a function of the lowest of the stored values.

The lowest demand charges are achieved with this method providing a reliable empirical value is available as the start value for the billed period considered; a reliable value, for example, would be that for the same period in the year before. This method can be conveniently used for both monthly and yearly invoicing agreements.

Summary

The BELAS program system is yet another user-function which Brown Boveri have designed for their supervisory network control system BECOS (BECONTROL) 28. BELAS is a high-performance software package for solving the energy management and load control problems of electric supply utilities, large-scale consumers of electricity, industrial companies and municipal works, where it can also be used in other control centres for the distribution of different types of energy.

For stored energies such as gas, BECOS (BECONTROL) 28 also offers the program system POGAL for forecasting and optimizing gas supply systems [3].

Both program systems operate with a multi-purpose telegram interface linking them to the process, enabling any type of time-multiplex telecontrol system to be used to gather data on the energy demand and to transmit control signals to the generating stations and loads. A high-performance operation and display system, coupled with features such as high flexibility and easy adaptation to the controlled process, ensure its successful handling by operators in dispatching centres.

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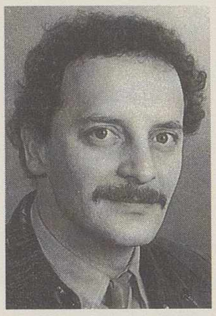
Electrical Power Control with BECOS 10 Plus for a Swedish Local Authority

Brown Boveri's family of BECOS®/BECONTROL® power control systems covers the entire range of customer requirements for electrical supply and management systems of every size. BECOS 10 Plus is a member of this family and is designed essentially for smaller power networks. The article describes a typical application and illustrates the flexibility and functional capability of the system, which also enables specific customer requirements to be satisfied.



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BECOS 10 Plus is a small system for monitoring and controlling local and regional electrical networks. It is, however, equally suitable for use with other types of network, such as for distributing gas, water or oil, as well as in water purification and treatment plants.

The primary objective in developing BECOS 10 Plus was to obtain a control system which offers the capabilities provided by large systems, but which avoids their inherently high costs.

BECOS 10 Plus is available in either single or dual computer configurations. The configuration chosen will depend on the degree of redundancy required and the envisaged financial investment.

The BECOS 10 Plus control centre is very compact thanks to the use of PDP11 microcomputers. This computer, equipped with 500 kbytes of extendable memory, is located together with a 31 Mbyte Winchester disc and a 400 kbyte double floppy disc inside one small cabinet. The cabinet can be installed vertically under a work desk, or horizontally inside the cubicle containing the process communication interfaces.

The control centre can be linked to the user's process by up to six communication links, with each link being connected to up to 15 remote terminal units (RTUs). The precise model of INDACTIC® RTU to be used will depend on the application for which the control system is intended, and can be chosen from the following range:

- INDACTIC 33
  Standard version
- INDACTIC 33/41
  Sequence-of-events recording, printed locally
- INDACTIC 33/42
  As 33/41, but printed in plain text
- INDACTIC 34
  Compact version

BECOS 10 Plus in the single computer configuration and with up to 15 INDACTIC 33 type RTUs per channel, has the following working data capability:

- 1300 analog measurands
- 5000 status values (input/output)
- 2000 commands
- 200 setpoints
- 300 counters
- 1300 calculated numerical values
- 1300 calculated logical values

Communication between the operator and the computer is facilitated by the system's full colour graphics capability and accompanying keyboard. Application software is designed to allow the operator to carry out his daily tasks as easily and effectively as possible. The user can design and generate pictures (including static background and dynamic fields) and modify and generate the database without any special knowledge of computer programming and with only a minimum time spent on training. These data maintenace operations can be completed with the control system 'on-line' and therefore without interrupting normal SCADA operations.

Each control centre can have up to three operator workplaces, each of which may be used for a different set of tasks, such as control of a designated part of the network, system extension or development, or training.

Electrical Distribution and Street Lighting in Solna, Sweden

Solna is a small Swedish town bordering on Stockholm. The energy department of the town's local authority is responsible for distribution of electricity in the town. This authority generates no electricity but obtains power from the Swedish State Power Board (SSPB). In 1983, the SSPB provided 350 GWh of energy, with the maximum load being 70 MW.

Power is currently received from the SSPB at a voltage of 20 kV via a substation 'M1'. It is then distributed at this voltage to transformer stations which step it down to 6 kV for feeding into the network. Progressive reconstruction of the network, amounting to five new substations a year, will permit later distribution of electricity at 20 kV.

To this end a new substation 'M2' is being built to enable the SSPB to supply power at 70 kV. This new station will allow 20 kV power distribution to the network.

Street lighting will be supplied from the substations and controlled from the control centre.

Up to the present time, 26 new substations have been added to the network, leaving 96 older substations to be replaced.

Climatic conditions in Sweden in winter are particularly severe and there is no question of the need for a control system capable of processing data and controlling the network to ensure maximum efficiency for the street lighting. In the event of a network disturbance, it is essential to be able to take appropriate action as soon as possible. And to ensure this, service personnel must have information promptly at hand to enable them to quickly analyse the state of the network.

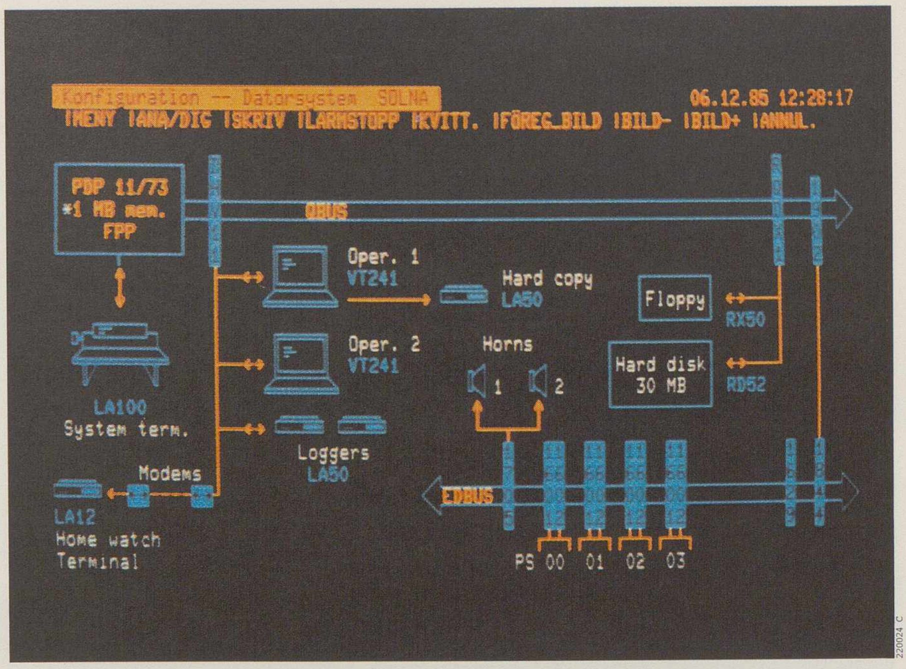


Fig. 1 – VDU display of the installation's hardware configuration

Principal System Requirements

The system must:

- Control, supervise and record events in high-voltage power networks
- Be easy to use for the operating personnel
- Make use of existing communication channels
- Not be affected by fluctuations in network voltage or transmission line disturbances
- Permit simple extensions, such as new substations or new breakers
- Be capable of having new functions added
- Ensure fast and effective processing of all data
- Offer high availability to limit the effects of unavoidable downtimes

BECOS 10 Plus Solves Solna's Problem

The BECOS 10 Plus control system from Brown Boveri was selected for this project. The decisive factors in this choice included the ease with which step-by-step extensions can be carried out and the speed with which operators without special training in computer science can master the system, plus the fact that this compact system entails only a modest investment.

The chosen solution with BECOS 10 Plus offers all the required features. The software covers all processing needs, including the purely SCADA functions and the calculation and historical archiving functions. In addition to having standard, tested programs, Brown Boveri have also developed programs for this customer's specific requirements. These facilitate street lighting control, presentation of archived data in table format, and data transmission to a separate and autonomous system that is not part of the BECOS 10 Plus system. Fast and efficient testing and commissioning are possible with the test program and the optional simulation program.

Fig. 2 – Rack-mounted units

Top: ED 1000 level (interfaces, communication, watchdog)
Centre: ED 1000 level (power supply, back-up)
Bottom: PDP 11/73 microcomputer with Winchester and floppy discs

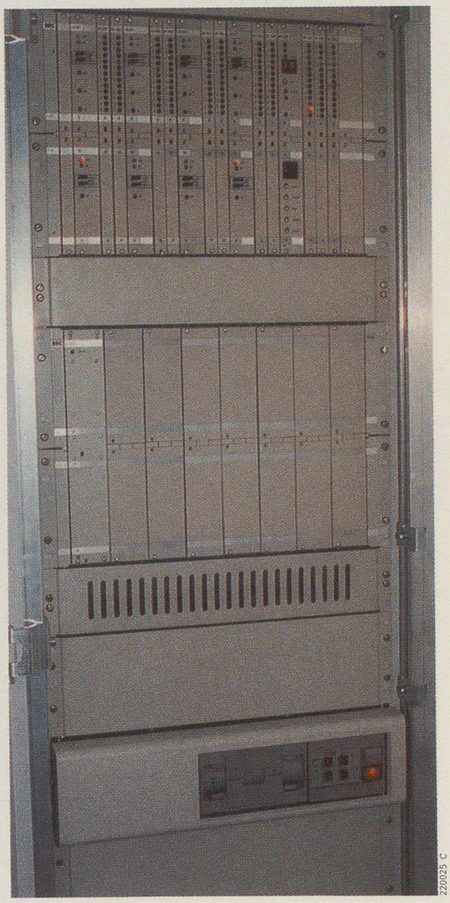


Fig. 3 – Terminal with keyboard

Left: Alphanumeric keys

Right and top row: Function keys

On the right is the hardcopy unit.

The Solna Control System

The complete installation *(Fig. 1)* comprises a control system from where the network and street lighting systems are controlled, a workplace for personnel training, data acquisition and processing facilities for real-time and historical data, and a SCADA system with 42 remote terminal units.

Control Centre

The control centre *(Fig. 2)* consists of a single computer configuration with the following equipment:

- PDP 11/73 computer with 1 Mbyte of MOS memory
- 31 Mbyte Winchester disc
- Two 400 kbyte floppy discs
- ED 1000 computer interface modules for data monitoring, transmission and reception over four links

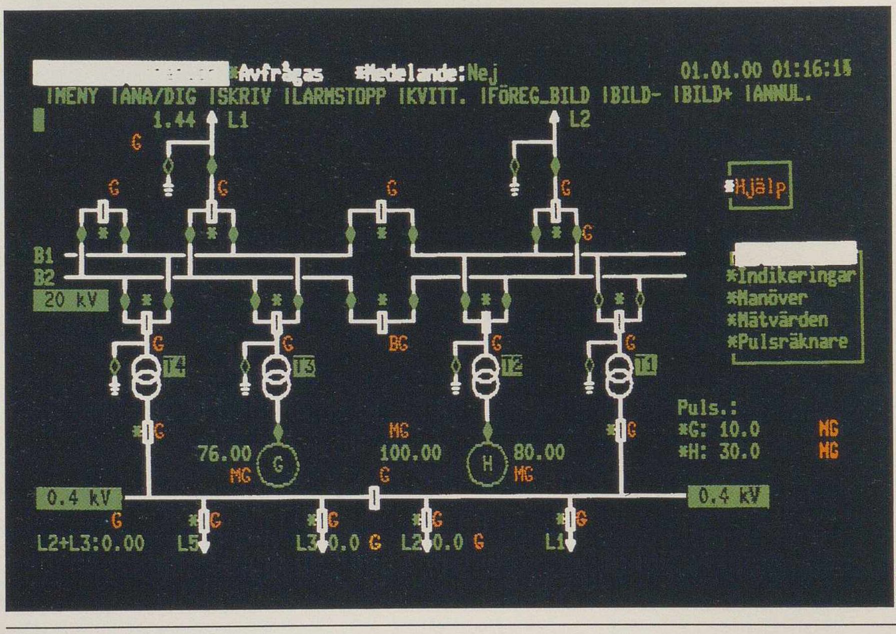


Fig. 4 – Station diagram

Fig. 5 – Graphic display or archived data

Three periods of different length have been selected.

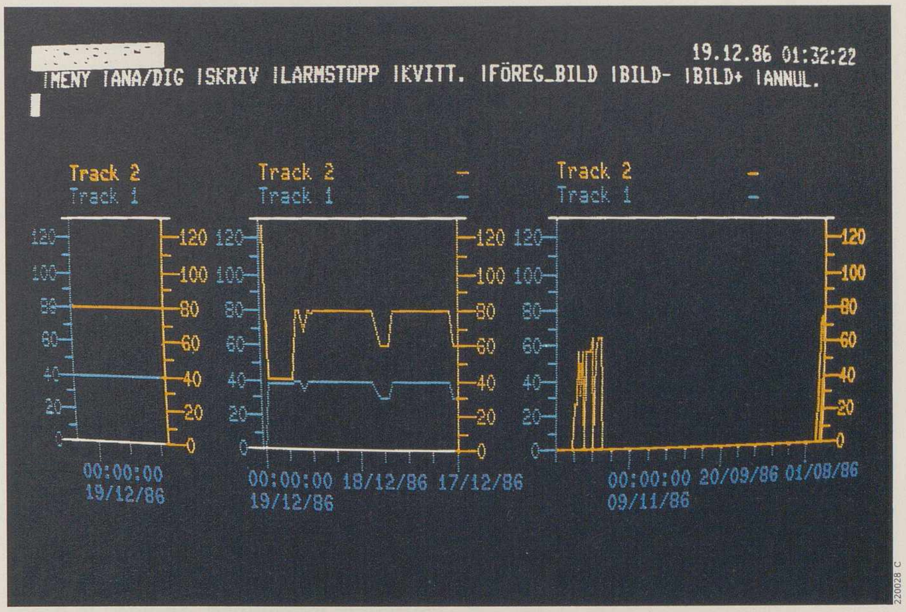


Fig. 6 – Town of Solna with the most important substations, including a curve showing the power consumed

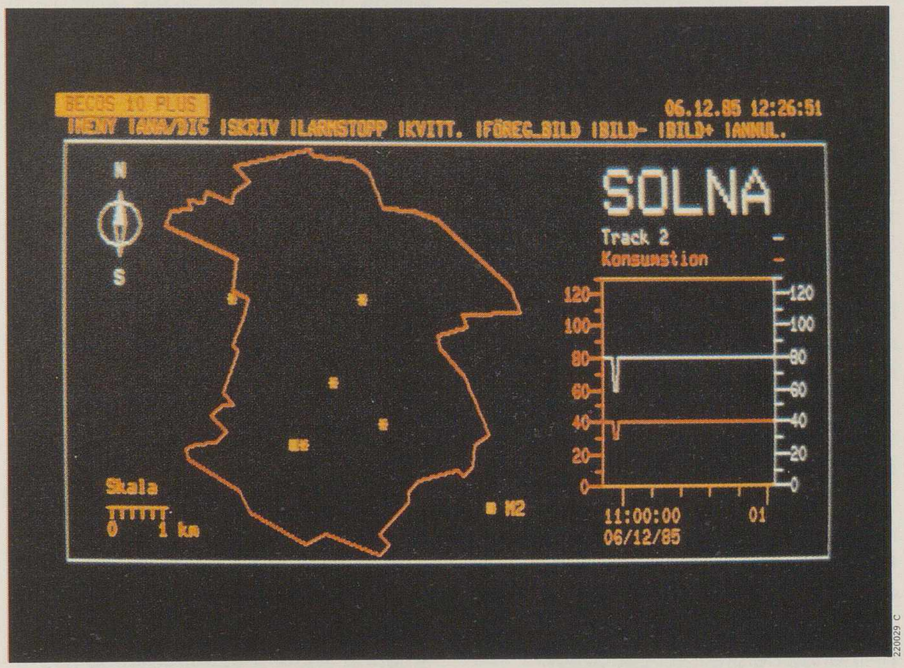
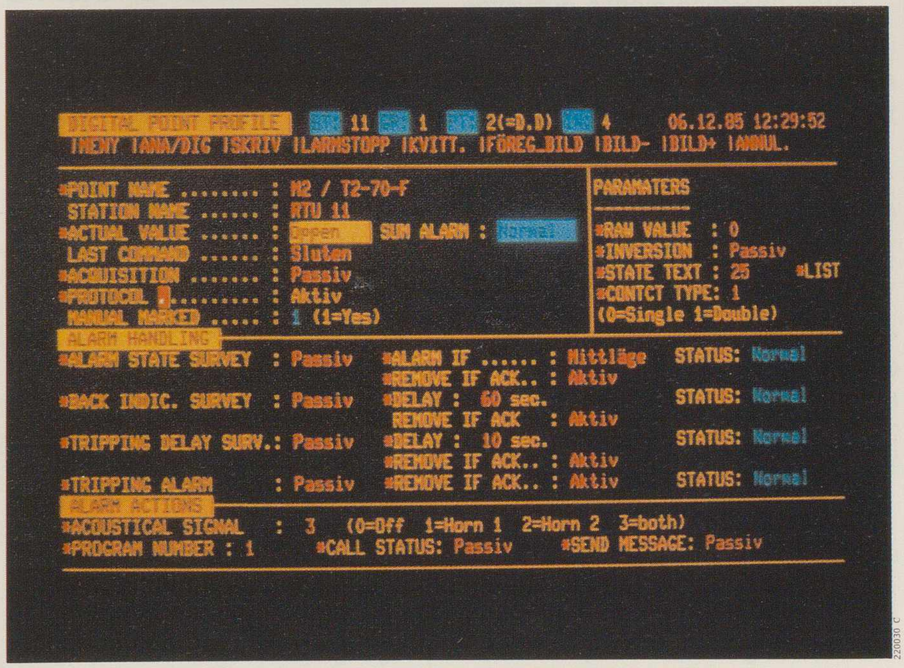


Fig. 7 – Profile of digital values



- One operator workplace

A non-interruptible power supply ensures continuous operation of this equipment.

Operator Workplace

The operator workplace *(Fig. 3)* comprises:

- One colour visual display unit (VDU) with graphics capability
- One keyboard with alphanumeric and dedicated function keys
- One printer for reports
- One hardcopy device for VDU pictures

Using the above equipment, the operator is able to execute the following operations simply by positioning the cursor on the VDU screen and pressing up to two function keys:

- Selection of VDU pictures, such as station diagrams, tables of measurements, alarm lists, etc. *(Fig. 4)*
- Graphic display of measurand values, historical or calculated data *(Figs. 5, 6, 7)*
- Alarm handling, acknowledgement and erasure
- Execute commands for system control
- Immediate notice of state changes or critical situations
- Operations with multiple analog values
- Dispatch of messages to operators working on later shifts, or to the autonomous system
- Verification of changes or commands before their execution

Three operating modes guarantee security by restricting access to particular system functions to authorized personnel. These modes correspond to functions used by the operator and programmers, and those used for training purposes. Specified additional functions may be added to these modes, each of which can only be accessed by means of a freely definable code.

The following functions can be activated in the different modes:

- On-line picture generation
- On-line database maintenance and extension
- Task definition
- Application programming
- Definition of symbols or their colours
- Redefining of function keys

This list, although representative, is not exhaustive.

Training and Data Maintenance Console

A training console featuring the same structure and handling as the operator's console is provided in a location away from the main control centre. It serves both for operator training (all commands and system responses can be simulated) and for test procedures carried out in the course of data maintenance.

Modifications and extensions are also possible with this console. To this end, the console has only to be set to the 'programmer mode' and new parameters introduced 'on-line'. In other words, the console at the workplace can be used for system development.

Although intended for training purposes, the console can of course also be used as an operator workplace. Each workplace can, in fact, be used in any mode as required, for training, operation or system development.

Home Watch Terminal

A list of recent events or historical data for a particular period can be printed out on a portable printer wherever a telephone line is available. This means that maintenance and supervisory staff can establish a link with the computer wherever they may be, even in their own homes, in order to be informed of the current situation and for them to react without losing valuable time.

The printer has an alphanumeric keyboard for direct transmission of data either to the computer itself or, in the case of messages, for presentation to the operator.

The main benefit of this terminal is its capability for directly obtaining essential, comprehensive information, without risk of error or omissions.

Remote Terminal Scanning

Three INDACTIC 33 and thirty-nine INDACTIC 34 RTUs provide the link to the user's process. Data is transmitted between these RTUs and the control centre over telephone lines leased by the national telecommunications company.

The system is divided into four transmission channels, according to the geographical areas defined by the customer. The transmission speed is 600 bauds for one of the channels and 200 bauds for the three others.

This configuration permits, for example, a maximum scanning cycle of 10 seconds for analog data. Software speeds up scanning when analog values must be known quickly following dispatch of a command.

Project History

BECOS 10 Plus underwent rigorous testing in Brown Boveri's test bay in the course of the 'Factory Acceptance Test'.

These tests were successfully repeated in Sweden following commissioning of the system, with the result that the four-week 'Site Acceptance Tests' took place in November 1985. These were completed to the customer's entire satisfaction. The installation was finally handed over to the customer on December 6, 1985, in accordance with the terms of the contract.

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Experience Gained with the Computer-Aided Plant Design System RAPAS

Efficient design of the plant layout and civil works is essential if power stations are to be built cost-effectively and according to schedule. Brown Boveri reduce costs and shorten processing times by employing their computer-aided plant design system, known as RAPAS. Experience has now been acquired with a number of plants designed using this system.

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Brown Boveri introduced in 1981 their three-dimensional program system RAPAS for the computer-aided design of power plant layouts. This system provides planners of power plants with an effective, high-performance tool which can successfully tackle the complex tasks facing them at every stage of design *(Fig. 1)*. A total of some 150 man-years of experience have been accumulated with this system to date. RAPAS is therefore proven in the field.

The name RAPAS is a German acronym for 'computer-aided plant design system'. The computer support ranges from acceptance of data from the system schematics to the generation of documentation for the prefabrication of pipework. The way in which RAPAS is used has been described on previous occasions [1, 2, 3].

Planning with RAPAS

The object of plant design (or layout planning) is to ensure that the components of the various systems are installed precisely in accordance with their functional duties. Any system which accomplishes this therefore also determines the dimensions of the power plant buildings and their locations on the site. Such projects involve specialists from the civil works, mechanical, electrical and control sectors, working together over a long period of time to find a overall plant layout which is both functionally optimal and cost-effective.

Since the plant design must proceed hand in hand with the planning of the civil works, Brown Boveri provide documentation which can be used as a basis for the calculations of static stress and load, and the drawings for the concreting and steel structures prepared by other companies.

The amount of information involved in plant and civil-works design has become so large and the planning itself so complex that its handling necessitates use of computer-aided, three-dimensional methods. Technical and economical advantages are gained, in particular, by transferring and storing the required data in the computer. This data can then be used for the cost-effective generation of layout and building drawings, isometric drawings of pipework configurations, parts lists and so on.

Design Sequence with RAPAS

As with conventional, manual design methods, the plant layout designer must first prepare the component data and associated system schematics relevant to the plant layout. The required component data can be taken from outline drawings and data sheets.

Project-related specifications for the pipework and valves, etc. are obtained from existing catalogues.

In parallel with this, the plant layout designer sets up on his CRT display a three-dimensional plant model with the building structures and components. This model is created with the assistance of catalogues and macros (stored instruction sequences for solving repetitive tasks). With these aids, complex geometrical representations of components and structural parts can be created from simple geometrical bodies, and design operations which are often repeated can be combined.

RAPAS supports the plant layout designer by systematically testing the pipework parts for consistency and for freedom from collision.

Should a stress analysis of the pipework system be necessary, the required data can be transferred directly from the computer model to the analysis program.

The computer uses CRT displays and plotters for output of orthogonal drawings and perspectives showing the results of the plant design obtained with the internal, three-dimensional model.

RAPAS prepares isometric drawings with the relevant parts lists for the pipework, and transfers these to stations where their processing is continued.

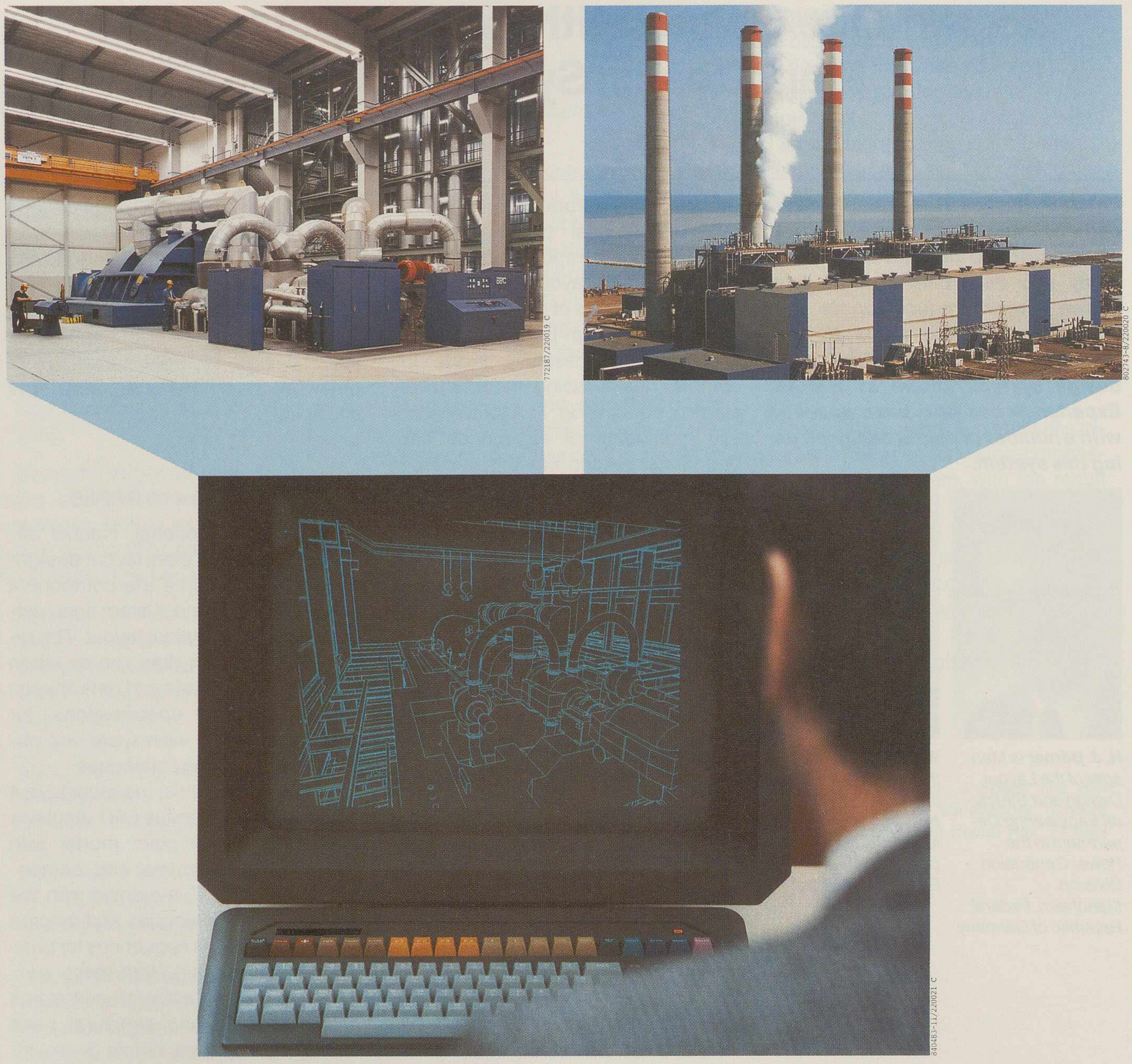


Fig. 1 – RAPAS computer-aided plant design system. This system has been successfully employed by Brown Boveri in the design and processing of several power plant projects.

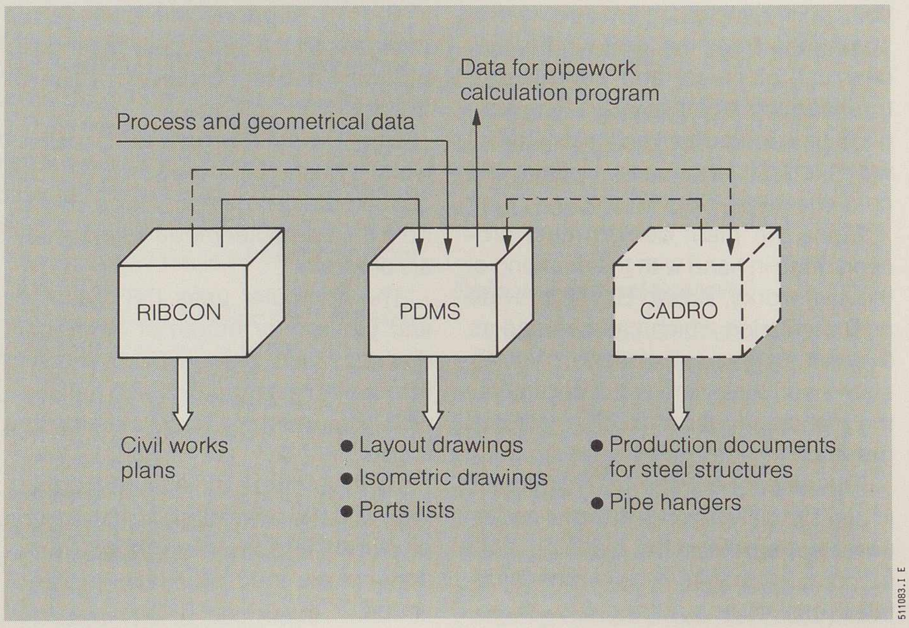


Fig. 2 – Structure of the RAPAS software

—— = Existing data interfaces
--- = Data interfaces being developed

RAPAS Software

Brown Boveri's RAPAS program system is based on their experience in designing and planning power plants over many years. Computer-aided design at all stages of plant design is made possible by the combination of different programs.

Figure 2 shows the basic structure of RAPAS. Its heart is the program system PDMS (for Plant Design Management System) from CADCentre Ltd., which is responsible for setting up the three-dimensional plant model and for generating layout drawings, isometric views of the pipework and also parts lists. The program RIBCON (from RIB/RZB GmbH) generates the three-dimensional building structures, which are either transferred to the PDMS or projected on civil works drawings.

Interfaces between RAPAS and the programs responsible for the system schematics and pipework calculations are also available.

Development work currently in progress aims at making use of the program CADRO in the future for generating production documentation for the pipe hangers and for their representation in the three-dimensional model.

PDMS and CADRO operate in text-interactive mode, in which the user enters his instructions on a keyboard and receives answers in the form of text and graphics. RIBCON operates in graphics-interactive mode.

RAPAS Hardware

The computer systems used *(Fig. 3)* have to satisfy complex, exacting requirements in order to implement:

- Acceptance of data from the system schematics
- Creation of the 3D plant model
- Transfer of data to the programs for the calculations
- Preparation and generation of drawings and lists

Trouble-free, cost-effective performance of these tasks is assured when the installed hardware is suitable for the job at hand. Brown Boveri have solved this problem by using VAX11/780 or 11/785 computers from DEC for the generation of the 3D model.

A complete workstation consists of a graphic and an alphanumeric CRT display, a hard-copy unit and a printer.

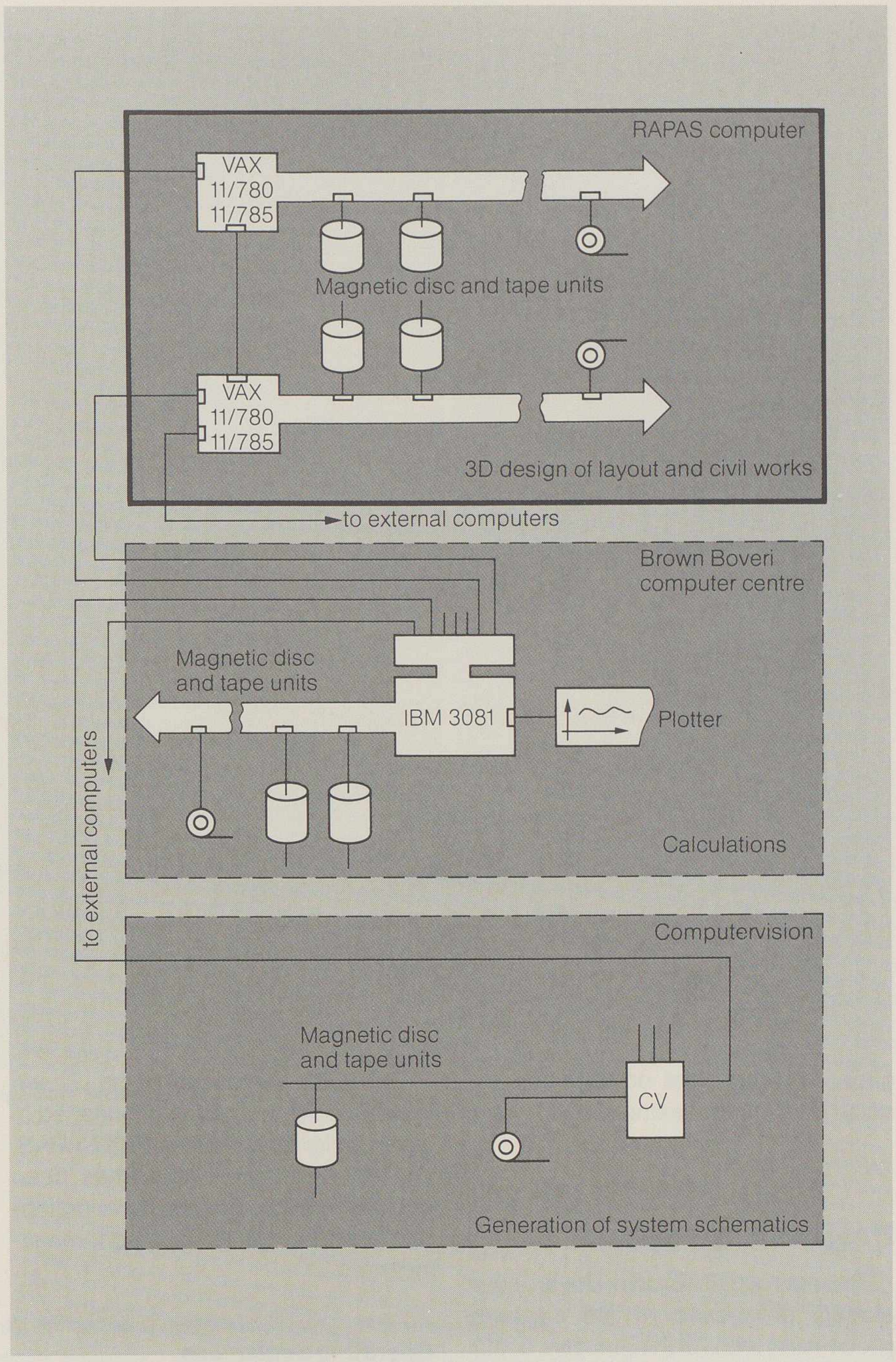


Fig. 3 – Hardware configuration of the computer-aided plant design system RAPAS

Most RAPAS design engineers have their own alphanumeric display to work on, while graphic displays are used by small groups of two engineers.

Data lines link the plant design computers in the Swiss and German offices of Brown Boveri.

Added to the RAPAS computer system are

- turnkey systems from Computervision (CV) for generating the system schematics, and a
- large computer from IBM for the calculations, with plotters connected for print-out of drawings.

Since the graphics-interactive work mode requires large computer capacities, use of hardware must be optimized by timely decoupling various processing steps *(Table)*.

The hardware outage times are so

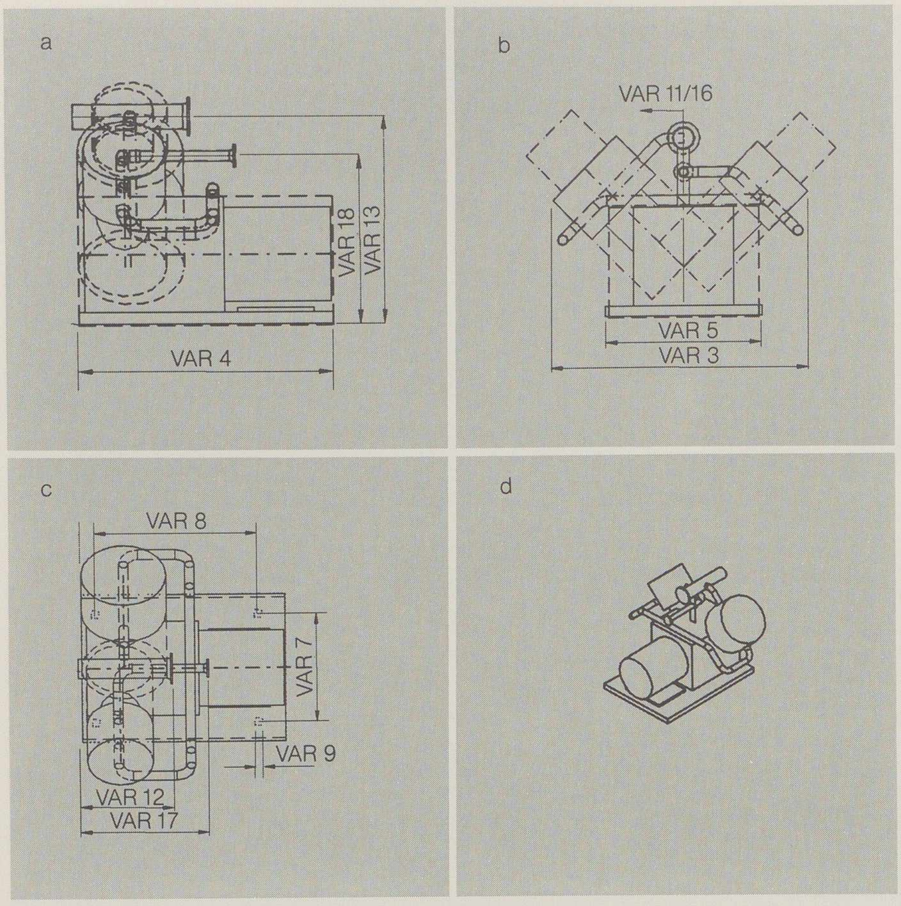


Fig. 4 – Component macro of a reciprocating compressor

a: View 1
b: View 2
c: View 3
d: 3D representation

short, however, that no 'bottlenecks' occur during processing of the project.

Project Experience

Projects which Brown Boveri have already processed or are currently processing with RAPAS involve a total of

- 17 turbosets and
- 6 machine rooms and switchgear buildings.

Some 50 members of the Brown Boveri Group are currently engaged in plant design engineering with RAPAS. The documentation which has been prepared ranges from offers to prefabrication drawings for pipework manufacturers.

Operating Sequences, Standardization

The operating sequences must be tailored exactly to the requirements of RAPAS plant design.

To keep the number of iterations small, and thereby ensure cost-effective use of RAPAS, precise information must be available at an early stage.

A standardized procedure and iterative methods are essential features of RAPAS applications.

Smooth, uninterrupted project processing depends a great deal upon how the catalogues are kept; they must be completely free from error and all standard parts must be included.

Software

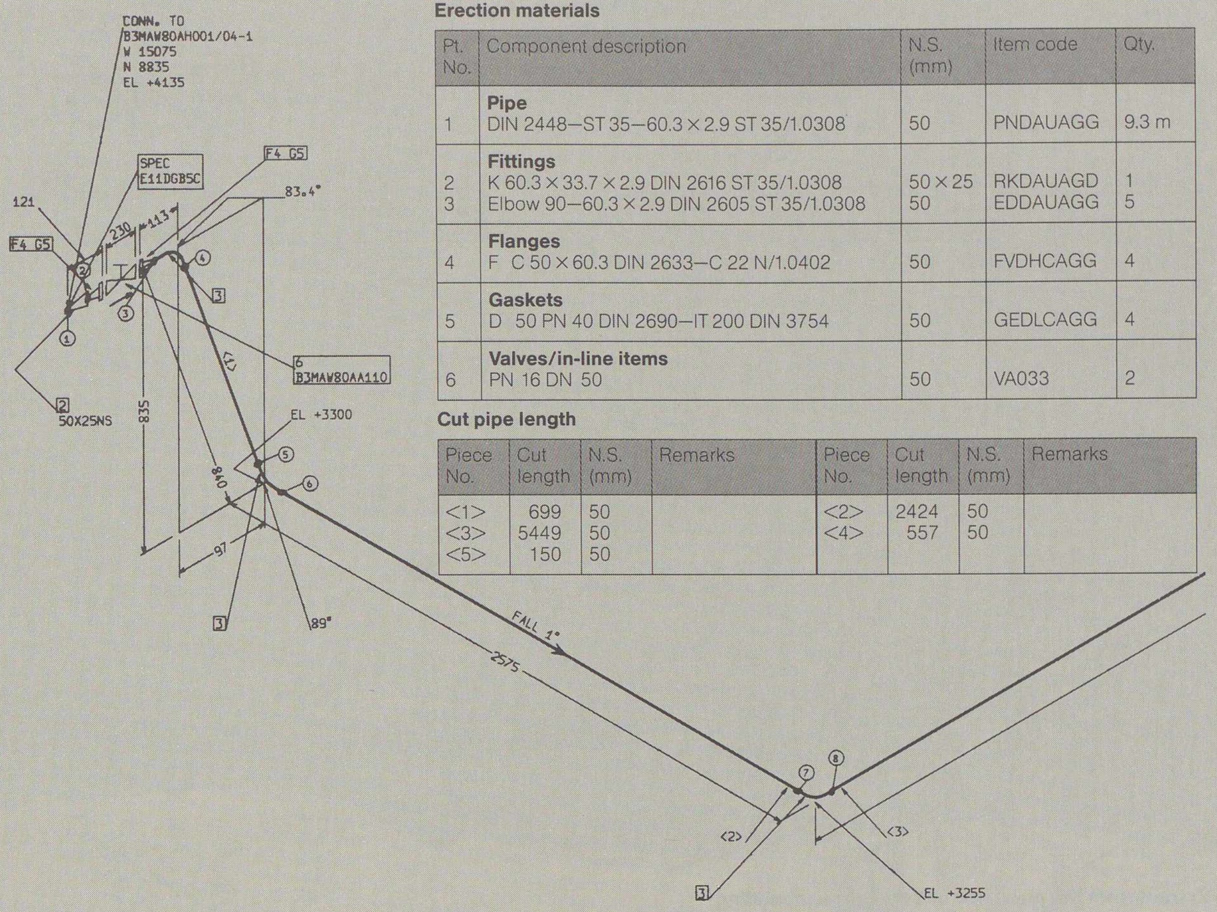
The experience gained worldwide with the program system PDMS is equivalent to 2000 man-years. An international user's organization co-ordinates the exchange of information and experience, as well as continuing development work.

The program systems PDMS and RIBCON—both central modules of RAPAS—are extremely reliable in operation.

New versions of the programs are introduced in such a way that the handling of a project is in no way disturbed.

Application of RAPAS hardware

Processing	Preferred method	Computer capacity required
Generation of computer model	Interactive Dialogue mode	During the day
Generation of drawings and lists	Batch mode	Preferably during the night and at weekends
Dimensioning of drawings, etc.	Interactive	During the day



Erection materials

Pt. No.	Component description	N.S. (mm)	Item code	Qty.
	Pipe			
1	DIN 2448—ST 35—60.3 × 2.9 ST 35/1.0308	50	PNDAUAGG	9.3 m
	Fittings			
2	K 60.3 × 33.7 × 2.9 DIN 2616 ST 35/1.0308	50 × 25	RKDAUAGD	1
3	Elbow 90—60.3 × 2.9 DIN 2605 ST 35/1.0308	50	EDDAUAGG	5
	Flanges			
4	F C 50 × 60.3 DIN 2633—C 22 N/1.0402	50	FVDHCAGG	4
	Gaskets			
5	D 50 PN 40 DIN 2690—IT 200 DIN 3754	50	GEDLCAGG	4
	Valves/in-line items			
6	PN 16 DN 50	50	VA033	2

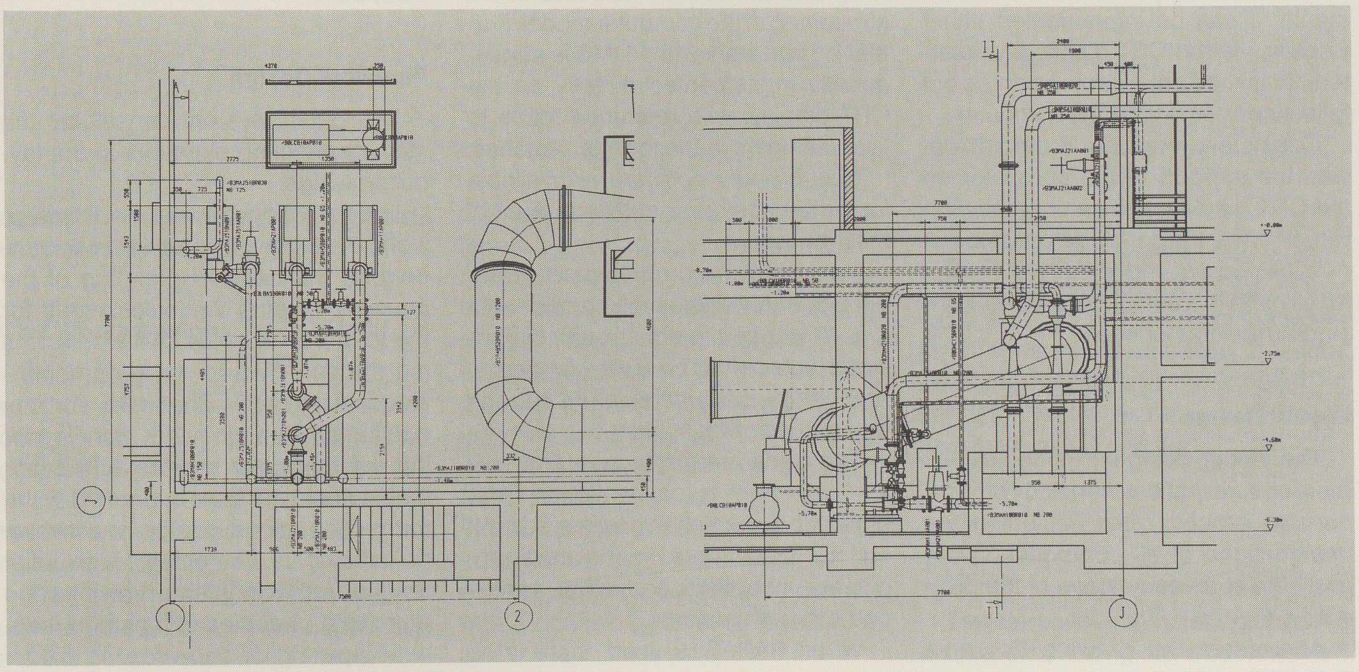
Cut pipe length

Piece No.	Cut length	N.S. (mm)	Remarks	Piece No.	Cut length	N.S. (mm)	Remarks
<1>	699	50		<2>	2424	50	
<3>	5449	50		<4>	557	50	
<5>	150	50					

511086.I

Fig. 5 – Extract from an isometric drawing of pipework with parts list

Fig. 6 – Plan view (left) and cross-section (right); extract from the layout drawings for a pump building



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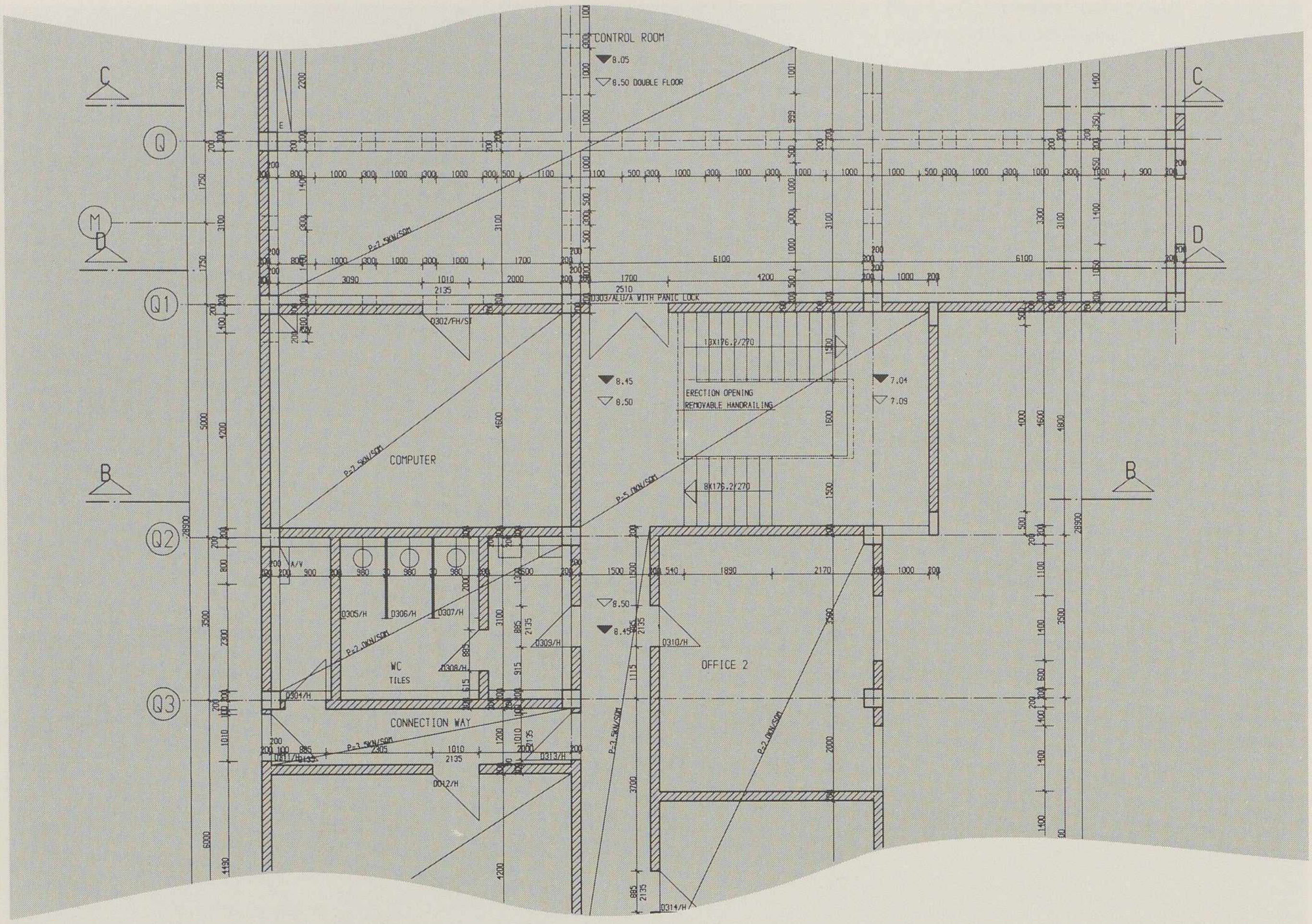

Fig. 7 - Extract from the plan view of a switchgear building

Collision testing is one of the main features of design work for complex plants. It can be implemented either visually, via the CRT displays or plotters, or in the form of tables printed out following checking by the computer.

Consistency testing is carried out with the support of the computer on the CRT display, and can be checked visually. The tests include checking of nominal bores and pressure ratings for all parts in a section of pipework, including the connections.

Layout Design

The layout designer using RAPAS must ensure that detailed and comprehensive process data (including the designations of all components) are available at an early stage of the project.

At present the drawing board is used only to prepare the concept. The results obtained form the basis for the structuring of the computer model. Further design work with PDMS is subsequently implemented directly on the CRT display, with reference made to layout studies in the form of sketches.

User-friendly software is available for the dimensioning and annotation of the drawings.

Numerous preprogrammed three-dimensional macros of components *(Fig. 4)* whose project-specific dimensions have only to be added, and comprehensive parts catalogues support rational use of the system.

The generated drawings and lists are equivalent to conventionally prepared documentation and are accepted by customers, consultant engineers, suppliers and other participants in such projects.

When RAPAS is used, there is no need for turboset models to be specially built.

Pipework Design

The piping system constitutes the main connecting elements in the layout drawings.

In conventional power plant design work, the pipework suppliers often undertook the detailed planning of the piping, including the calculations for the load points in the civil works. It is more cost-effective with computer-aided design when Brown Boveri carry out the detailed pipework planning for the different plant sectors as the isometric drawings are a byproduct of the three-dimensional design, and involve no extra costs. The pipework supplier receives either isometric drawings and parts lists or copies of these on magnetic tape *(Fig. 5),* and adds to the doc-

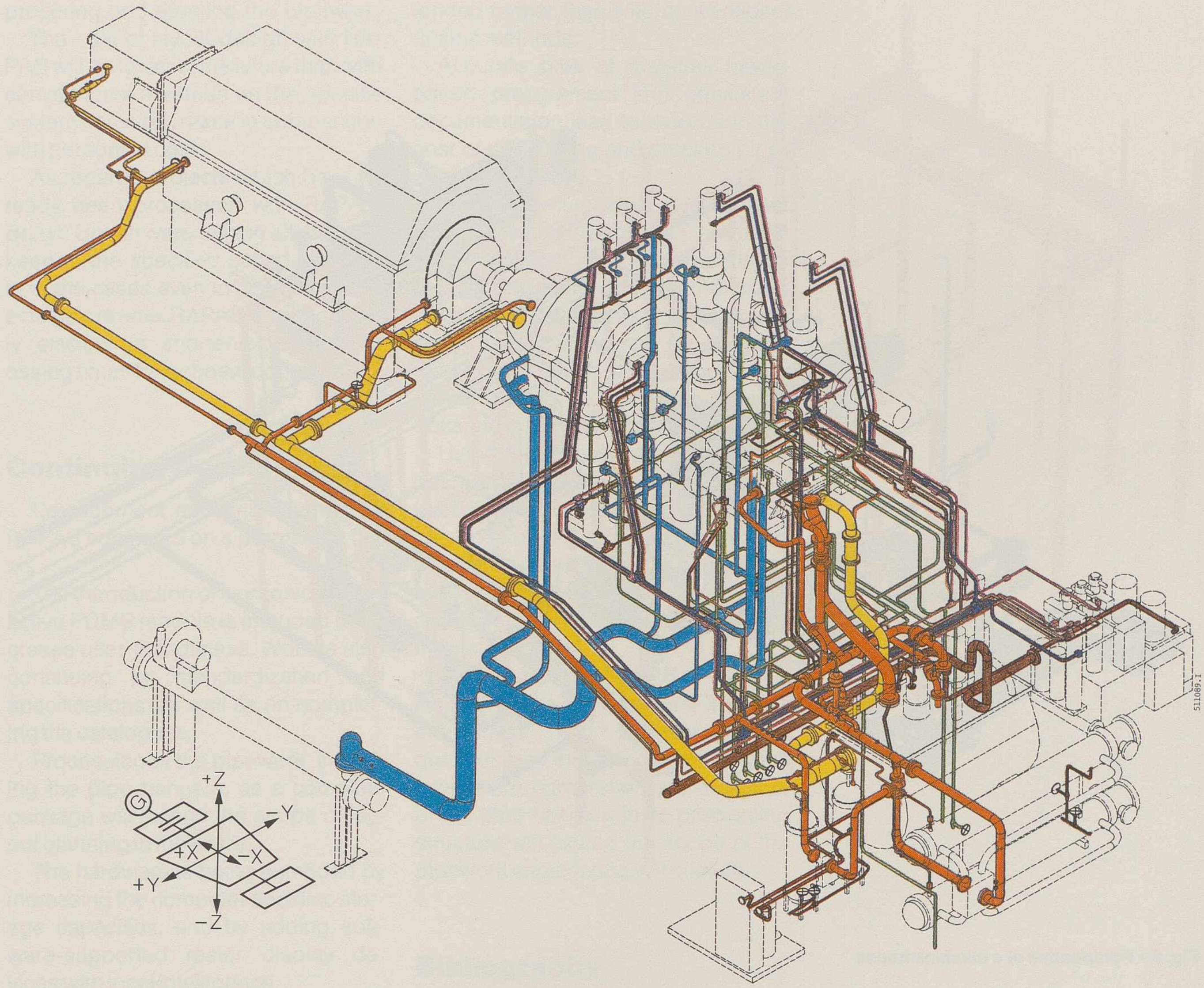

Fig. 8 – Perspective of a steam turboset with internal piping

OIL RETURN	DRAIN	CONTROL OIL
LUBE OIL	GLAND STEAM SUCTION	POWER OIL
STEAM	CONTROL OIL RETURN	SAFETY OIL

umentation according to his own production requirements.

Civil Works Design

The program system RIBCON, which is specifically for the civil works design, has been successfully integrated in RAPAS. It facilitates cost-effective planning of all civil works and the design of building structures for layout drawings *(Fig. 6)*.

The 'layer' method used supports uninterrupted design work. Building models consist of several layers which themselves comprise a number of different planes. These planes contain construction lines, dimension lines, texts and section lines (hatching). The representation of the various layers can be suppressed on the CRT display as required, thus enabling the structure to be built up in accordance with requirements and the speed of work to be adjusted to suit. As with the PDMS program system, processing is speeded up by macros which, in the case of RIBCON, contain design units with a specific geometric representation.

Approach

A compound approach to design has proved to be an advantage. In this case, a certain proportion of the working time is spent obtaining the data, preparing drafts and participating in meetings, while the rest of the time is spent at the CRT display.

Training

The personnel selected for RAPAS project processing have been trained

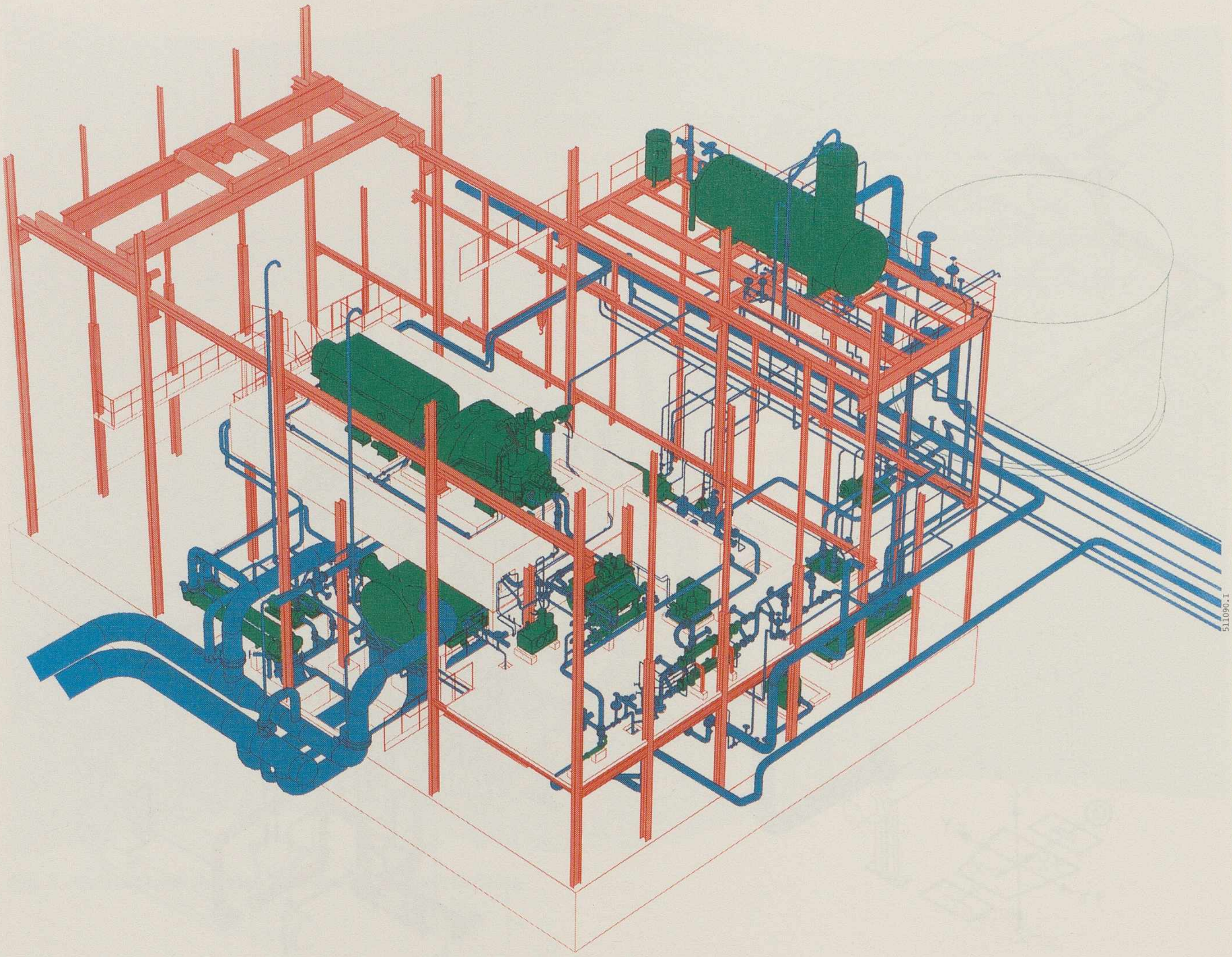

Fig. 9 – Perspective of a machine house

together in inter-group courses to facilitate a broad exchange of experience. The number of employees trained in the use of RAPAS is sufficient for today's requirements. Further training courses will deal specifically with applications, and will involve small groups of trainees working to the same program.

Instruction in the use of RIBCON lasts one week, while approximately four weeks are required for the program system PDMS. The length of the subsequent training on the job depends upon the knowledge which the trainees bring with them and their natural ability.

Modifications

Modification procedures are also supported by the computer. Specific program functions simplify these procedures and secure the contents of the documentation (with date and reason for the modification).

Engineers engaged in design work may only undertake modifications within their own sphere of responsibility.

Documentation

The results of the design work are presented for the most part as orthogonal views and sections in the layout drawings *(Fig. 6)* and building plans *(Fig. 7)*.

Additional perspectives *(Figs. 8 and 9)* have proved useful for offers as well as for certain erection documentation, training documentation and operating handbooks.

Special advantages are offered by the selective representation of certain model contents. This feature enables the components of different specialist fields to be separated, or 'overloaded' representations to be split up into several drawings at only little extra cost. Drawings of cable ducting and measuring points, for instance, can be easily prepared with this method.

Costs, Scheduling

For layout and pipework design drawings for turbosets and machine rooms, and also for the building plans for these rooms and the switchgear buildings, the cost of design work with RAPAS is of the same order as for conventional design methods. However, the consistent and practically error-free documentation obtained with RAPAS results in a saving in the cost of procuring and erecting the pipework.

The cost of layout design with RAPAS will be lower in the future than with conventional methods as the specific system costs decrease in comparison with personnel costs.

As regards projects which have already been processed with RAPAS, Brown Boveri were able in all cases to keep to the specified schedules, and in some cases even to complete projects before time. RAPAS was especially efficient in shortening the processing times for turboset contracts.

Continuing Development

Development and improvement of RAPAS continues on a permanent basis.

The introduction of a graphics-interactive PDMS module is intended to increase user-friendliness. Work is also continuing on standardization and specifications, as well as on completing the catalogues.

Processing of the pipework, including the pipe hangers, as a complete package will extend the scope of layout planning in the future.

The hardware is being extended by increasing the computer and disc storage capacities, and by adding software-supported raster display devices with local intelligence.

Summary

Brown Boveri have employed the computer-aided RAPAS system for designing plants for about five years. The experience gained in service is equivalent to approximately 150 man-years. Documentation which can be generated ranges from offers to prefabrication drawings for the piping [4]. Pipework engineering can be extended further than with conventional design methods.

Accurate bills of material, lower-priced procurement and consistent documentation lead to savings in the cost of purchasing and erecting pipework installations.

RAPAS documentation is at least equivalent to conventionally prepared documentation. Since perspectives can also be generated, RAPAS offers additional advantages for sales engineers, for training and for erection. Installations which have already been erected testify to the improvements obtained in the quality of the design.

Using RAPAS, Brown Boveri have been able to keep to the schedules specified for projects, and in some cases have even completed them long before the deadline. It was possible to reduce the processing time between receiving the order and hand-over to the customer.

Development of RAPAS is continuing with a view to improving its user-friendliness and operational sequences, and to making its catalogues even more comprehensive. Inclusion of the pipe hangers in its processing structure will extend the scope of the pipework engineering in the future.

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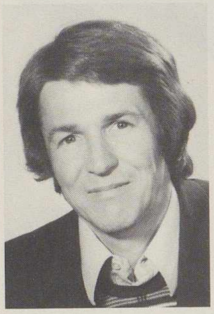
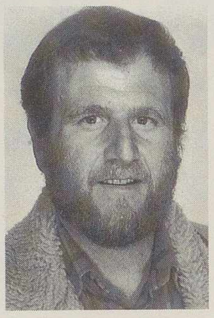
Superconductors for Use in Electromagnetic Windings

Over the past two decades, the technology used in the manufacture of superconducting wires—particularly those based on niobium-titanium alloys—has developed to the point where they can be reliably used for electromagnetic windings. Superconductors manufactured by the Swiss Superconductor Consortium are used in a wide variety of magnet systems for research equipment employed in high-energy physics and nuclear fusion. The authors look at the basic properties, construction and applications of superconductors.





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Overview of Physics Involved

Fundamentals of Superconductivity

The essential feature of superconductivity is the complete disappearance of electrical resistance in some materials below a certain transition temperature close to absolute zero. The physical characteristics of superconductivity are outlined briefly in the following.

The capability of electrons to flow through a solid without colliding with the crystal lattice—which would lead to electrical resistance and heat being produced—cannot be explained by classical physics alone. A satisfactory explanation of the various aspects of superconductivity only became possible in 1957 with the quantum mechanical description by Bardeen, Cooper and Schrieffer. The central concept of this theory, known as the BCS theory, is based on the formation of electron pairs (so-called Cooper pairs) through an interaction with the lattice vibration, these pairs having a lower energy than unpaired conduction electrons. The electrons of a pair exchange energy mutually without energy loss by way of the lattice and can thus move through the material without resistance. All Cooper pairs are in the same quantum mechanical state, i.e. they can be described by one single wave function. As the temperature is reduced towards absolute zero, increasingly more electrons condense to Cooper pairs up to a certain maximum value. If the energy decrease achieved by the transition to the superconducting state is reversed in some way (via the temperature, magnetic field, current, etc.), the Cooper pairs are broken up and the system returns to the normal conducting state with resistive current transport.

Not all superconductors behave in the same way in a magnetic field. At a temperature below a critical value T_c, most superconducting elements displace the magnetic field entirely, i.e. it is moved away from the interior due to superconducting screening currents flowing in a thin surface layer. This behaviour, which is referred to as the Meissner effect, cannot be attributed solely to the ideal conductivity of the material since the field displacement in the superconducting state always occurs independently of the material's previous history. Above a maximum flux density (the critical field B_c, also termed the thermodynamic critical magnetic field) a very sudden transition to the normal conducting state takes place and the magnetic field penetrates the material. Due to the superconductor's geometry and the associated demagnetization factor, the flux density can then fall below the value B_c, leading to the formation of an intermediate state with normal and superconducting zones. This behaviour is exhibited by most superconducting elements (e.g. Pb, Hg, Sn, Al and so on) and is designated Type I superconductivity. A current can only flow on the surface of such a material, and may not create a magnetic field greater than B_c since, otherwise, normal conduction would again take place. Since the critical fields of Type I superconductors are far below 1 tesla, there is little prospect of these materials being used for conductor production. An exception is the use of the Josephson effect in measurement systems and in high-speed logic components.

The elements niobium (Nb) and vanadium (V), as well as numerous alloys and intermetallic compounds, behave quite differently; they remain superconducting even in higher magnetic fields since, above a small lower critical field B_{c1} (with an order of magnitude of about 10^{-1} T), magnetic flux in the form of quantized flux lines can penetrate the substance. This condition, the so-called Shubnikov phase, is the characteristic feature of Type II superconductors. The flux lines, also referred to as flux vortices, exhibit normal conduction in the interior and repel each other; if no obstacles are present this usually leads to a triangular arrangement within the material. The density of the flux lines increases with an increasing magnetic field until they finally overlap. No intervening superconducting zones can then exist, and the material assumes the normal conducting state. For certain materials, the corresponding magnetic field, called the upper critical field B_{c2}, can be far above 20 tesla.

Another contrast with materials of Type I is that with the penetration of magnetic flux, current can flow inside a superconductor of Type II. In an ideal, defect-free superconductor of Type II, the Lorentz force causes a transport current to set the flux vortices in motion through the material. Each flux movement, however, leads to an induced voltage and the transport current no longer appears resistance-free; energy is dissipated.

In practical superconductors, however, the flux displacement is more or less inhibited by the flux lines finding locations where the energy for their preservation is lower and, as a result, remaining fixed. This flux anchoring (so-called pinning) is possible wherever there are defects or inhomogeneities in the crystal structure, as for example in voids, normal-conducting precipitations, phases with poorer superconducting characteristics than those of the host material, dislocation concentrations, and at the grain boundaries. The various pinning centres are not all equally strong, and the summation of the influence of all pinning centres in the material on the flux-line lattice yields the volume-pinning force F_p as a function of the magnetic field and temperature. The Lorentz force associated with the transport current, and which influences the flux-line lattice, must be greater than F_p in order to cause a significant flux motion. For each value of the magnetic field in which the superconductor is situated there is a maximum critical current density J_c below which no flux motion occurs and the electrical resistance is equal to zero.

Each time the transport current changes or external magnetic fields change, the flux-vortex distribution in the superconductor must adjust to the new conditions. This cannot occur without flux motion, leading to an albeit very small conductor resistance. What is more, the flux lines can only be displaced with great difficulty because of the pinning. This leads to non-uniform flux densities in the material. If an applied magnetic field is increased, then the internal flux lags behind this change, while the flux remains trapped if the magnetic field decreases. The magnetization over a field cycle thus passes through a hysteresis loop, the area of which is a measure of the quantity of heat occurring per cycle. This dissipative process can be reduced by dividing the superconductor into many fine filaments embedded in a copper wire.

It is clear that the three critical values T_c, B_{c2} and J_c are interdependent. Thus, for example, the critical value of the magnetic field at a temperature of 4·2 K—the boiling point of liquid helium at normal pressure—and in the presence of a transport current, is smaller than if no current were flowing. The critical temperature is defined as the transition temperature in the absence of a current or magnetic field. The critical magnetic field is usually specified for a certain temperature in a current-free condition, while the critical current density is determined for a defined temperature and magnetic flux density.

Materials with the above-mentioned pinning characteristics are designated 'hard Type II superconductors'. They can carry very high current densities (up to 10^4 A/mm^2 at 5 T and 4·2 K) without losses. Some important examples of this category of superconductors are given in *Table I.*

Superconducting Materials of Technical Interest

The alloy NbTi enjoys its key position among the superconductors in use today not only because of its good superconducting qualities, but particularly as a result of the fact that it is excellent for processing together with copper. NbTi superconductors can be produced economically in long length and can be made into cables and insulated by conventional methods. The resulting conductor is ductile, so that windings for electromagnets can be made without any particular difficulties.

Superconductors are produced from NbTi alloys with a Ti content of 45–50% by weight, which are melted and remelted in electron-beam or electric-arc furnaces. The critical current densities reach values up to 3000 A/mm^2 (at 5 T and 4·2 K), where the density of dislocations and special, fine normal-conducting titanium precipitates play a decisive role.

Of the materials with the cubic body-centred crystal lattice designated A15, the compounds Nb_3Sn and V_3Ga are considered foremost as they can be produced by diffusion reaction. However, their very brittle behaviour detracts from their attractive superconducting qualities: under tension, Nb_3Sn breaks in the elastic region at an elongation of only 0·2%. A15 superconductors cannot therefore be manufactured directly by extrusion and drawing processes, although this is routine with NbTi. The superconducting compound can only be produced with the final diameter of the wire.

In the case of Nb_3Sn, numerous Nb rods in a matrix of bronze (a copper-tin alloy), with a maximum allowable Sn content of 13% by weight, are usually drawn into a wire which subsequently undergoes diffusion annealing, typically at 700°C for 60 h. As a result, the tin migrates to the niobium and reacts to yield Nb_3Sn. An alternative manufacturing process, which Brown Boveri helped to develop, involves processing niobium rods in pure copper into a wire. A tin layer is subsequently applied to the wire and diffused into the copper by heat treatment. Transformation of the niobium into Nb_3Sn results from the annealing reaction. Instead of a coating of tin being applied to the

Table I: Important Type II superconductors

Material		T_c [K] without magnetic field	B_{c2} [T] at 4·2 K
Nb	ductile	9·2	0·2
NbTi	ductile	9·5	11·5
V_3Ga	A15 very brittle	15·4	24
Nb_3Sn	A15 very brittle	18	26
Nb_3Al	A15 very brittle	18·9	29
Nb_3Ge	A15 very brittle	23·3	37
NbCN	very brittle	16	50
$PbMo_6S_8$	very brittle	15	60

Fig. 1 – Assembly at Brown Boveri's Mannheim works of a prototype deflecting magnet for the HERA project of DESY, Hamburg. This is the first superconducting dipole magnet to be designed and manufactured by industry.

surface, it is possible to incorporate it in the original billet and to form it with the wire. The two variations mentioned above have the advantage that no bronze has to be processed, since after 30–40% cold working this may become brittle and require intermediate annealing. Furthermore, the limitation placed on the allowable quantity of Sn with the bronze method no longer applies, permitting larger cross-sectional areas of superconducting material to be produced.

The processing of A15 superconductors into coils and other electrical components is difficult as the permitted bending radii are limited and irreversible damage could easily occur. One possible solution is to wait with the diffusion annealing until after the coil has been wound. However, this process requires insulation materials such as quartz glass fibres or ceramic materials which can withstand temperatures of 700 °C.

To what extent other materials, such as the Chevrel phase $PbMo_6S_8$ or the compound niobium carbonitride (NbCn) will gain acceptance depends on whether it will be possible to use them to produce long wires with reproducible characteristics at competitive prices. In addition, as explained below, it must also be possible to embed the superconductor (in the form of fine filaments) in a highly conductive host material of the matrix.

Swiss Superconductor Consortium

As early as the 1960s, soon after the discovery of high-field superconductors, a number of Swiss companies formed a group with the goal of developing and manufacturing superconducting wires and cables. Today, the Swiss Superconductor Consortium counts as its members Brown Boveri, who have the overall administrative and technical responsibility, the companies Metallwerke Dornach and Schweizerische Metallwerke Selve, which specialize in the area of copper material processing, and Isola-Werke and Huber & Suhner, who are specialists in the manufacture of a wide range of wires and cables and their insulation. The extensive range of production machines available and the wealth of experience gained over the years make it possible for a broad spectrum of requirements—from simple superconducting wires to monolithic or cabled high-current conductors—to be satisfied.

Superconductor Applications

The use of superconductors is practicable where either strong magnetic fields or very large field volumes are required. With superconducting laboratory magnets, which are used widely throughout the world, magnetic fields of 2 to 15 T and above can be generated.

Large-scale use of superconductors began with detector magnets for

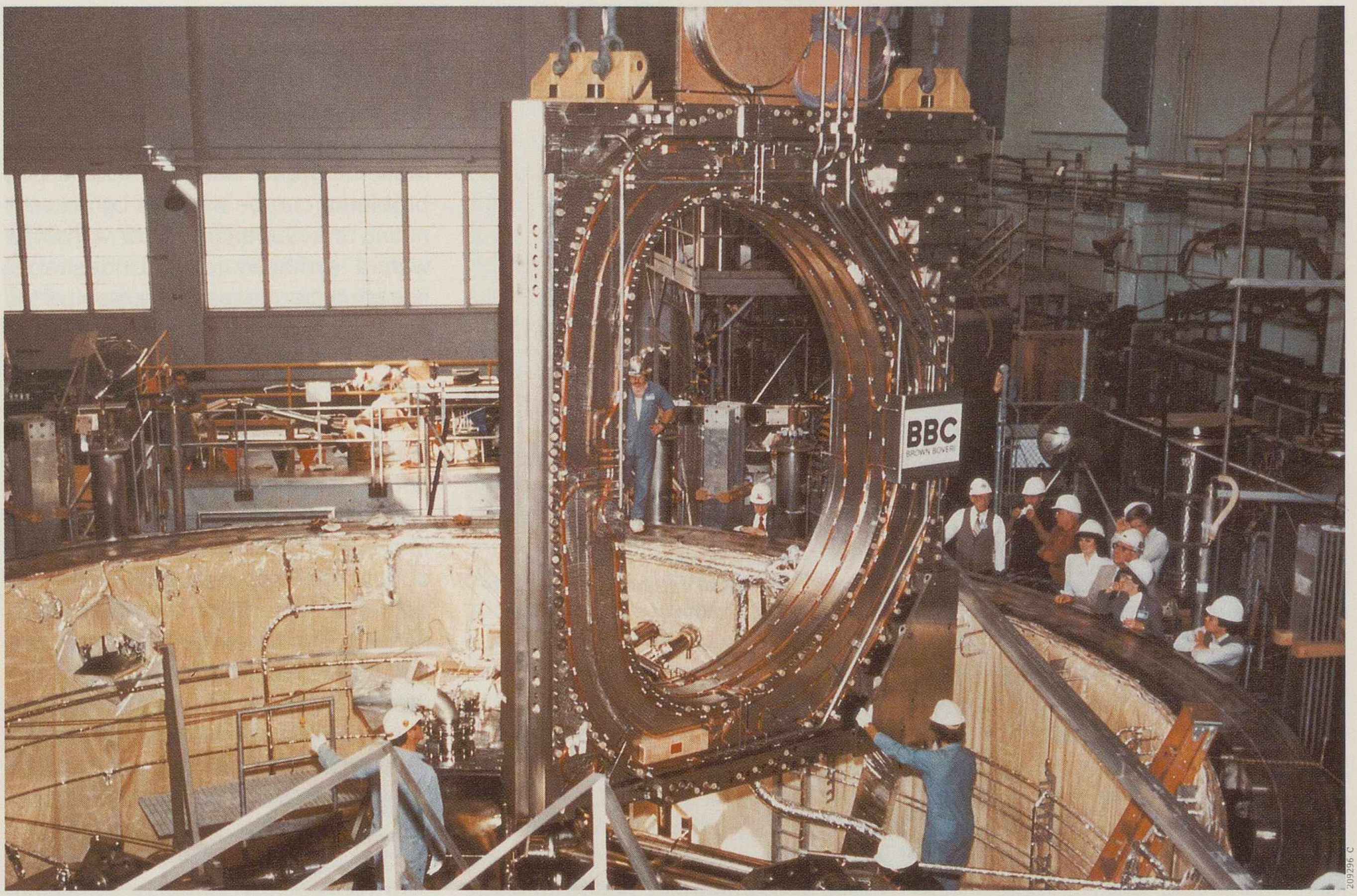


Fig. 2 – Installation of the Swiss LCT coil at the test facility of the Oak Ridge National Laboratory, Tenn., USA. A Swiss contribution to international fusion research in which Brown Boveri cooperated with SIN. Initial tests have been successful.

high-energy physics. In fact, the magnet placed in operation in 1971 in the large European bubble chamber (BEBC) at CERN[1] in Geneva is still today the largest single magnet ever built. In 1972, two superconducting magnet coils (5·5 m in diameter) supplied by Brown Boveri for the Omega spark chamber magnet at CERN were also put into operation, this being the first time that a hollow conductor had been used. Since liquid helium flows under pressure through the cable, it was possible to provide the conductor with glass-fibre insulation impregnated with epoxy resin without impairing the cooling [1]. And for the Swiss Institute for Nuclear Research (SIN), thirty coils were built for two muon channels [2] and two sets of 65 coils for the toroidal deflecting and focussing magnet system of the pion therapy facility PIOTRON [3].

[1] CERN = Organisation Européenne pour la Recherche Nucléaire

As more experience was gained in the application of superconductors, the step was taken to build superconducting magnet systems for large particle accelerators, such as that at the Fermi Laboratory near Chicago, in order to obtain even higher particle energies through stronger magnetic fields for the same size of installation. Brown Boveri also contributed significantly to the development of the deflecting magnets for the HERA project presently under construction at the German electron-synchrotron DESY in Hamburg. *Figure 1* shows the construction at Brown Boveri's Mannheim works of a prototype magnet, for which the conductor in Fig. 6b was used. The order for 465 km of superconducting cable (Fig. 5c) for half of the HERA deflecting magnets can be considered a great success for Brown Boveri and the Swiss Superconductor Consortium.

A particularly promising source of energy for the future is nuclear fusion employing the principle of magnetic plasma confinement. A toroidal arrangement of the magnet coils, which must be superconducting to achieve a positive energy balance, is particularly well suited for this. And, in connection with the technological development project known as the 'Large Coil Task', which is coordinated by the International Energy Agency, Brown Boveri (under the project leadership of SIN and in cooperation with the Swiss Superconductor Consortium) have also been involved in the development and production of one of the six D-shaped (4·5 × 3·6 m) coils being tested at the large coil test facility of the Oak Ridge National Laboratory (*Fig. 2* and 6d) [4].

Other possible areas in which superconducting magnet windings can be used, for instance in magnetohydrodynamic (MHD) energy generation, energy storage (SMES), magnetic separators, magnetically levitated railways, and turbogenerators [5], have great market potential for the future, although they are still at the develop-

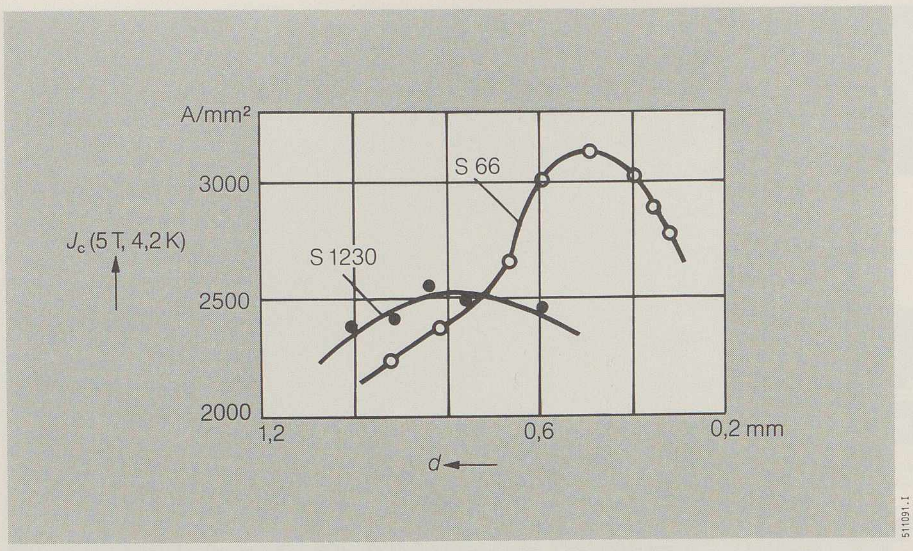


Fig. 3 – Critical current density J_c in NbTi at 5 T for S 66 and S 1230 wires as a function of the wire diameter, i.e. the degree of final cold working. The point of optimization is the diameter where the maximum value occurs, and can be adjusted by pretreating the wire.

ment stage and must compete with conventional technologies. A real breakthrough on the international market, however, has been made in the area of nuclear spin analysis technology and, more recently, in nuclear spin tomography, where superconducting magnets of high field homogeneity are essential.

The wide variety of applications for superconductors ensures that custom-made conductors will remain one of their characteristic features.

NbTi-Based Multifilament Superconductors

The first commercially available superconductors were niobium-zirconium alloys, which are difficult to work and do not exhibit particularly good superconducting properties. They were finally superseded by the alloy niobium-titanium, which is now generally used in most superconductor applications. Only in special cases where particularly high magnetic fields in excess of 8 T have to be produced, must the very brittle and costly compound Nb_3Sn be used with its attendant risk.

The most important design criterion for a superconductor is, of course, the required current-carrying capacity for a specified temperature and magnetic field, this yielding the required NbTi cross-section. In most cases, the total current of the conductor must be shared between several individual strands formed into cables and connected in parallel, not least because the inductance of an electromagnet would otherwise be too great. In addition, superconductors demand specific design measures without which operation would be uncertain or even impossible, and inadmissibly high energy losses would occur in a.c. applications even though the material is superconducting. Extensive research and development carried out by Brown Boveri have yielded important knowledge which ensures the reliable operation of superconducting installations.

Electric Stabilization of Superconductors

To stabilize a superconductor electrically means to create a situation in which, under specific conditions, the superconducting state is maintained or recovered even in the event of a disturbance. Disturbances in a magnet can have many causes, a distinction being made between continuous heat sources and short-time mechanical or magnetic faults. Since superconductors often carry large currents in high magnetic fields, the correspondingly large forces arising lead to conductor movement and frictional heat. These problems can be avoided by impregnating the superconductor windings with a synthetic resin. Undesirable, fine cracks in the resin as a result of the magnetic forces and stresses caused by the different thermal expansion coefficients of the components, are no rare occurrence. And, in addition to such mechanical faults, there are magnetic instabilities (so-called flux jumps) which must also be prevented. Flux jumps occur when entire bundles of flux lines are suddenly torn away from their pinning centres after a very minor fault or a change in the operating conditions. Such an avalanche of flux movement leads to heat being produced, which can trigger the transition to the normal-conducting state.

A superconductor is stabilized electrically by connecting a thermally and electrically highly conductive material —in the form of a copper or aluminium coating—in parallel with the conductor. However, this measure alone will not eliminate the undesired flux jumps. What is more, the diameter of the superconducting zone must not exceed a certain value specific to the material—in the case of NbTi about 100 micrometres. For larger sizes, the thermal diffusivity in the superconductor is unable to prevent initiation of the flux movement under adiabatic conditions up to the transition to the normal-conducting state when a minor disturbance occurs. To achieve stability, and because of the way in which superconductors behave during variations in the current and magnetic field (described below), the cross-section must be divided into numerous fine filaments within a good normal-conducting matrix.

Alternating-Current Losses

Both flux jumps and so-called hysteresis losses are a consequence of the irregular distribution of the flux lines in the superconducting material. The extent of the flux displacements taking place during changes in the operating conditions, can be reduced by using the finest filaments possible [6]. Diameters below 1 micrometre can be achieved today. For most applications, however, filament thicknesses of 10 micrometres and above are permitted.

The use of superconducting filaments embedded in a highly conductive matrix, however, has the disadvantage that, in accordance with the law of induction, in a magnetic field varying perpendicular to the conductor axis, screening currents are generated which flow into the filaments and the intervening normal-conducting matrix. These currents, which oppose the external magnetic field variation, feature very high time constants. The filaments are thus coupled magnetically and the conductor behaves as a thick superconducting wire with corresponding flux density gradients and a strong tendency towards flux jumps. Filamentization of the conductor for the purpose of stabilization results in a large contact surface with the matrix, but does not have the desired influence on the flux distribution in the conductor. By manufacturing twisted wire, the effective surfaces for the induction become smaller and the coupling currents and their time constants thereby significantly reduced. Although the coupling currents flow through the filaments without any resistance, they must also flow transversely through the conductor in the normal-conducting matrix, where they cause ohmic losses (the so-called coupling losses). Calculation of the frequency-dependent coupling losses per magnetic field cycle establishes a quadratic dependence on the twist pitch. On the other hand, the coupling losses decrease as the electrical resistance of the matrix increases. And for stability this resistance must be kept low. In the case of NbTi filament conductors, this dilemma can be resolved by using high-ohm copper-nickel barriers to obtain a honeycomb distribution of the conductor cross-section. The barriers increase the transverse electric resistance of the matrix, upon which the coupling losses depend.

Another method of preventing excessive a.c. losses involves dividing the conductor into many thin individual wires, woven into a transposed cable. In this arrangement, the location of a strand varies periodically between the surface and the centre of the cable, ensuring uniform current loading of the strands.

Critical Current Densities

It has already been explained how the high current densities of Type II superconductors occur due to the pinning of the flux lines. The type, size and distribution of the pinning centres varies from material to material. In the case of NbTi superconductors, flux movements are impeded by defects in the form of dislocations which occur during cold forming and have a band structure, and by normal-conducting alpha titanium precipitates. The alpha particles are produced by annealing at 300 to 400 °C for several hours. Good pinning structures are obtained as a result of a certain sequence of cold-working steps and heat treatment when the wire is drawn. The relevant process parameters depend on the composition of the NbTi alloy and the final diameter of the wire. Fundamentally, cold forming creates the dislocation subband structure mentioned above, which then serves for the grain formation of the alpha titanium precipitates. During the deformation, the particles move closer together and are simultaneously stretched, becoming thinner until they lose their effect on the flux lines. Thus, the last cold-working step must be arranged in such a way that a maximum current density is obtained for the final diameter and nominal field. *Figure 3* shows the variation in current density with increasing cold working of an S 66 filament wire optimized at 0·5 mm and an S 1200 wire optimized at 0·84 mm. This process of optimization is to a large extent based on experience, with empirical formalisms simplifying the analysis of the data [7].

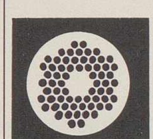
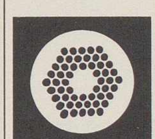
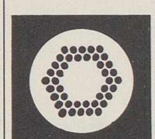
Manufacturing the Wire

Table II shows a selection of NbTi multifilament superconductors from the Swiss Superconductor Consortium. Billets are produced from standardized components—NbTi rods and copper elements such as hexagonal tubes, filling components, cylindrical casings and covers—and finally extruded. The final diameter is obtained by a process with several drawing operations, the intervening heat treatment mentioned previously having a significant bearing on the optimum pinning behaviour.

The manufacturing process has to be subjected to strict quality control. Wire data have to be determined precisely for each manufactured conductor, ranging from the critical current as a function of the magnetic field, through the NbTi cross-sectional ratio to the residual resistance ratio (i.e. the quotient of the resistance at room temperature to that just above T_c).

Table II: Standard wires of the Swiss Superconductor Consortium

These wires can be used individually or combined into cables as required (Figs. 5–7).

Wire type		S 66		S 54		S 42		S 1000	
									
Ratio Cu: NbTi		1·3		1·8		2·6		1·8	
Number of filaments		66		54		42		~1000	
Wire diameter	mm	0·7	0·4	0·7	0·4	0·7	0·4	0·84	0·5
Filament diameter	μm	57	33	57	33	57	33	~15	~10
Critical currents A at 4·2 K and magnetic fields of	2 T	731	240	598	197	465	153	862	308
	3 T	580	192	475	257	369	122	689	247
	4 T	467	154	382	126	297	98	551	197
	5 T	370	123	303	101	235	78	436	158
	6 T	299	98	245	81	190	63	353	126
	7 T	240	79	196	64	153	50	283	101
	8 T	167	55	137	45	107	35	197	70

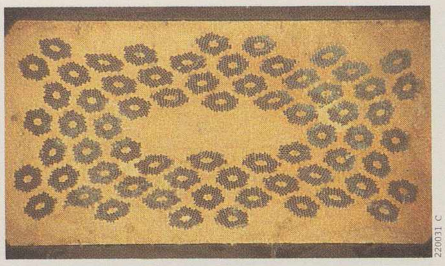
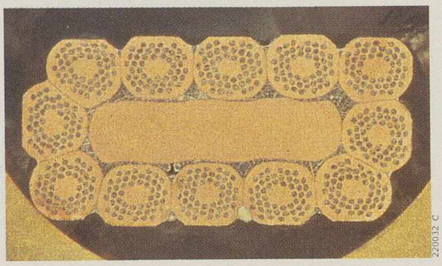
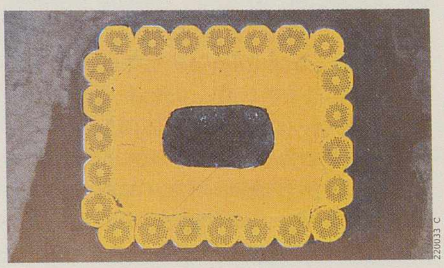


Fig. 4 – Monolithic superconductor with 6732 filaments (3·6 × 1·8 mm). The conductor can be insulated with a varnish.

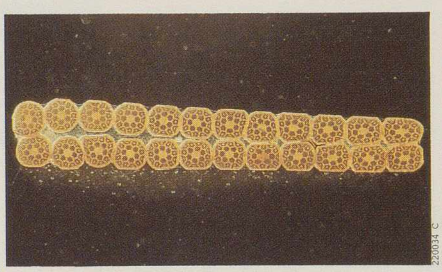
Fig. 5 – Single-stage cabled superconductors consisting of standardized wires



a: 3·6 × 1·8 mm, 3000 A at 5·0 T and 4·2 K



b: 5·4 × 4·5 mm, 4700 A at 7·0 T and 4·5 K



c: 10·0 × 1·28/1·67 mm, 8000 A at 5·5 T and 4·6 K

High-Current Superconductors

Monolithic High-Current Conductors

Basically, it is possible to manufacture high-current superconductors as rectangular profiled conductors by employing the same principle as for the wires described above. *Figure 4* shows such a conductor with about 7000 filaments and a Cu:NbTi ratio of approximately 3.

These conductors have excellent mechanical properties and their production involves no problems of any consequence. For various reasons, however, it is not economical to use them in large magnet windings.

As has already been explained, several cold-working steps with intervening precipitation annealing are necessary to achieve high critical current densities in the NbTi cross-section. Thus, the degree of cold working should be as high as possible. As this cannot apply to monolithic superconductors of large diameter, the expensive NbTi material is poorly utilized. In addition, an enormous number of filaments, possibly in excess of 10 000, is necessary for such conductors in order to satisfy the adiabatic stability criterion. As a rule, this necessitates multiple-step extrusion of the material, which increases the material losses at the end of the extruded bars, or use of many thousands of fine copper and NbTi elements, which increases the cost of assembly and quality control significantly. Such conductors are also disadvantageous in terms of a.c. losses. What is more, the maximum active weight of the extrusion billets, at present about 140 kg, places a limit on the unit length which can be manufactured.

Superconductor Cabling Technology

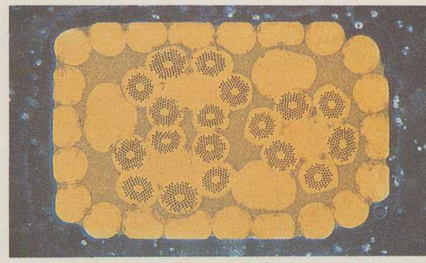
The cabling of superconducting wires to form high-current superconductors has continued in recent years to gain ground on the monolithic superconductors as the above-mentioned disadvantages can be largely avoided [8] and the conductor adapted exactly to the needs of the customer. For conductors with especially large diameters, this technology or a similar process such as the Röbel method offer the only means of obtaining a reasonable unit length. This length can even be increased considerably by means of sophisticated joining methods. Cables also permit additional stabilizing materials, cooling tubes and high-ohm intermediate layers to be incorporated simply and inexpensively. The conductors can be simply cabled or manufactured in a multi-step process to obtain complicated forms. Single-stage cable configurations such as those in *Fig. 5* are obtained quite easily. The diameter and number of wires to be cabled are determined, with account taken of the increase in cross-section due to cable twist and cable compaction (realistic values are 0·85 to 0·92), with reference to the central profile, or for conductors without a central profile, to the theoretical axis.

In the case of cables wound in several steps *(Fig. 6)*, the same fundamental procedure is employed for every cabling stage. However, the actual degree of compaction, particularly for very complex cable structures, can generally only be determined by experiment.

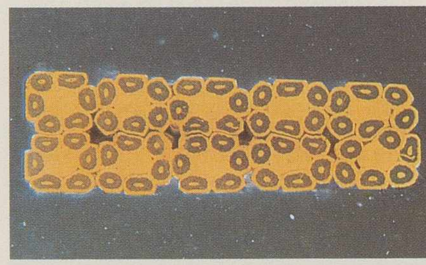
Cabling offers highly flexible adaptation to the geometric features of the windings. For example, conductors for superconducting deflecting and focussing magnets for accelerators and storage rings used in high-energy physics, are rolled to a slightly trapezoidal cross-section (Figs. 5c and 6b) to facilate the construction of the vault-like 'Grace-track' windings of such magnets. About 1000 km of this type of cable are required for the HERA project presently under construction, of which about half will be manufactured by the Swiss Superconductor Consortium.

Other requirements must be satisfied by conductors used in large magnet coils for nuclear fusion, where very high currents with very strong magnetic fields and enormous forces are needed. In cooperation with the Swiss Institute for Nuclear Research, Brown Boveri have developed the conductors shown in Figs. 6c and 6d for the 'Large Coil Task' (LCT) project of the International Energy Agency, to which six teams comprising research institutes and industrial firms each supplied one superconducting toroidal field coil. Although the first helium-transparent cable was provided with a steel casing, a special solder was used for the chosen cable variant to ensure the necessary mechanical strength. The six LCT coils are at present in the Large Coil Test Facility at the Oak Ridge National Laboratory in the USA.

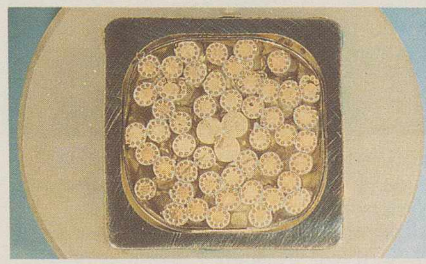
Fig. 6 – Multistage cabled superconductors. These can be manufactured with many different geometries thanks to sophisticated cabling techniques.



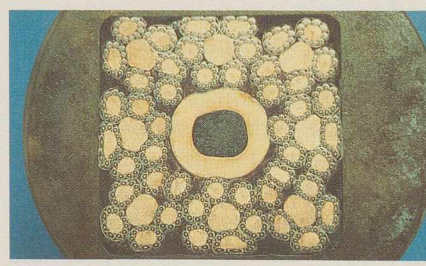
a: 4·0 × 2·8 mm, 2500 A at 5 T and 4·2 K



b: 8·0 × 2·15/2·65 mm, 10500 A at 5·5 T and 4·6 K



c: 23·0 × 23·0 mm, 15000 A at 8·3 T and 5·0 K



d: 18·5 × 18·5 mm, 13000 A at 8·15 T and 5·0 K

Special Conductors

For some applications it is preferable or even necessary to combine superconductors with other components to obtain specially composed conductors *(Fig. 7)*. It may, for example, be more advantageous to solder a monolithic or cabled superconductor to additional stabilizing material, a cooling tube and/or reinforcing elements.

This method could be particularly suitable for conductors for large fusion magnets based on Nb_3Sn superconductors [9, 10]. Figure 7a shows such a conductor developed and manufactured by the Swiss Institute for Nuclear Research, partly in cooperation with companies of the Swiss Superconductor Consortium. From this conductor, which is soldered together in a sandwich arrangement consisting of two steel bands, a copper tube and profile, as well as a twisted multistage Nb_3Sn cable, Brown Boveri manufactured a 12 T insert coil for the superconductor test facility (SULTAN) at SIN. This could clearly demonstrate the feasibility and performance of such conductors and coils.

An elegant way of providing a superconductor with additional stabilization material is to clad it with high-purity aluminium by means of coextrusion. The superconductor is fed into the die of a profile extruder such that it reaches the middle of an aluminium profile. Depending upon the degree of purity and the microstructure, high-purity aluminium may have a residual resistance ratio of about 250 (99·99%) to 2000 (99·999%) and above. Brown Boveri have, in cooperation with the Alusuisse subsidiary Alusingen, developed this process whereby such conductors can be manufactured in lengths greater than 1000 m since the

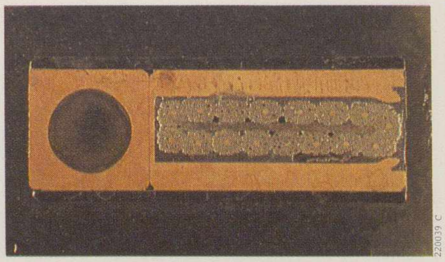
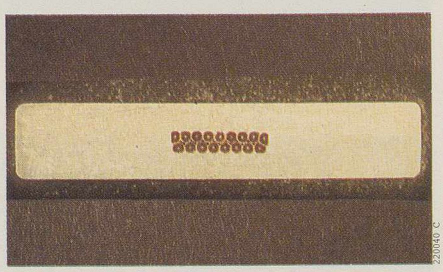


Fig. 7 – Special superconductors

a. Superconductors in sandwich arrangement consisting of brazed steel bands, copper tube and profile, into which a multistage Nb_3Sn cable is soft soldered. This conductor was developed and manufactured by SIN in cooperation with companies of the Swiss Superconductor Consortium. Such conductor configurations are used at high flux densities up to 15 T.



b. Superconductor cable enclosed in high-purity aluminium, produced by coextrusion
24·0 × 4·5 mm, 10000 A at 2·4 T and 4·5 K

process also permits loading of new aluminium billets. A good metallurgical bond between the two components, and therefore low contact resistances between the superconductor and aluminium, is achieved by appropriate control of the extrusion conditions [11]. The conductor shown in Fig. 7b is intended for a large superconducting solenoid approximately 6 m in diameter and 6 m long constructed by the Rutherford Appleton Laboratory in the United Kingdom. Good stability is important for this detector magnet for the DELPHI experiment carried out on the electron-positron accelerator (LEP) at CERN. At the same time, by using aluminium instead of copper the weight is reduced by 15 t and the radiation transparency is increased.

Insulation

NbTi filament wires are generally insulated with a layer (about 0·05 mm thick) of polyvinyl acetal varnish or esterimide varnish. In special cases, such wires can be wound with polyimide tape or wrapped with glass fibre.

Cabled or special high-current superconductors complete with insulation are also available. The possibilities depend upon the coil manufacturing method used: wrapping with polyimide foil, combined glass/polyimide tape, glass fabric tape, pre-impregnated glass/epoxy tape or combinations thereof. In such cases, Brown Boveri benefit from the vast experience they have gained in the field of magnet technology.

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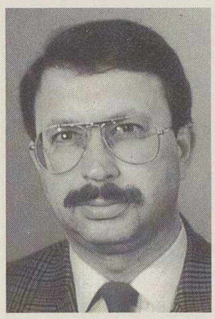
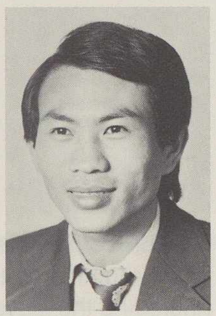
Digital Torque Computer for Test Rig Drives with DC Motors

The article describes a simple method by which torques produced on test rigs in the automobile industry are calculated by computer. The test rigs considered can now be equipped with conventional electric drive components. Special equipment such as dynamometers and torque measuring shafts are no longer necessary. For control purposes the computer provides an actual torque value which can be coupled back without causing any reaction in the system.





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Test rigs are used in the automobile industry for the realistic simulation and measurement of loads. Internal combustion engines as well as vehicles and their components are often tested by subjecting them to torques produced by d.c. machines. In such tests, the torque can be determined from

- the force of reaction on the lever arm of a dynanometer (balance method),
- the torsional stress on torque measuring shafts, or
- the measured electrical quantities of the loading device, using a torque computer.

For the latter method, Brown Boveri have developed a torque computer for d.c. shunt-wound motors which has proved successful in a number of testing facilities.

Measurement with the Torque Computer

The power P_e produced at the air gap of a d.c. motor is determined by the loss-summation method. P_e is obtained from the power input $U_A . I_A$ by subtracting the copper losses $I_A^2 . R_A$, the brush losses $U_B . I_A$, the iron and friction losses V_o and the stray-load losses V_z:

$$P_e = U_A . I_A - R_A . I_A{}^2 - U_B . \cdot |I_A| - V_o - V_z \tag{1}$$

The electromagnetic torque M_e generated at the air gap can be calculated from the power P_e at speed n:

$$M_e = \frac{60}{2\pi} \cdot \frac{P_e}{n} \tag{2}$$

The idling torque M_o corresponding to the iron and friction losses depends upon the rotational speed and is determined from runs at no load.

The torque M_z corresponding to the stray-load losses is dependent upon the speed and varies as the square of the current:

$$M_z = M_{zN} \left(\frac{I_A}{I_N}\right)^2 \tag{3}$$

M_{zN} is a function measured with respect to the speed at nominal current.

The torque M_d acting on the shaft is obtained by subtracting the acceleration torque M_B from the electromagnetic torque:

$$M_d = M_e - M_B \tag{4}$$

The acceleration torque M_B is determined by the moment of inertia J_{pr} of the test rig and the change in speed dn/dt:

$$M_B = \frac{2\pi}{60} \cdot J_{pr} \cdot \frac{dn}{dt} \tag{5}$$

At standstill and low speeds equation (2) is either invalid or too inaccurate for determining the torque. In such cases, use is made of another, different method of torque calculation in which the air-gap torque is found from the magnetic flux and the armature current:

$$M_e \sim \Phi . I_A \tag{6}$$

The magnetic flux is determined in calibration runs which take account of the armature reaction.

The torque computer developed by Brown Boveri thus employs two methods: from standstill up to a defined speed n_1, equation (1) is used, and from this speed up to the maximum speed, equation (2).

Operation and Design

Figure 1 shows a schematic diagram of the torque computer. The algorithmic calculations and the determination of the calibrated quantities are performed by a digital computer,

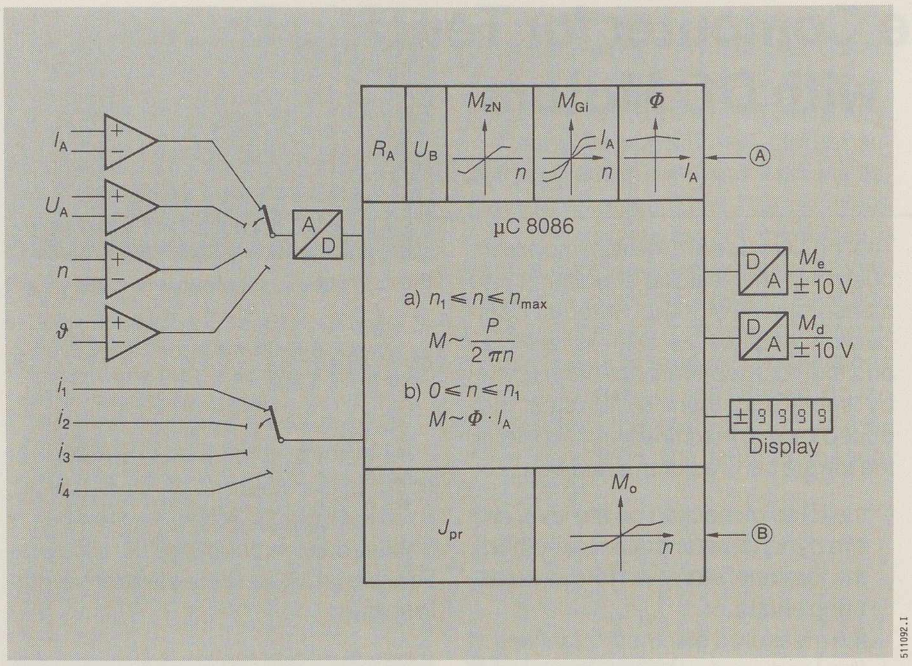

Fig. 1 – Basic configuration of the torque computer

Ⓐ = Data input and calibration (commissioning)
Ⓑ = Calibration (by user)
R_A = Armature circuit resistance
U_B = Voltage drop at brushes
M_{zN} = Torque at nominal current, corresponding to stray-load losses
M_o = Torque at no load
M_{Gi} = Torque corresponding to gear losses
Φ = Magnetic flux
I_A = Armature current
U_A = Armature voltage
n = Speed
ϑ = Armature circuit temperature
i = Gear ratio
M_e = Electromagnetic torque
M_d = Shaft torque
t = Time
P = Power

which is based on a programmable control system from Brown Boveri consisting essentially of a modular microcomputer with a 16-bit Intel 8086 microprocessor.

Its user-friendly module language means that the system can be configured and programmed by users unfamiliar with computer languages. All devices needed for program development, including the operating units, are mounted in a rack. Easy to use, the system is employed for the automation of drive systems [1].

The analog signals for the armature current I_A, armature voltage U_A, speed n and the reference temperature ϑ measured at the interpole winding are received by differential amplifiers, adapted in input stages to a 10 V voltage level and then digitized by A/D converters before being transmitted in multiplex form to the microprocessor for additional processing.

A high-accuracy measuring system registers the armature current. Speed is measured by a precision tachogenerator or a high-frequency pulse generator with frequency/voltage converter. The torque computer has a fast binary input for the pulses when the pulse generator is used for speed measurement.

The armature circuit resistance R_A is also measured. Its dependence on temperature is largely eliminated as the computer corrects the resistance by referring it to the value of ϑ.

Information on the stray-load loss torque M_{zN} is obtainable from the motor manufacturer, or the torque can be measured on the test rig. A function generator stores these losses, which are determined for the nominal current. Otherwise they are assumed to be 0·5% of the nominal torque for compensated motors, or 1% for motors which are not compensated [2].

Calibration runs at no load are performed to determine the idling torque loss M_o. The torque computer automatically stores these losses in a nonvolatile memory. The storage procedure can be repeated as often as required.

If slave gears with a choice of ratios are used for the adaptation to the test object's required loading and speed, the computer can assign the idling losses according to the different speed steps, and then store them.

When slave gears are used, the computer has to allow for load-dependent gear losses. These losses, which vary with both speed and load, are specified as a family of curves representing $M_{Gi} = f(n, I_A)$, and are stored in the computer as functions of the respective gear ratios.

In such a case, the computer takes account of the inertia J_{pr} in equation (5), which applies to the entire shaft line (including the slave gearbox) up to the measuring point, again for each gear ratio. In a calibration run with the motor operating on no load, i.e. without the test object, the computer automatically evaluates and stores the total moment of inertia of the test rig as a function of the gear ratios.

When the test rig is in operation, the idling torque loss, the load-dependent gear losses and the acceleration torque are represented as torque corrections for each gear ratio and with the correct sign.

Allowance can be made for up to four speed ratios, so that the calculated torque takes account of all losses up to the point of measurement.

The torque computer operates with a cycle of 2 ms and employs D/A converters for the output of the actual torque value as an analog quantity (in the form of a d.c. voltage, ± 10 V). The analog quantities generated are:

- The electromagnetic torque M_e, corrected for all losses
- The shaft torque M_d, corresponding to the reaction torque of a dynamometer or the signal from a measuring shaft

In addition, the shaft torque M_d is transmitted in binary coded decimal

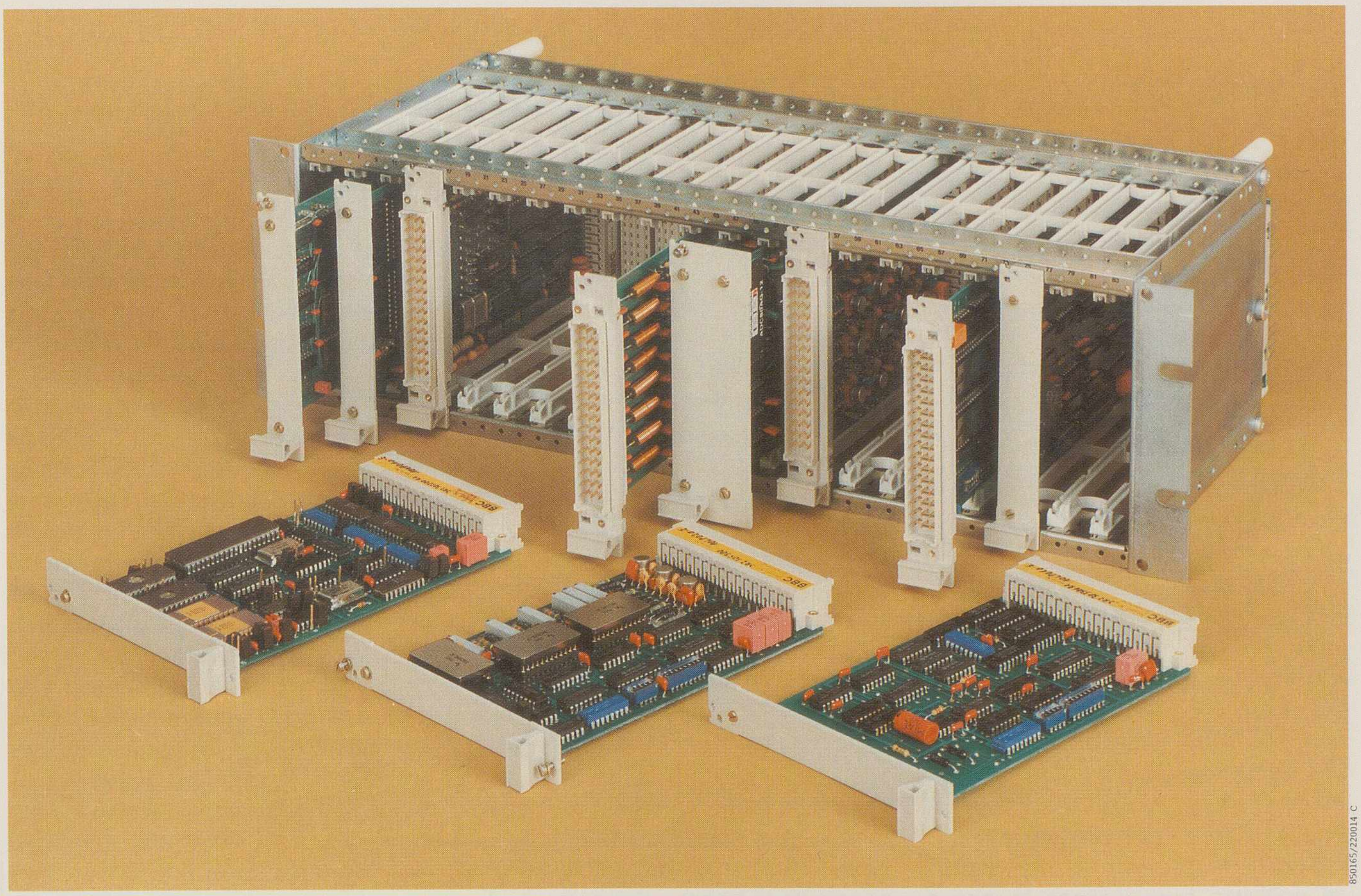

Fig. 2 – Brown Boveri's stored-program computer system in a 19-inch rack (arrangement used for the torque computer)

form direct to a digital display. The torque computer itself consists of a 19-inch subrack with three height units (Eurocard format). The power supply is rated 24 V/1·8 A and is non-regulated (+30%, −12%). *Figure 2* shows this equipment.

Torque Computer Accuracy

The accuracy of the torque computer depends on errors inherent in the computer itself, on the accurary of the measuring sensors and on errors introduced by the wrong loss values being entered. The total error is determined on the basis of the following assumptions:

- The error of the 16-bit microcomputer is negligible.
- Highly accurate sensors are used to measure the actual values.
- With the motor losses measured electrically and the winding temperature recorded, the total error of the torque computer will be 0·5%
- If the motor losses are not measured and the winding temperature is not recorded, the total error can be as high as 1%.

Use with Dynamic Test Rigs

Brown Boveri developed the torque computer principally for use in test rig facilities.

Modern test rigs for road vehicle components are required to perform dynamic test cycles that faithfully simulate the vehicle's moment of inertia or the actual driving conditions.

The test rig initially has a constant inertia. With the electric motors employed it is possible to simulate the desired vehicle inertia, i.e. the total inertia can be increased or reduced by simulation with the aid of suitable control algorithms.

The reference values used to control the torque during simulation must come from a test program or some other source. To achieve the required dynamic response, realistically simulated loads and stable control, the actual torque value has to be coupled back without any interference arising. The actual value obtained from measuring shafts reflects both the influence of the dn/dt signal and the natural torsional frequency of the test rig's entire mechanical construction. In some cases this can restrict the control system's dynamic behaviour and stability.

It is therefore important for the torque control system of such a test rig to make use of the electromagnetic torque M_e as the actual value. *Figure 3* shows the basic layout of a torque control system of this kind with PI action.

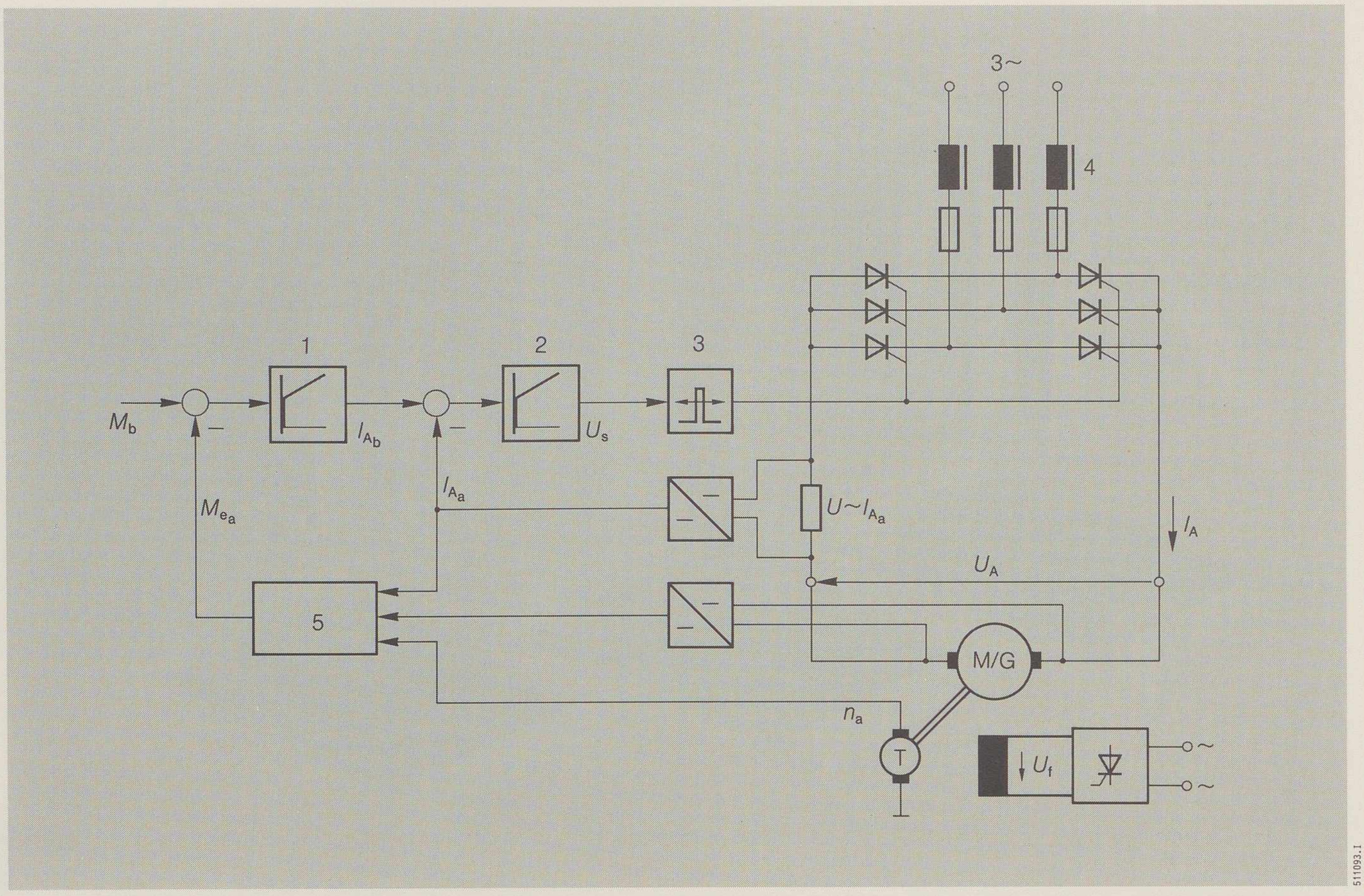

Fig. 3 - Basic circuit diagram of the torque control system

1 = Torque controller
2 = I_A controller
3 = Pulse generator
4 = Reactors
5 = Torque computer

n = Speed
I_A = Armature current
U_s = Control voltage
U_A = Armature voltage
U_f = Exciter frequency

M_e = Electromagnetic torque
a = Subscript, actual value
b = Subscript, reference value

Summary

The torque computer described has been installed in a number of rigs used to test gearboxes, axles, engines and even complete vehicles; in all cases it has performed satisfactorily. Its advantages over dynamometers and measuring shafts are as follows:

- Simple, standard electric motors of type B 3 are used.
- It is short in length and creates no additional moments of inertia as there are no extra bearings or a clutch, which might give rise to torsional vibration in the drive system, leading to unstable conditions in the control loop.
- It features high static accuracy and improved dynamic response.
- It is unaffected by the system's mechanical construction and by shock loads.

With this torque computer, Brown Boveri offer users of modern test facilities a system which conforms to the vehicle industry's concept of dynamic simulation.

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Pipework Packages— Engineering Services of the General Contractor

Within the vast scope of power station contracts, the pipework package offers just the flexibility required to meet customers' requirements as to financing, the question of currencies to be used for payment, services to be contributed by the customer, local obligations and the subject of compensation. However, this presumes that the general contractor has the necessary know-how and a planning organization with modern aids and planning methods at its disposal. Brown Boveri have adjusted to a change in market requirements which began around the mid-seventies, by increasing their commitment to pipework planning, introducing CAE/CAD aids and concentrating all activities concerning the pipework package in one organizational centre.

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Introduction

Brown Boveri build and equip turnkey power stations of all ratings throughout the world. In doing so they act as general contractor, as the manufacturer of key components for the turbines, generators and thermal equipment, and as suppliers of power and control systems.

The market for power generation plants in the highly industrialized countries has shrunk considerably over the last decade. At the same time, a steadily increasing demand for power in 'industrializing' and Third World countries has led to a shift in major market activities. To be competitive in these new markets, combined technical and commercial packages must be offered along with completion dates which emphasize speed at all stages of a project.

Given these difficult market conditions, the handling of the pipework package (comprising the pipes, hangers, valves, insulation and erection) poses a special challenge. And this is not without reason considering its 6 to 9% share of the total cost of the plant, the complex interdependency of the information matrix and the significant influence it has on the ultimate operation of the plant.

Business Transactions with Pipework Packages

The constant search for an optimum solution for each new order leads to a large number of business transactions, which can be represented in a supplier/performance matrix *(Table)*. These transactions are largely characterized by order-sharing between the customer and a consortium led by the general contractor, as well as between the consortial partners themselves. Sharing may be based on systems, components or even rooms. And the scope of services and activities included in each individual package can also be subdivided on the basis of the technical processing involved, material supplied, prefabrication or erection. The extent of this sharing and subdivision, however, is limited by the increased co-ordination it requires (and which has to be organized by the general contractor) and the blurring of the

Supply/services matrix for pipework packages

Supply \ Services	Design criteria	Basic engineering	Detail engineering	Material supply	Prefabrication	Erection
High-pressure pipework	B	B	B, F	F	F	F
Intermediate-pressure and low-pressure pipework	B	B	B, F	F	F, K	F, K
Internal turbo-generator pipework	B	B	B	F	B, F, K	B, F, K
Pipework outside of building	B	B	B, F	F	F, K	F, K

B = Brown Boveri
F = Pipework contractor
K = Customer or local erection company, supervised by B or F

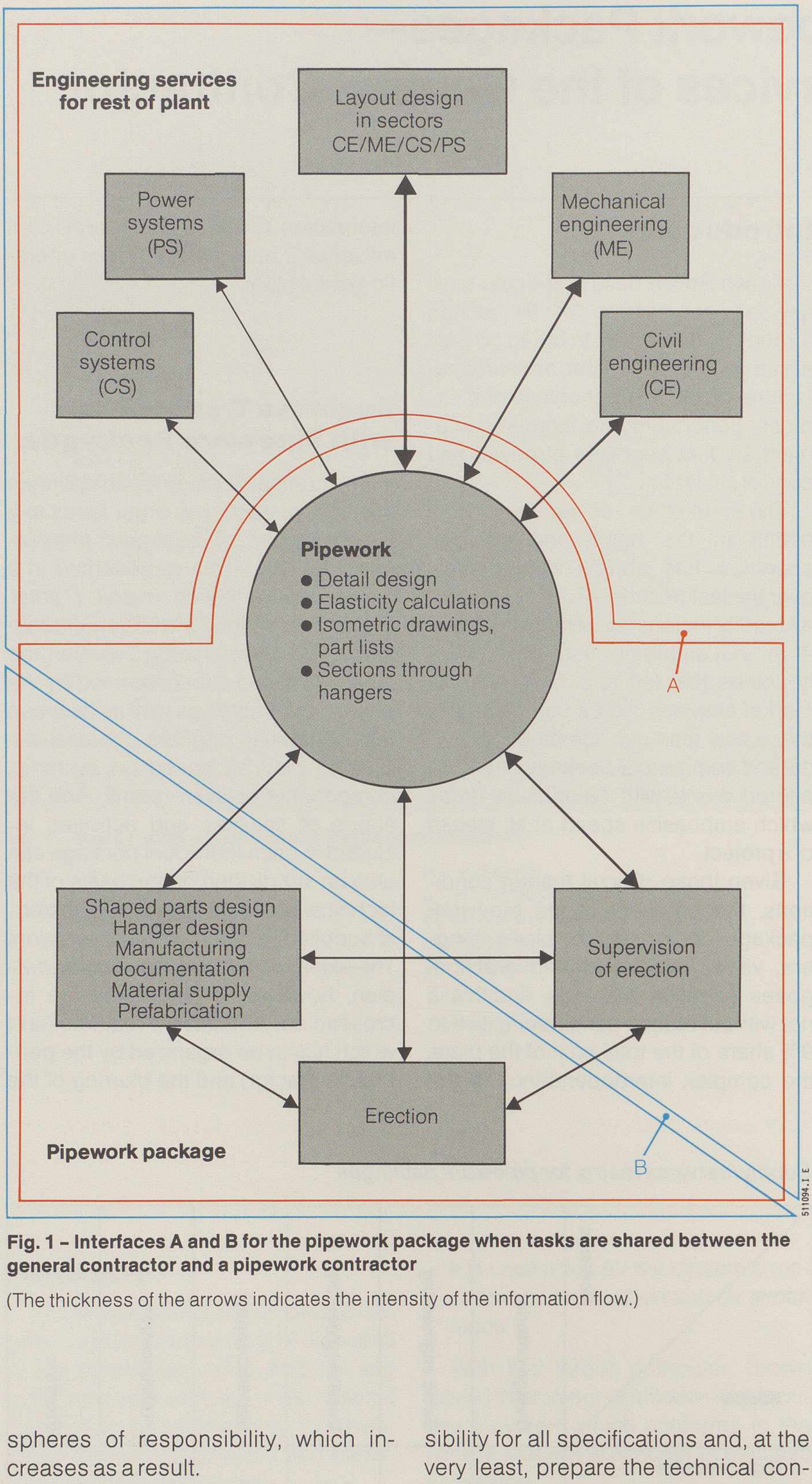

Fig. 1 – Interfaces A and B for the pipework package when tasks are shared between the general contractor and a pipework contractor

(The thickness of the arrows indicates the intensity of the information flow.)

spheres of responsibility, which increases as a result.

Order-sharing is often the wish of customers in industrialized countries who can offer their own project engineering services. To secure the required financing and risk coverage in the industrializing and Third World countries, it may be necessary to assign the entire pipework package, or parts thereof, to a member of the consortium (e.g. the boiler manufacturer). When acting as general contractor, Brown Boveri always take full responsibility for all specifications and, at the very least, prepare the technical concept and carry out all co-ordination work.

Task-Sharing Between General Contractor and Pipework Contractors

The demands made on engineering services have increased tremendously in recent years due to the greater complexity of modern plants and an increased need to keep costs down and to offer early completion dates. The detail in the technical documentation, and also its accuracy, have increased enormously, while quality assurance has been extended to the engineering services. The result of these changes is a tendency for valid, cost-related information to be handed over to parties working in parallel at ever-earlier stages of the project. This development has led to the design work and project engineering having to be carried out by the general contractor as soon as possible. What is more, the general contractor must consider how much time and engineering capacity he wishes to invest in any one specialized area. This can vary from a 'necessary minimum' to a 'justifiable maximum'. Interfaces result between the general contractor and the pipework contractor which are shown in *Fig. 1* by A and B.

Up until the early 'eighties, Brown Boveri's engineering services in respect of the pipework package were for the most part those referred to as the 'necessary minimum' (interface A). Generally, they were limited to integration of the pipework package in the overall power station concept and to determination of the completion schedule, the cost and technical objectives. The pipework package was subcontracted, with or without valves but including the erection, to a contractor specializing in this field who was also capable of working out the technical details.

In order to be more flexible in meeting the wide spectrum of market requirements, Brown Boveri meanwhile acquired the know-how enabling them to offer a maximum in engineering services—the 'justifiable maximum' (interface B). In the course of this, it was assumed that any contractor qualified and specialized in this field would have sufficient information at his disposal to enable him to carry out the remaining design and engineering work without having to refer back to the general contractor. The subcontractor is supplied with a definition of the pipe routing (including the surroundings), as required for full operation. All pipe valves, shaped parts, flanges, orifices, hangers, etc., are specified according to type and geometrical location. The subcontractor is responsible for the detailed design of non-standard items (shaped parts, pipe hangers, etc.) and for adding to the isometric drawings specific production information concerning the pipe spools. Brown Boveri actively support the subcontractor by providing data processing interfaces or by preparing the technical documentation. As a result, the subcontractor is still free to make the most of his own organizational and production structure. And if the subcontractor prefers not to or is unable to prepare the production documentation, Brown Boveri can generate at short notice and via computer systems, data-consistent production documentation (e.g. for the spools, pipe hangers, etc.) up to any level of prefabrication and in conformance with international standards.

From the general contractor's point of view, the existence of interfaces A and B is still justified today; moreover, both must be dealt with efficiently and professionally. When project-specific boundary constraints allow it, efforts will preferably be directed at interface B. This is because, as Fig. 1 shows, the information flow between the general contractor and pipework contractor is then substantially reduced. Optimization of the overall plant's performance remains in the hands of one company, and data consistency is improved and processing times shortened since the iterative steps overlapping from one company to another are minimized.

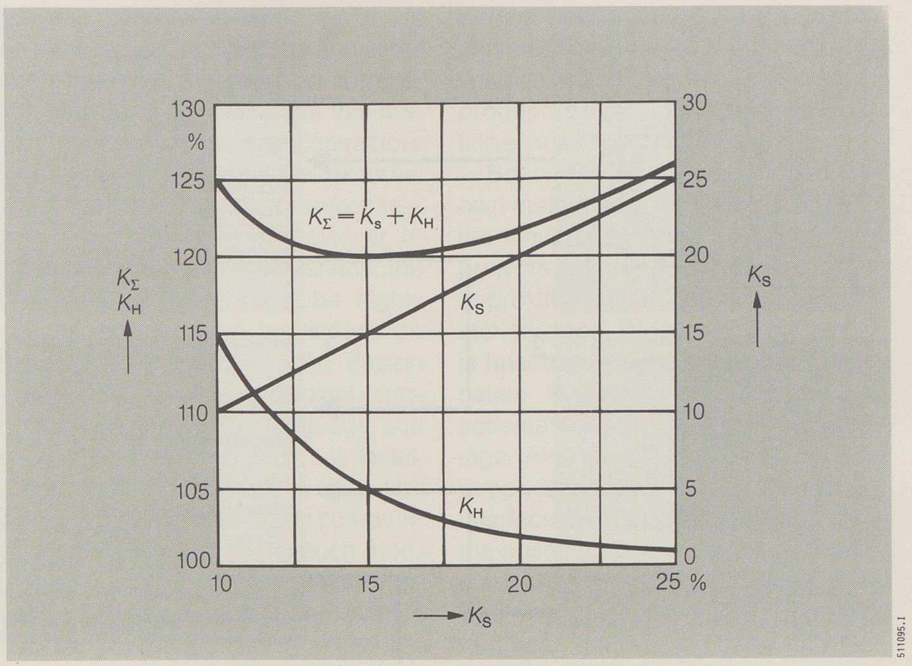

Fig. 2 – Reducing total costs by optimizing the degree of detail involved in the technical processing of a representative, conventional power plant

K_H = Hardware costs as a percentage of the minimal costs
K_S = Software costs as a percentage of the minimal costs
K_Σ = Total costs as a percentage of the minimal costs

(The minimal costs are the theoretically attainable minimal hardware costs of the pipework package.)

Optimum Level of Detail During Design Work and Project Engineering

The overall cost of the software and hardware can be minimized by choosing precisely the degree of detail required for a given function *(Fig. 2)*.

As the degree of detail for the software increases, the hardware costs for an assembled pipework package approach asymptotically a minimum. The advantages of detailed documentation are:

- A higher level of prefabrication is possible in the workshops and quality is improved.
- Tonnage is lower due to optimized pipe routing and pipe hanger designs, while the extra lengths required for fitting and reserve material are reduced.
- Erection costs per unit weight are lower and co-ordination and supervision are less expensive.

On the other hand, as the level of detail increases, so too does the cost of the software.

It might be expected that by minimizing the total costs, the scope for the degree of detail involved in the design work and project engineering would be greater. However, today's market requirements demand more detail than in the past. For some applications, the ideal limits may range as far as isometric drawings and parts lists for even the small-diameter piping.

Pipework Technology

The state of development of the hardware is determined by the suppliers of the materials, the manufacturers of the semi-finished products and components, and the erection companies. Standards also play a major role in determining where and for what these parts can be used. It is not the business of the general contractor to develop his own pipework technology, but to select the most suitable technology for each project. In other words, the general contractor's contribution to the technology chosen is of a conceptional nature. It is Brown Boveri's practice to deliver to their customers plants exhibiting high availability. And to achieve this the most appropriate of all possible solutions must be chosen.

This then defines the basic requirement for a broad-based, reproducible technology featuring feedback of experience gained in the field, which is also suitable for licenced manufacture. To this end, for example, standard pipe classes were developed with only proven parts, which satisfy the relevant thermal requirements, which can be interconnected without problem and which meet the demands of project-specific quality assurance. And only proven products are used for the valves. New products or new designs are thoroughly tested in close cooperation with the manufacturers, and are made use of only when verifiable references exist or convincing test results can be presented.

Data Processing Tools

Only when comprehensive data processing tools are available is it possible to satisfy the higher qualita-

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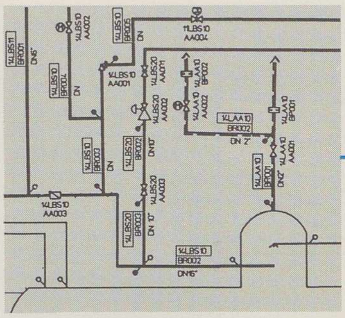

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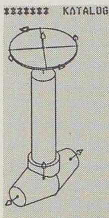

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PARAMETER:

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PA3 = AUSSENDURCHMESSER EINTR.
PA4 = AUSSENDURCHMESSER AUSTR.
PA5 = VERBINDUNGSTYP EINTRITT
PA6 = VERBINDUNGSTYP AUSTRITT
PA7 = BAULAENGE
PA8 = AUSBAUHOEHE
PA9 = HOEHE ANTRIEB
PA10 = HANDRADDURCHMESSER

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FITTINGS: ASTM A234 WP11
FLANSCHE: ASTM A182 F11
SCHMIEDETEILE ASTM A182 F11

ZUGEHOERIGE TEILE:

TEILE-BEZEICHNUNG: STAHLGUSS-VENTIL GESCHWEISST "CRANE'" CLASS 600

TYP	NAME/KKS-BEZ.	DN	KATALOG-REF.	STL-TEXT-REF.	MAT.TEXT REF.
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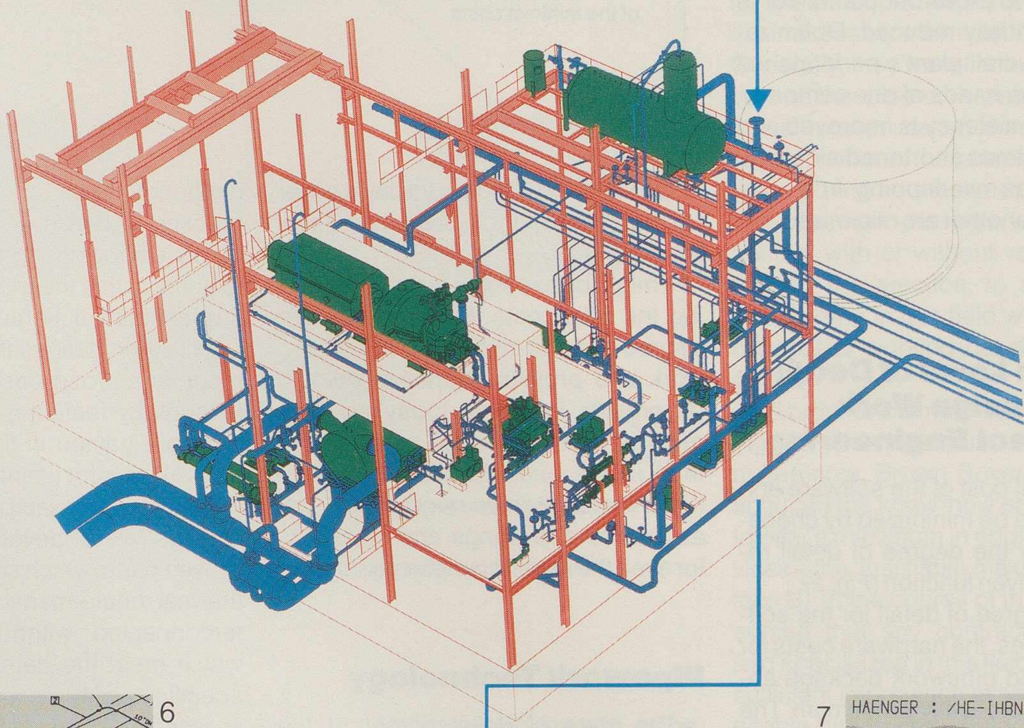

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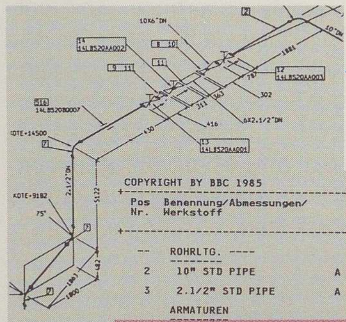

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	ARMATUREN					
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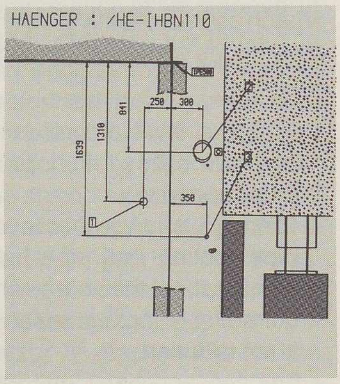

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Fig. 3 – Integrated processing with RAPAS

1: Process and instrument diagram with interface for data relevant to process
2: Pipework data sheet with pipe classification
3: Pipe fitting from RAPAS parts catalogue
4: Specification of pipe parts and pipe fittings
5: Three-dimensional, collision-free computer model generated from specifications, with interface for calculation of elasticity
6: Isometric drawing of pipework with parts list, automatically drawn by 3D computer model
7: Section through a pipe hanger with surrounding edges and interface for relevant data from the calculation of elasticity

tive and quantitative demands made on the engineering services and at the same time guarantee shorter completion times and low costs. For this reason, most of the general contractors involved in the plant sector work today —with varying degrees of success— with CAE/CAD systems. However, to justify the cost of these systems, the CAE/CAD modules must be highly specialized, place no restrictions on the project engineering and design work, and feature an efficient, programmable instruction language and programmable, intelligent interfaces. Moreover, they should be designed for use with the widest variety of computer hardware. Although many such modules are available on the software market, none of the overall systems which can be purchased satisfy all of the complex requirements involved in power plant construction.

In 1981, after thorough evaluation of various systems, Brown Boveri purchased the Plant Design Management System (PDMS). To its software modules have been added, in the meantime, numerous self-developed modules, intelligent interfaces and comprehensive parts and components catalogues. For the actual civil works, Brown Boveri have acquired the program RIBCON and integrated it in the existing software. The overall system [1, 3], known by the German acronym RAPAS (for computer-aided plant design system), has been introduced throughout the Brown Boveri Group. This system ensures data-consistent treatment at all stages of process engineering and design, ranging from layout planning and construction to isometric drawings of the pipework and preparatory drawings for the concreting. For more extensive treatment, an interface was developed which allows the engineering work to overlap between companies [2]. To date, Brown Boveri have completed 23 orders using RAPAS, to both DIN and ANSI standards. Erection problems arising from the engineering design are practically non-existent with this system. The example in *Fig. 3* shows, in simplified form, how the engineering design work is carried out for i.p/l.p. pipework with fittings.

Processing of Tenders

The pipework package's large share of the total costs makes it important both because of the business chances it offers and the risks involved. When tendering, the main problem is to offer the customer realistic services at a competitive price.

Brown Boveri have developed their own instruments for clear definition of the limits of supply and services for projects involving entire plants. The approximate limits are defined by the standardized 'Division of Work', which is based on the Power Station Designation System, with supplementary schematic diagrams and layout drawings. Also specified are the detailed supply/services limits (e.g. the defined interface between the pipework and the buildings or the pipework and the components, etc.). Special attention was paid to ensuring that once limits had been defined, the services which fell within their scope are fully comprehensive. The customer is thus assured that the unit he purchases is capable of functioning without extra costs being incurred. The supply/services within the scope of the specified limits are shared between Brown Boveri, partners and the pipework contractors on the basis of standard specifications for the particular business sector. Depending upon this business sector and the information density involved, pipework contractors may be invited to tender already at the initial tendering phase. In accordance with interfaces A and B in Fig. 1, a distinction is made between comprehensive inquiries and inquiries involving a bill of material.

For good cooperation between the general contractor and the subcontractor, the risk involved in the 'bill of material' method should be borne by the same company that carries out the detailed engineering work. This means that, for comprehensive orders, the interface between the general contractor and the specialist subcontractor is generally type A. However, experience has shown that only a small number of pipework contractors are able to make comprehensive offers which are competitive in price. Even the word 'comprehensive' is interpreted relatively loosely, and numerous discussions are necessary to achieve a basis which is acceptable to all parties concerned.

When a pipework contractor is invited to tender a bill of material, the above considerations will result in the interface between the general contractor and the subcontractor being of type B. In the tender, the subcontractor will agree to adjust the price for larger or smaller quantities according to the agreed unit price. Irrespective of which solution is chosen, Brown Boveri, as general contractor, endeavour to offer the customer a service which is dependable and competitive.

Processing the Order

Today, order processing centres around the extremely short time in which it has to be accomplished. For oil or gas-fired medium-size plants rated up to 150 MW, approximately 24 months must be seen as the lower, feasible limit, while approximately 30 months may be necessary for larger plants. And for coal-fired power plants, four to six months longer will be required. In the case of a processing time of only 24 months, the pipework material must be ordered within six months of the contract having been signed, while the isometric drawings must be prepared within nine months and the prefabrication concluded within 14 months. Shaped components of the cooling-water system which are to be concreted in position must be available even earlier.

RAPAS is not used when an order is processed in accordance with interface A as the design and engineering work does not then extend far enough. Conventional, manual concept planning by the general contractor is followed by detailed planning of the pipework by the chosen pipework contractor. When interface B is used a simplified, abstract form of manual concept planning takes place, with RAPAS employed for the subsequent detailed planning. The subsequent processing carried out by the pipework contractor is preferably undertaken with the aid of an appropriate data processing interface.

Whichever interface is chosen, the valves should be specified, co-ordinated and procured by the general contractor. This is even more so the case as Brown Boveri are always responsible for the process layout and the pipework contractor cannot guarantee its functioning. Experience also shows that the company carrying out the erection must assume responsibility for calling up valves from the diverse subcontractors and for their proper storage on the site.

Brown Boveri refers, whenever possible, to recognized quality assurance standards for pipework components. When restrictions are not imposed by specifications or regulations laid down by authorities, standardized materials, construction and site inspection plans are used. Only pipework contractors and other subcontractors with the required qualifications are engaged, and these must demonstrate that their quality assurance organization is able to satisfy the various categories of requirements applying to the components to be manufactured.

For the erection work itself Brown Boveri specify, specially for the project, a site organization plan in which the pipework contractor is integrated. A system announcing any deviation from the specified plan ensures that any problems occurring on the site are promptly resolved by the engineering department.

On completion of the contract the customer receives, whichever interface was chosen, 'as-built' pipework documentation in the form of layout drawings, isometric drawings and parts lists. And if interface B has been chosen the customer can request from Brown Boveri long-time archives of the stored three-dimensional plant model, permitting trouble-free processing at some later date for extensions or other modifications.

Summary

The cost of the pipework package represents a considerable proportion of the total cost of a power plant, while the pipework itself has a lasting effect on the plant's functional capability. Market requirements and the increasing availability of data processing equipment have led to the general contractor undertaking an ever-greater number of tasks. By upgrading the design and engineering work carried out on the power plant pipework, introducing CAE/CAD systems and concentrating the organization of activities related to the pipework package, Brown Boveri have been quick to adjust to this new market situation.

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In-Line Production of Enamelled Wire

Enamelled wire manufactured by the in-line method is notable for its excellent workability, good ductility being ensured by the relatively slight deformation of the copper strand which takes place between the last two annealing processes. Enamelled wire made in this way is far more capable of withstanding the fierce, abrupt acceleration forces exerted by high-performance coiling machines (fewer breaks) than wire produced by traditional methods. The dimensional stability of coreless windings is also superior.

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The manufacturer of enamelled and winding wire has not only to ensure a uniform, high-grade coating of insulation, but also to produce an electrical conductor with qualities enabling it to withstand extreme mechanical stresses when being wound.

The principal characteristics of the conductor material—predominantly copper—are its yield point, its elongation at rupture and its breaking strength. The word 'ductility' is often used to denote the workability of winding wire.

The ultimate performance of an enamelled wire in a winding is greatly influenced by how it is deformed, and to what extent.

The in-line process—a composite production method in which the wire is drawn and coated in one pass—is particularly effective in providing the desired working properties.

Conventional Method

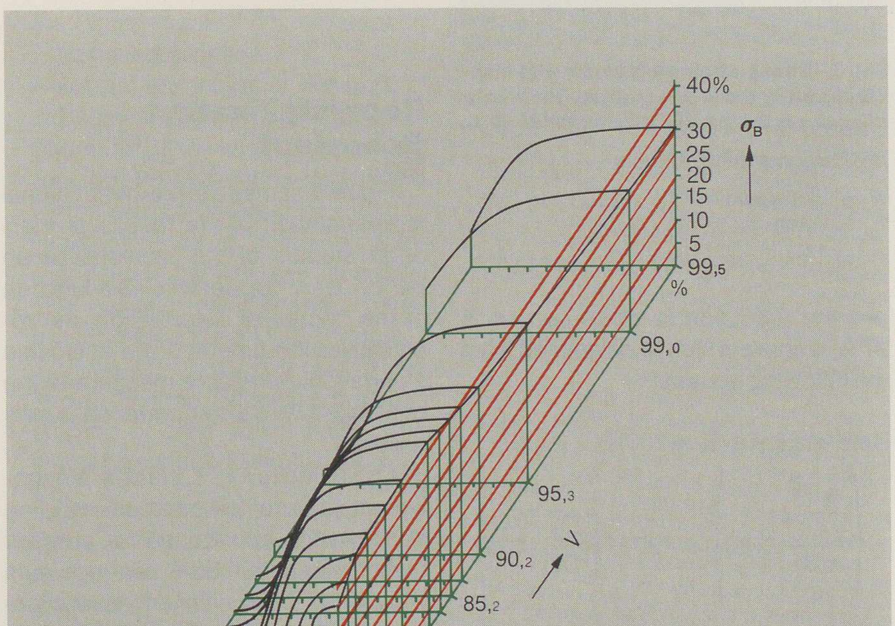
The conductor material used for most types of enamelled wire is high-grade electrolytic copper, which can be shaped very effectively by drawing.

A look at the drawing process shows that the drawing machines operate most economically when they produce the largest possible reduction in cross-sectional area. On a modern rough drawing machine, for exam-

Fig. 1 - Elongation at rupture as a function of the recrystallization time and deformation

Recrystallization temperature 250 °C, wire diameter 0·5 mm

t_T = Annealing time V = Degree of deformation σ_B = Elongation at rupture



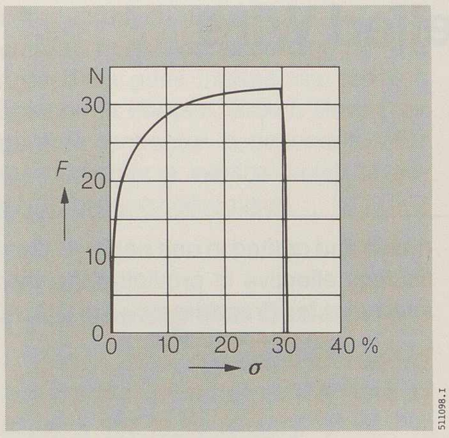


Fig. 2 – Stress-strain diagram for wire manufactured by the conventional method. The wire's diameter is 0·4 mm and its elongation 30 %.

Breaking strength 254 N/mm^2

σ = Elongation
F = Force

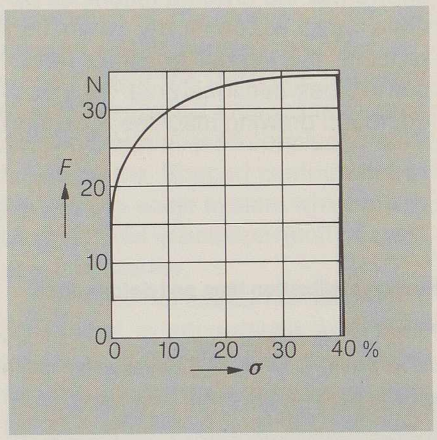


Fig. 3 – Stress-strain diagram for wire manufactured by the in-line method. The wire's diameter is 0·4 mm and its elongation 40 %.

Breaking strength 274 N/mm^2

σ = Elongation
F = Force

ple, the reduction in cross-section is 97%, a figure which is calculated from the following equation:

$$\text{Deformation in \%} = 100 - \left(\frac{\frac{\pi D_2^2}{4}}{\frac{\pi D_1^2}{4}} \cdot 100 \right) = 100 - \left(\frac{D_2^2}{D_1^2} \cdot 100 \right)$$

In this process, the drawing machine requires a number of passes to reduce the diameter of the incoming wire from 8·0 mm (D_1) to 1·4 mm (D_2).

The drawing operation is usually followed by annealing, so there is no further increase in deformation during subsequent reduction of the wire to still smaller diameters. The annealing plant, in most cases an integral part of the drawing machine, heats the wire in a continuous process to the recrystallization temperature, thereby relieving stresses in the crystal structure. Afterwards the wire is once again soft and elastic, i.e. 'ductile'.

A different procedure is followed when the wire reaches the diameter at which it is to be enamelled later. Annealing then no longer takes place in the drawing machine as the coating plant is preceded by its own annealing facility, which is also equipped for thorough cleaning of the wire surface. This preparation is essential for the enamelling process which follows.

It is at this point in the conventional method that drawing ends and coating begins. In fact, the drawing process ends when the wire attains its nominal diameter, after which special coating machines, usually some distance away, apply the enamel insulation.

The relatively large deformation which occurs in such a process—the result of having to use the modern drawing machines as cost-effectively as possible—has an adverse effect on the ductility of the wire. This relationship depends to a large extent on the degree of the deformation, and therefore on the production process itself.

Recrystallization Behaviour

Figure 1 shows a three-dimensional representation of the results of thorough studies of the recrystallization behaviour of copper wire as a function of the degree of deformation, the recrystallization time and the attainable elongation—a reliable measure of the enamelled wire's performance during winding.

According to Fig. 1, the best elongation at rupture for optimum winding performance is obtained for a deformation of about 80%, an optimum which has been verified as not depending upon the rate of deformation. It is also worth noting in this respect the different recrystallization times as a function of recrystallization temperature. To ensure complete recovery of the crystal structure, slightly deformed wire must be exposed to a given temperature for longer than wire which is severely deformed.

The relatively slight deformation of about 80% at which the best figures for elongation at rupture can be achieved is uneconomical with conventional drawing machines. A preferable method here is the in-line manufacturing process.

In-Line Method

The dominant feature of the in-line method is the combination of part of the overall drawing process with the coating process. These are combined in such a way that, between two recrystallization phases, the wire is deformed to precisely the extent ensuring optimum ductility properties when the wire is wound.

The first recrystallization phase takes place during the annealing which takes place after the wire is passed through the drawing machine before the in-line process. The machine must produce wire having a diameter that, with a typical reduction in cross-section of about 80% in the in-line process, allows the exact nominal diameter required to be obtained.

The second recrystallization phase takes place when the wire passes through the annealing plant belonging to the coating machine. Stresses in the crystal structure are again relieved by heat, producing the ductility which is the dominant feature of the in-line process.

The mechanical design of an in-line drawing machine with the output and number of deformation stages required to meet just these requirements is comparatively simple. Also acceptable is the investment cost for such a machine.

Stress-strain diagrams are particularly suitable for illustrating the difference in the ductile qualities of wire produced by the two methods.

Figure 2 shows the typical curve for winding wire produced by the conventional method with the associated yield point, breaking strength and elongation at rupture. *Figure 3* shows, for the purpose of comparison, the curve for a winding wire of the same size produced by the in-line method. Here the high figure for elongation comes up to the expectations illustrated in Fig. 1 for a deformation of about 80%. The higher breaking strength is

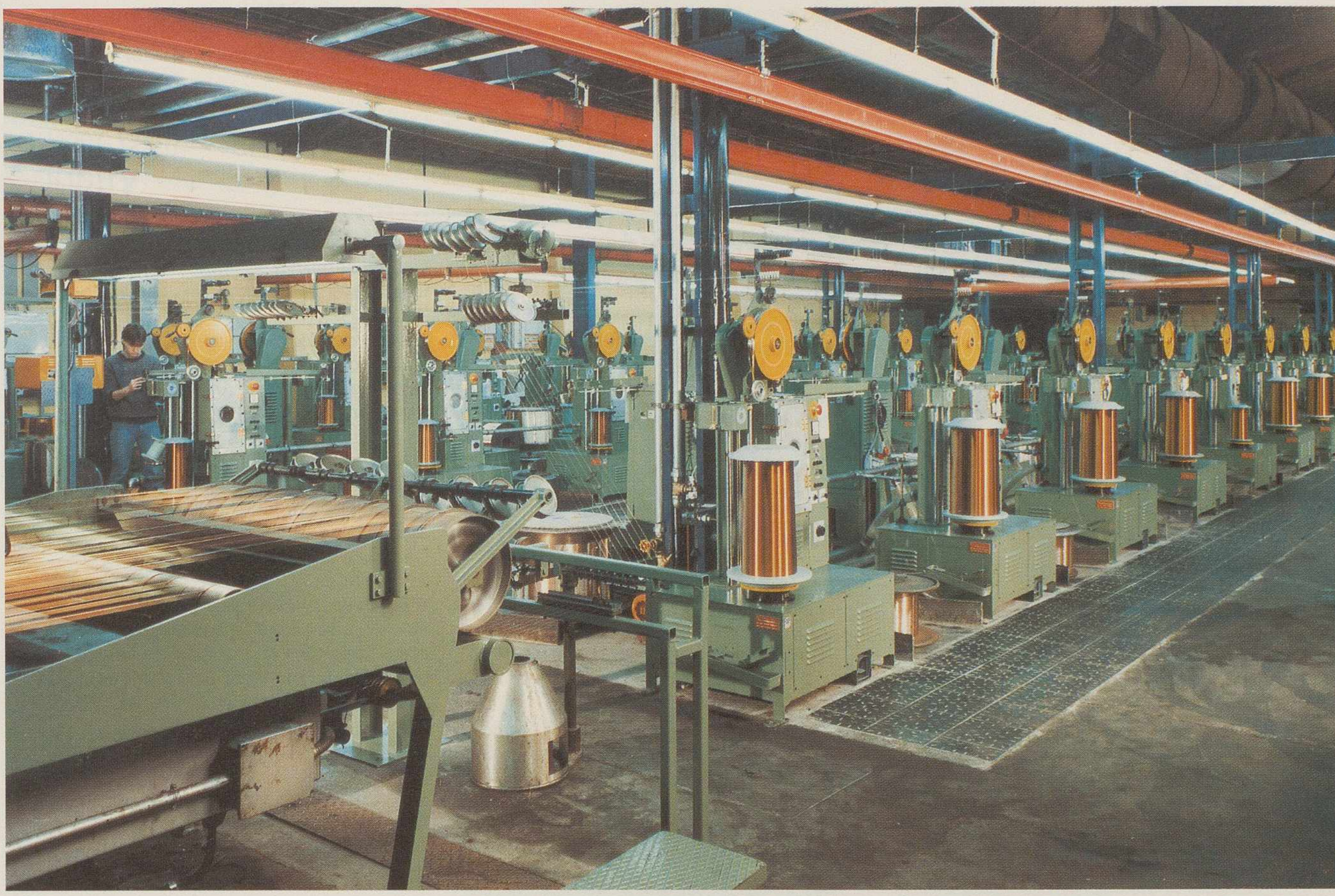


Fig. 4 – Winding station for enamelled wire, with in-line drawing machinery

also a typical feature of this method of manufacture.

A winding station for enamelled wire in the works of Kabel + Draht (Federal Republic of Germany) is shown in *Fig. 4*. The winding units already incorporate the in-line drawing machines for a production line.

Summary

The in-line production method meets users' wishes for enamelled wire which is more suitable for winding. From the results of extensive studies it is possible to state three major advantages of this method from the production engineering standpoint—advantages which have been fully corroborated by experience gained in practice over the past three years:

- The wire's improved elongation and breaking strength *(Figs. 2 and 3)* significantly reduce the rate at which the wire breaks on high-speed winding machines.
- A special advantage is that coils of extreme shapes and awkward ratios of length to width, such as are required for ballasts for fluorescent lamps, etc., can be wound.
- Coreless coils of outstanding dimensional stability are possible. The usually unwelcome barrel shape of coils meant to be square—a result of insufficient ductility—is largely avoided. Bunching and overlapping of coils which have been wound are reduced significantly.

It can be claimed, in summing up that the in-line method substantially improves the working properties of enamelled wire.

In electrical terms, enamelled wire produced by the in-line method has a much higher dielectric strength due to the wire being drawn and coated in a continuous operation. The firm of Kabel + Draht currently produces wire with diameters between 0·1 and 1·5 mm, for the most part using the new, in-line method described.

BBC
BROWN BOVERI

Product Range

(Does not include series products)

Power Generation

Project engineering and erection of turnkey power plants of all sizes for public and industrial power supply, acting as general contractor or member of a consortium

Conventional steam power plants for base, medium and peak-load duty
Nuclear power plants with various types of reactor
Gas turbine power plants rated over 20 MW
Air-storage gas turbine plants
Combined cycle (gas/steam) power plants
Power plants with steam or gas turbines for supplying process heat to industry, for district heating, for desalination of sea-water and for coupling with coal gasification or refuse incineration plants
Hydro-electric and pumped storage plants
Diesel-electric plants
Emergency generating equipment

Supply of components and systems

Reactors for nuclear power plants
Pressurized-water reactors[1]
High-temperature reactors[2]
Associated components and systems

Steam turbines
from 2 MW to the highest levels demanded by the market
Steam turbines with or without reheat for conventional and nuclear power plants
Industrial turbines for generation of heat and electricity, such as back-pressure, extraction, condensing and dual-pressure turbines
Steam turbines for driving power plant auxiliaries
Steam turbines for mechanical drives

Gas turbines
Open-cycle gas turbines rated 20 MW and over
Air-storage gas turbines rated 290 MW at 50 Hz or 45–100 MW and 200 MW at 60 Hz

[1] Brown Boveri Reaktor GmbH, Mannheim
[2] Hochtemperatur-Reaktorbau GmbH, Dortmund

Heat-exchangers
Condensers, deaerators, feedheaters, water separator/reheaters

Generators and motor-generators
Salient-pole and turbogenerators, motor-generators of all sizes and capacities with air, gas and/or liquid cooling

Overall control and monitoring systems
for turbosets and complete power plants
Data acquisition, telecontrol, protection and process automation systems
Complete control rooms

Auxiliary and station supply systems
Electric drives, rotating and static excitation systems for generators, static frequency converters for run-up of gas turbines and pumped storage sets, as well as for high-speed boiler feed pump drives
Uninterruptible power supply units

Components and systems for power delivery
Generator circuit-breakers and busduct systems, transformers, switchgear, etc.

Power Distribution

Engineering and erection of complete installations for transmitting, switching and transforming power

For alternating and direct current
For all voltages
For installation indoors or outdoors
With associated protective, control and automation systems
Power system analyses

High-voltage substations and switchgear
for power stations, national and local networks, industrial and transport systems

Power line construction
Overhead lines and underground cables, including dimensioning and routing

Static converters
for power transmission, traction, industrial applications, etc.

High-voltage direct-current transmission systems

Installations for power system ties and compensation

Low-voltage distribution gear and installations
for industry, trade and all communal purposes

Supply of components and systems

High and medium-voltage switchgear
Generator circuit-breakers
Outdoor airblast and SF_6 circuit-breakers
SF_6 gas-insulated switchgear installations
Indoor circuit-breakers, including associated factory-assembled cubicles
Isolators of all kinds
Load-break switches, disconnector switches and compact substations
Surge arresters
Instrument transformers

Transformers and reactors
Large single and three-phase power transformers
Distribution transformers
Transformers for converters, electric furnaces, locomotives and other applications
Reactors of all kinds, including shunt reactors for h.v. systems

High-power static converters

Rotating and static frequency changers

Capacitors and capacitor banks

Insulator bushings

Automation and control of power networks
for monitoring, control, management and optimization of power networks including automation of substations
Complete control rooms

Protection schemes
Protective gear for transformers, busbars, lines, cables and complete networks at all voltages
Relays of all kinds for monitoring networks, load shedding and for protection against overloads and short circuits

Buildings automation
for lower operating costs and enhanced safety in large buildings or complexes

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for industry and the trade

Cable and wire
including bare conductors of copper, aluminium and their alloys

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A broad assortment for such industries as
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Building materials
Iron and steel
Non-ferrous metals
Foundries
Metalworking
Heavy engineering
Machine tools
Chemicals and petro-chemicals
Plastics and rubber
Ceramics and glass
Woodworking
Pulp and paper
Printing
Foodstuffs

A broad assortment for the infrastructure and environmental protection
Drinking-water supplies
Drainage and irrigation
Refuse incineration and waste-water treatment
Underground installations, road and railway tunnels

A wide range of products, systems and installations

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Turnkey industrial power plants, steam and gas turbosets, emergency generating equipment, static uninterruptible power supplies, h.v. and m.v. switchgear, transformers, static converters, low-voltage gear, distribution gear

Drive equipment
Complete drive systems of standard and special design
Static frequency converters for running up blowers and compressors
Variable-speed three-phase drives
Asynchronous, synchronous and d.c. motors for a wide range of ratings, mountings and enclosures

Automation and control
Higher-order systems for monitoring, control, management and optimization of industrial processes

Measuring and regulation equipment
Equipment and systems for measuring, recording and controlling physical and chemical quantities

Protection
Protective systems for boilers, steam turbines, generators, motors, transformers, busbars, lines, cables and complete networks at all voltages

Equipment for industrial heating processes
Electric furnaces and accessories, e.g. arc furnaces, coreless and channel-type induction furnaces for melting, holding and pouring metals
Moulding equipment, pouring systems
Mains, medium and high-frequency equipment for heating and heat treatment
Conductive heating units
Electrically and gas-heated ovens for various industrial heat-treatment applications

Refrigeration and air-conditioning
Refrigerating machines and equipment, as well as components of air-conditioning systems for industrial and commercial applications, for ships and vehicles, including freezing tunnels for deep-freeze goods, refrigerated display cabinets for shops
Heat pumps for outdoor and indoor swimming pools

Special products, systems and installations
Installations and equipment for water treatment, e.g. ozonizers and UV lamps for sterilization, reverse osmosis systems for demineralization; contact and ultrafiltration systems for precipitating and separating solid substances, controlled supply equipment for dust precipitators
Electrolyzers for production of hydrogen
Winding machines, impregnating and drying equipment for manufacture of electrical machines and equipment
Test beds for automobile and machinery manufacturers
Laboratory equipment, including magnets and their supply systems for research establishments

Traction

Design, supply and installation of complete sets of electrical equipment for all traction fields

Main-line, local and industrial railways, including systems for very high speeds
Surface, elevated or underground mass transit systems, including suburban and urban commuter trains, light rail vehicles, streetcars and trolleybuses
Rack railways and ropeways
New, unconventional transport systems

Supply of components

Electrical machines for traction and auxiliary duties, for a.c., d.c. and multi-system vehicles, thermo-electric and thermo-hydraulic vehicles as well as battery-fed vehicles
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Protective and control systems for traction and auxiliary circuits
Lighting, heating and air-conditioning equipment for railway coaches
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Contact-wire systems for all traction applications
Radiocommunication equipment and control and monitoring systems

Pressure-charging systems for diesel engines

Exhaust-gas turbochargers for traction diesel engines
COMPREX® pressure-wave superchargers for diesel engines of cars and trucks, earthmoving machines, tractors, shunting engines, etc.

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Engineering, supply and erection of complete electrical installations of all kinds on ships and offshore facilities

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Bulk and ore carriers
Freighters and container ships
Tankers
Special ships
Floating docks
Floating cranes and dredgers
Offshore drilling and production rigs

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Complete drive systems of standard and special design
A.c. and d.c. motors for a wide range of ratings
Monitoring and automation systems
Refrigerating and air-conditioning equipment and installations

Pressure-charging of diesel engines

Exhaust-gas turbochargers for diesel engines of all ratings

Automation, Protection and Control Telecommunications

Engineering and erection of complete systems and installations
Supply of components

Automation and control

Higher-order systems for monitoring, controlling, managing and optimizing technical processes, primarily in generation, transmission and distribution of electricity, and in:
Distribution systems for water, gas and oil
District heating networks
Industrial installations
Manufacturing and logistic control systems
Traction
Large buildings and complexes

Turnkey automation and control installations

Data systems, autonomous or as part of automation and control systems

Products and systems for automation and control
Micro and minicomputer systems
Display and indicator systems
Monitoring and recording equipment
Programmable automation equipment
Equipment for control rooms
Process data input/output units
Data transmission systems, including telecontrol and ripple control, industrial local area networks
Realtime relational database management system, software tools
Manufacturing automation systems

Software systems and services, such as:
Studies and investigations for automation and control systems
System analyses
Simulation of power plant cycles
Drafting of specifications
Training of customers' technical staff
Development of special products and systems
Development of application software
Project management and supervision
General engineering services
Maintenance and after-sales service contracts

Instrumentation and regulation

Complete instrumentation and control systems

Measuring and control equipment, such as:
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Controllers and limiters for electronic and pneumatic systems
Analog and digital displays
Recorders and visual display units
Electrical and pneumatic final control elements
Analyzers for water and gases
Portable instruments for use during erection, operation, after-sales service, in test bays and laboratories
Flowmeters, e.g. for water and oil

Protection

Complete protective schemes for boilers, reactors, turbines, generators, motors, transformers, busbars, lines, cables and complete networks, at all voltages
Protective relays and ancillary devices with static and mechanical measuring systems
Current and voltage relays, time-lag relays, auxiliary relays and contactors, frequency and directional relays
Line protection units for railways

Telecommunications

Long, medium and short-wave broadcast transmitters with carrier powers from 50 to 2000 kW, including power amplifiers, rectifier tubes and antenna arrays

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REVIEW

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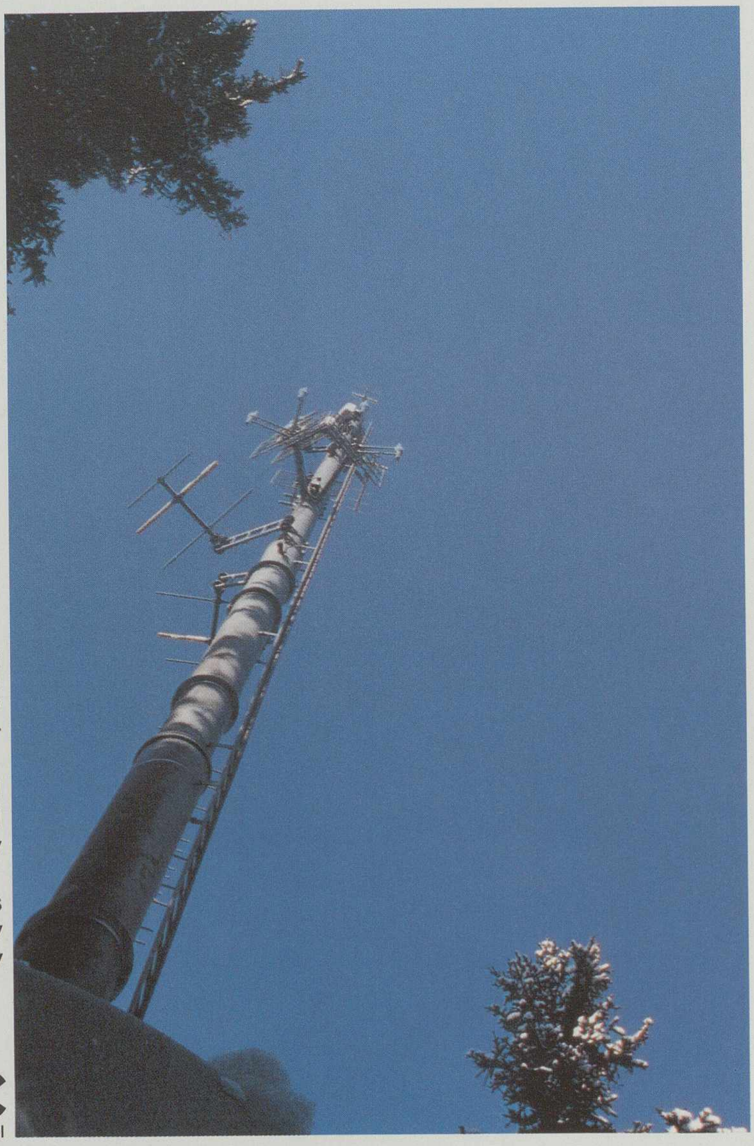

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