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ICONGRAPH—Program Package for Interactive Controller Design by Graphical Plotting*

R. TUSCHÁK,† R. BARS,† R. HABER,† M. HABERMAYER,† T. KOVÁCS,† I. VAJK† and M. VAJTA†

Based on the highest level in man–machine communication, an interactive program package with graphical outputs has been found useful in both educational programs and industrial applications for computer-aided identification, controller design, and simulation of control systems.

Key Words—Computer-aided design; control systems.

Abstract—ICONGRAPH is an interactive program package for CAD of control systems. The system under investigation has to be basically a linear single-loop one with lumped parameters. ICONGRAPH covers the following subjects: identification, design of controllers in the frequency and operator domains by minimizing integral criteria, discrete controller design, block-oriented simulation, state-space techniques and transformations among various system descriptions. The program package is written in FORTRAN and is run on the minicomputer R10 of 64 kbyte operative memory. All the results are plotted on a digital plotter.

1. INTRODUCTION

At the Department of Automation, Budapest Technical University, systematic work has been done in the field of computer-aided design, analysis and synthesis of control systems in the last decade. In 1974 the program system PICADOS (Process Identification and Computer Aided Design of Optimum Systems) was developed (Csáki and co-workers, 1975). It was written in ALGOL for the computer RAZDAN, worked in batch mode and also had graphical output (Haber, Vajk and Vajta, 1981). The computer factory VIDEOTON sponsored development of a program system in FORTRAN and batch mode for their minicomputer. In 1975 the following packages were developed: ANALYSIS, SYNTHESIS, IDENTIFICATION and TAPSO (Transient Analysator for the Purpose of Simulation and Optimization) (Keviczky, Habermayer and Bányász, 1974). In 1974 the Central Research and Design Institute for Silicate Industry set up a so-called Moving Process Computer Laboratory to solving real-time control problems arising in the silicate industry. The program package MERCEDES (Moving computER Control and procEss iDEntification Systems) was developed by the Institute and the Department (Fehér and co-workers, 1979). The real-time system is of modular construction and is run on the TPA/i process computer (similar to a PDP 8) of 24 kbyte memory. All this experience was useful in the development of a new interactive program package for CAD of control systems on the R10 minicomputer of the Department of Automation.

2. THE PROGRAM PACKAGE ICONGRAPH

The program package ICONGRAPH (Interactive CONtroller design by GRAPHical plotting) is an interactive one, and the outputs are displayed graphically. The hardware backgrounds are the minicomputer R10 (made by VIDEOTON, Hungary) of 64 kbyte operative memory, two magnetic tape units, two discs of 800 kbyte, line printer, display and a TEKTRONIX 4662 digital plotter.

The operator's dialogue is CRT-terminal oriented. The input data, the results of each step and the final output can be displayed on the CRT and a hard copy obtained on the line printer. The outputs can be displayed by alphanumeric characters and can be plotted online on the digital plotter.

Linear, single-loop control systems with lumped parameters can be basically designed by means of ICONGRAPH. There are modules for the analysis of nonlinear and multiloop systems, too. Analysis and synthesis can be performed either in the time, frequency or operator domain. There are also programs for transforming the different descriptions to each other. The system under investigation can be

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† Department of Automation, Budapest Technical University, 1111 Budapest XI, Hungary.

TABLE 1. SUBSYSTEMS OF ICONGRAPH

Subject	Name of program	Application area
Identification	IDENT	Data preparation and process identification
State-space control	STASIM	State space simulation
	STAREC	State variable reconstruction
	STACON	Optimal LQ control design
Simulation	BLOCK	Block-oriented digital simulation
Design of controller in the frequency and operator domain	PODOM	Design of controller by root locus technique
	FREDOM	Design of controller using Bode plots
Design of controller based on minimization of integral criteria	TIDOM1	Optimization based on quadratic integral criterion
	TIDOM2	Optimization based on arbitrary integral criterion
Transformation	SIFRED	Reduction of multiloop control system
	TRAN	Discrete-continuous transformation
Discrete control	DISCON	Discrete control of continuous systems

continuous or discrete, disturbed by deterministic or stochastic noise and can be described by transfer functions or state space equations.

A list of the programs in the package ICONGRAPH is shown in Table 1. A brief description of the individual programs is given in the appendix.

The identification program (IDENT) handles measurement data: it makes possible easy data correction, filtering, plotting, etc. Assuming a model structure between the input and output data files it gives a parameter estimation on the basis of the extended least-squares method. The dispersion of the parameters is also calculated. Model validity checking is included too. This part of the program package proved to be an effective tool in different industrial applications (Vajta, Haber and Kovács, 1978).

Simulation programs provide the opportunity to compute and visualize the transient responses in complex control systems. With a block-oriented simulator (BLOCK) multiloop, nonlinear continuous systems can be investigated similarly to analogue programming (Keviczky, 1974). Simulation of the transients of single-loop DDC systems is possible with the program DISCON. Time behaviour of systems given by state equations can be simulated with the program STASIM. In this case the reconstruction of the state variables and the determination of the optimal feedback matrix have to be executed previously with the programs STAREC and STACON (Höfler and Grübel, 1976, Kwakernaak and Sivan, 1972).

Transformations between the different system description forms (continuous and discrete transfer functions, transfer functions and state equations) are made available by the program TRAN (Csáki, 1976, Keviczky, 1977).

Interactive CAD of controllers gets an emphasis in this program package. The state of the art of controller design is built into the programs to some extent, making them 'intelligent enough' to give a proposal on the structure and the parameters of the controller statisfying the prescribed quality requirements. The user may accept or reject this proposal, trying out the effects of his own compensators as well. The program PODOM is for controller design on the basis of the root-locus method (Kovács, Lakatos and Haber, 1974, Kovács, 1977). FREDOM designes the controller in the frequency domain with the Bode plots, and programs TIDOM give optimal controllers minimizing different integral criteria (Csaki, 1978).

The ICONGRAPH is a portable system easy to implement on a similar minicomputer configuration having an online digital plotter (e.g. HP or TEKTRONIX) and an alphanumeric CRT terminal. The computer must have a FORTRAN-IV. compiler and a PLOT-10 (or similar) subroutine package.

3. INTERACTIVE CAD OF REGULATORS

The use of the ICONGRAPH will be illustrated through one of its programs for controller design.

The input data can be read in from the CRT terminal in a free format. Wrong data can be corrected easily. An interactive dialogue is used to give all the input information necessary for the program. The user has the option to choose at the decision points of the program among the possible branches. He can accept or reject any design proposal. The behaviour of the control system with different regulators designed by the user can also quickly be analysed and visualized. Several return points to previous questions are built in the programs, giving the possibility to change only a few data, and easily investigate several variants of the same problem. After modifying some input parameters and re-running the programs the results of the new version can be obtained and visualized. This program structure provides repeated return to choosing another output device or giving the new domains for calculations, if for example enlargement of some parts of the diagrams is necessary. [Return to a previous point is realized by the reading procedure itself: typing a carriage return (instead of giving the data required) ensures a jump to a previous program label.]

The structure of a program for interactive controller design will be illustrated now through FREDOM.

This program tries to mechanize some realizations of the 'art of compensation' based on the widely known classical frequency domain synthesis methods applying mainly Bode plots.

The input information typed in from the CRT terminal are transfer functions of the process and the feedback, and the static and dynamic requirements. At the beginning the controller is a P regulator of unity gain.

The program determines first the gain necessary to meet the static requirement. Then the frequency characteristics of the open and closed loops are calculated with this gain factor. If desired, the frequency diagrams are plotted. The program evaluates the open-loop frequency response and gives the values of the actual cut-off frequency (settling time) and the phase margin. Upon request it determines and plots the unit-step responses of the open and the closed loop.

If the system does not meet the prescribed requirements, the program offers a compensator. If accepted, the program calculates the frequency and time responses for the compensated system. The designer has the option to give other compensators and examine their effect too.

The control algorithm works as follows. First it makes a decision on the type of the compensator (P, PI, PD or PID where P means the gain, I and D the lag and lead effects, respectively). The necessity of an integrating effect in the compensator is determined with knowledge of the required static accuracy for the given input signal and the denominator of the open-loop's transfer function. Comparing the prescribed and the estimated settling times, the algorithm determines whether an accelerating PD effect is necessary or not. Comparison of the prescribed and actual phase margins provides a viewpoint for the decision: if the phase margin has to be increased, the algorithm considers again the necessity of a differentiating effect. The decision scheme is seen in Table 2.

Having decided on the type of the regulator, the next task is to determine the parameters of the compensator. If possible, the parameters are calculated to satisfy exactly the dynamic requirements for the cut-off frequency and the phase margin.

The algorithm calculates the cut-off frequency desired for the compensated system from the prescribed settling time, and for this frequency it determines the amplitude and phase angle of the uncompensated system. Then it gives the parameters of the compensator, which brings the cut-off frequency to this place ensuring the prescribed phase margin. Of course some *a priori* assumptions may be necessary. For example, in the PID regulator the ratio of integrating to differentiating time constant is fixed. The required dynamic properties cannot always be met with the given type of compensator. In some of these cases the algorithm makes some efficient alterations. If, for example, in the case of PD or PID compensation the necessary phase shift was greater than 90°, the program reduces the cut-off frequency to its third, and calculates the parameters again. In the case of a PID regulator, if the necessary phase shift would be negative, the program changes to a PI regulator.

TABLE 2. CAD BY FREDOM

Integrating effect necessary?	Accelerating necessary?	Phase margin has to be increased?	Type of the compensator
NO	NO	NO	P
		YES	PD
	YES	NO	
		YES	
YES	NO	NO	PI
		YES	
	YES	NO	PID
		YES	

The compensation algorithm also handles the dead time. It checks whether the desired cut-off frequency is greater than 1.5/dead-time. If not, the design procedure is as described above (for a pure dead-time without lags the program computes an appropriate integrating controller). If so, the program gives a warning: UNREALIZABLE COMPENSATION, SETTLING TIME HAS TO BE INCREASED. The parameters of the compensator offered by the design algorithm are visualized on the CRT, followed by the question: O.K.? Depending on the answer, the calculations continue with this compensator, or the program waits for the parameters of the user's own compensator.

4. EXAMPLES

Example 1

Figure 1 shows the scheme of a continuous system. The transfer function of the plant is

$$G_p(s) = \frac{1}{(1+0.1s)(1+s)(1+10s)}.$$

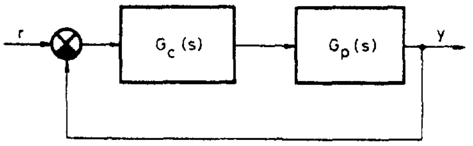

FIG. 1. Continuous control system.

The feedback is a proportional element of unity gain. The task is to choose the compensator in a way to satisfy the following requirements:

static accuracy for unit step input	0.01
phase margin	60°
settling time	10 s

With an appropriately increased gain [$G_c(s) = 100$] FREDOM calculates the frequency characteristics of the open and closed loops (Fig. 2), gives the value of the phase margin and estimates the settling time. Upon request it gives also the unit step response (Fig. 4). Then the program offers a compensator, in this case a PI regulator

$$G_c(s) = \frac{5.64(1+9.5s)}{9.5s}$$

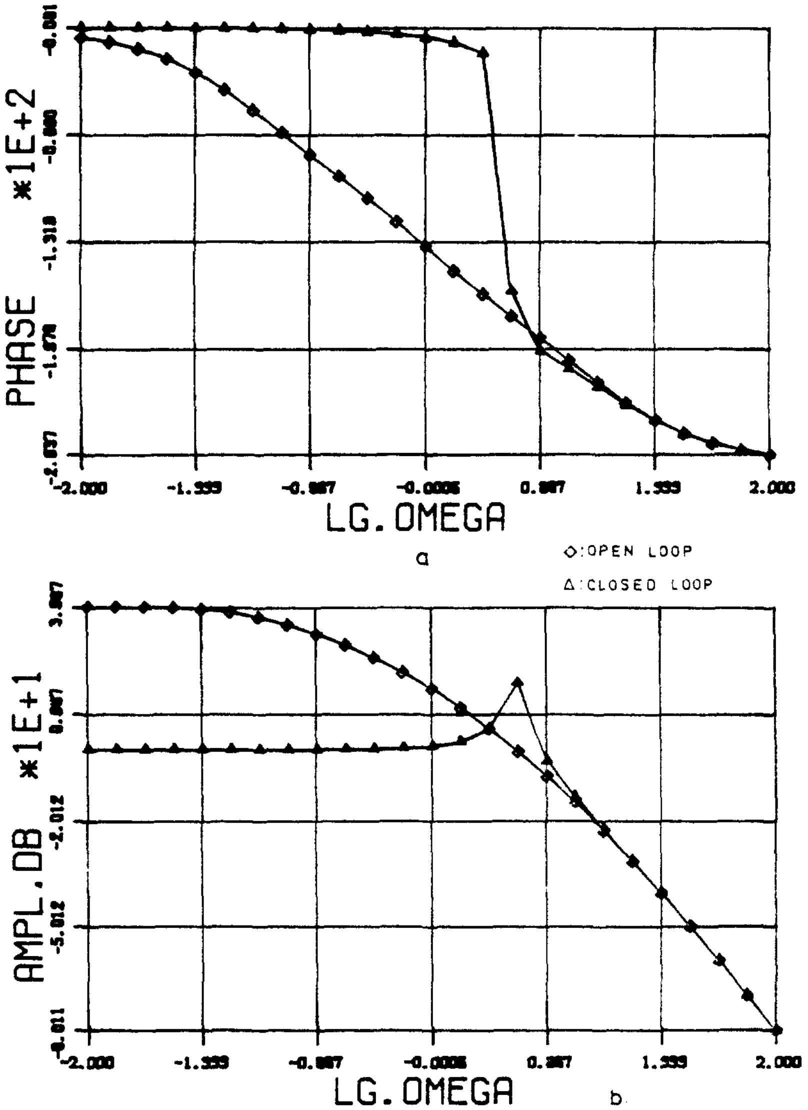

FIG. 2. Bode plots of the system with regulator $G_c(s) = 100$. (a) Phase angle; (b) magnitude ratio.

Accepting it, the characteristics above are calculated for the compensated system, as well (Figs 3 and 5).

Example 2

Let us design a discrete regulator to the continuous plant (Fig. 6):

$$G_p(s) = \frac{1}{(1+100s)(1+10s)}$$

and simulate the control action and the controlled variable for a step in the reference value.

The sampling time of the regulator is chosen as $T = 1$ s and the simulation step-size is $h = 0.05$ s. The program DISCON computes the impulse transfer function of the plant (for $T = 1$ s)

$$G_p(z) = \frac{0.0004821(1+0.964z^{-1})}{(1-0.99z^{-1})(1-0.905z^{-1})}.$$

A PD-type regulator is now selected

$$G_c(z) = A_p(1 - 0.905z^{-1})$$

in order to eliminate one pole of the plant's transfer function. The parameter A_p was chosen by repeated simulations. The control action and the controlled signal are shown in Fig. 7 by the finally accepted value $A_p = 1000$, which results in about 35% of overshoot.

Example 3

Consider the control system given by the state equations

$$\dot{\mathbf{x}}(t) = A\mathbf{x}(t) + \mathbf{b}u(t)$$

$$y(t) = \mathbf{c}^T\mathbf{x}(t)$$

where

$$A = \begin{bmatrix} -1 & 1 \\ 0 & -0.1 \end{bmatrix}, \mathbf{b} = \begin{bmatrix} 0 \\ 0.1 \end{bmatrix}, \mathbf{c} = \begin{bmatrix} 1 \\ 0 \end{bmatrix}.$$

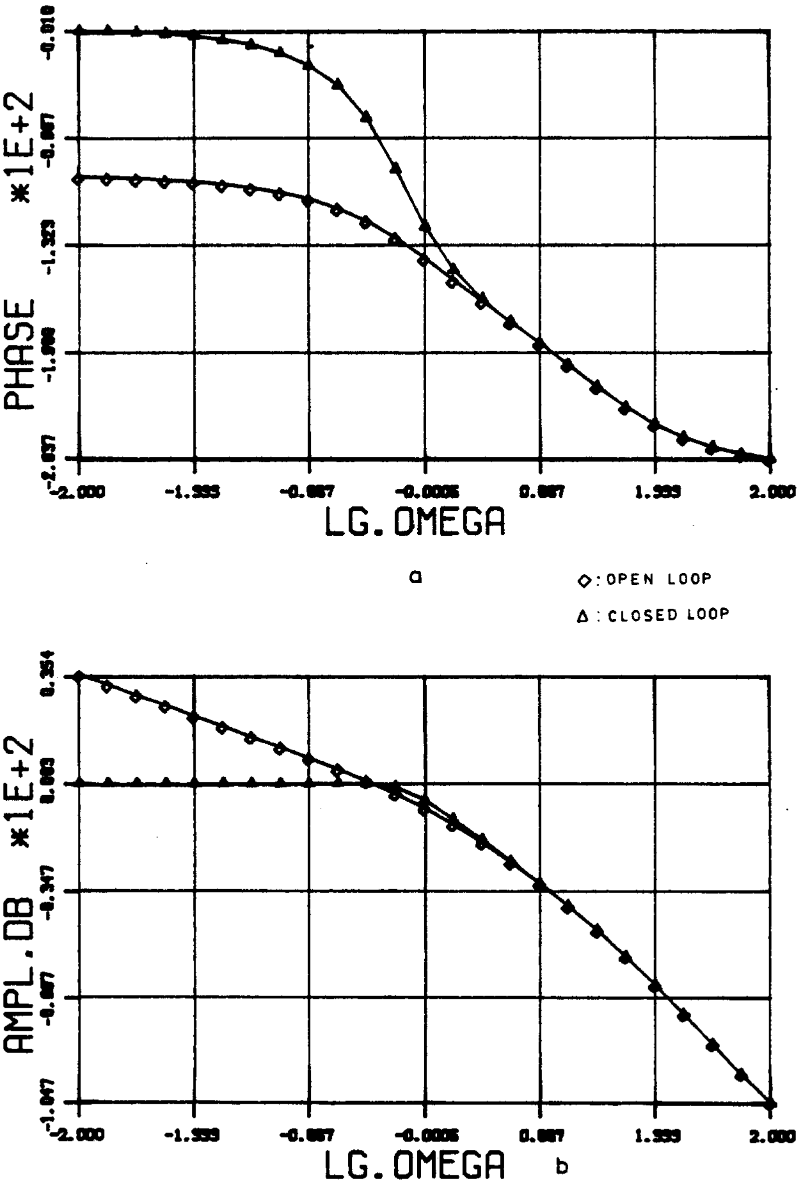

FIG. 3. Bode plots of the system with regulator $G_c(s) = 5.64\ (1 + 9.5s/9.5s)$. (a) Phase angle; (b) magnitude ratio.

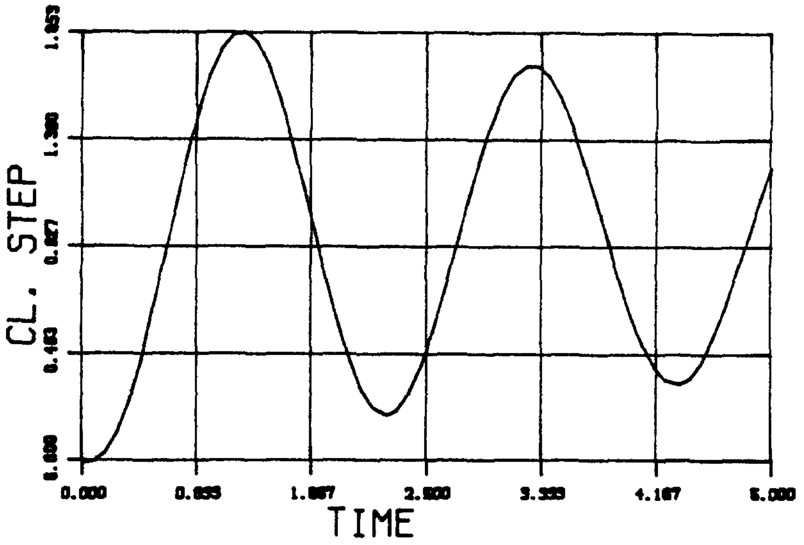

FIG. 4. Step response of the control system with regulator $G_c(s) = 100$.

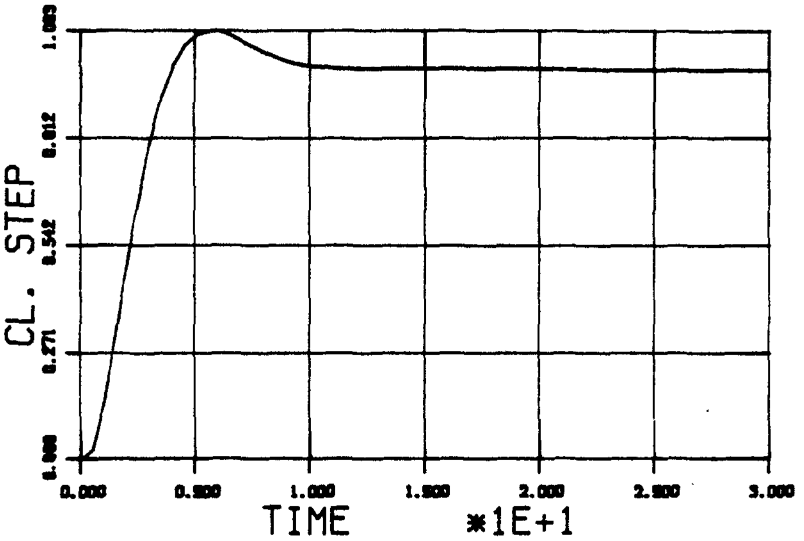

FIG. 5. Step response of the control system with regulator $G_c(s) = 5.64\,(1 + 9.5s/9.5s)$.

Let us calculate the optimal state feedback matrix minimizing the performance criterion

$$I = \int_0^\infty [\mathbf{x}^T(t)R\mathbf{x}(t) + u^T(t)Qu(t)]\,dt$$

where the weighting matrices are

$$R = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}, Q = 10^{-4}.$$

To obtain the solution the algebraic Riccati equation has to be solved. Using the program STACON the optimal state feedback matrix is

$$\mathbf{k}^T = [64.17 \quad 34.83].$$

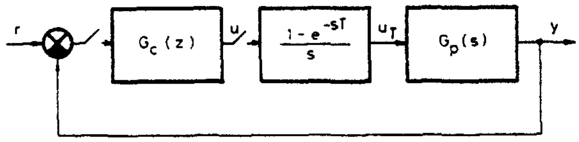

FIG. 6. Continuous system with discrete regulator.

Let us calculate the optimal Kalman-filter, when the covariance of the state-noise is a white noise with zero mean and covariance

$$V_x = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$$

and the observation noise is also characterized by a white noise process with zero mean and covariance

$$V_y = 0.0025.$$

The optimal feedback vector of the Kalman-filter can be calculated by the program STAREC and the result is

$$\mathbf{l}^T = [19.9 \quad 18.0].$$

Finally let us simulate the transients of the control loop by the program STASIM. Figure 8 shows the control system to be simulated. The initial conditions were chosen as

$$\mathbf{x}^T(0) = [1 \quad 0],$$

$$x^T(0) = [0 \quad 0].$$

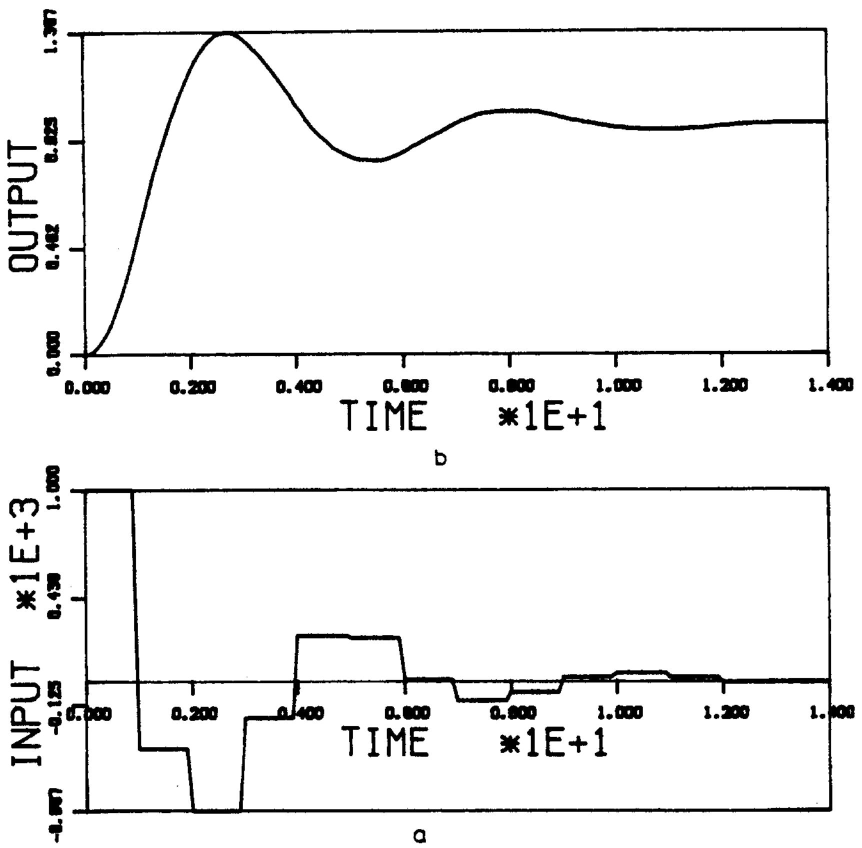

FIG. 7. (a) Control action and (b) controlled signal.

After a short interactive dialogue the simulation step size was chosen to be $h = 0.01$ s. Figure 9 shows the control signal driving the state variables from the initial state to the zero steady-state and shows the output signal $y(t)$ and its estimate obtained by the state reconstructor. Although their initial conditions were different [$y(0) = x_1(0) = 1$; $\hat{y}(0) = \hat{x}_1(0) = 0$], the estimated output signal very closely approached the actual output signal after a short transient period.

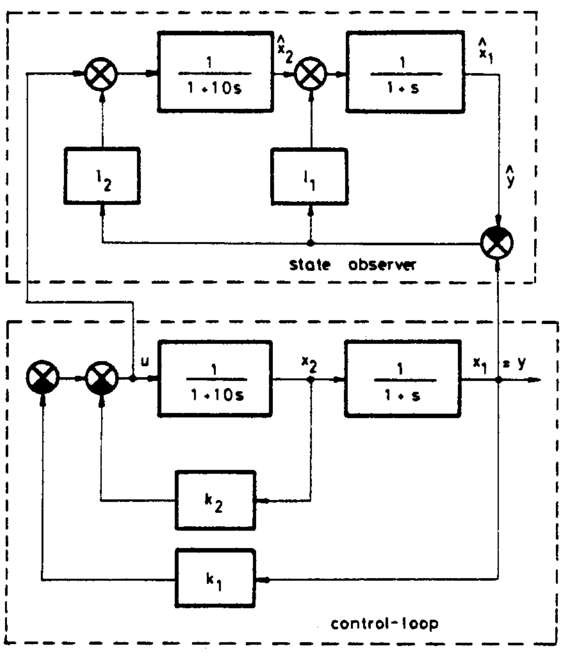

FIG. 8. Scheme of the state space control and state reconstruction.

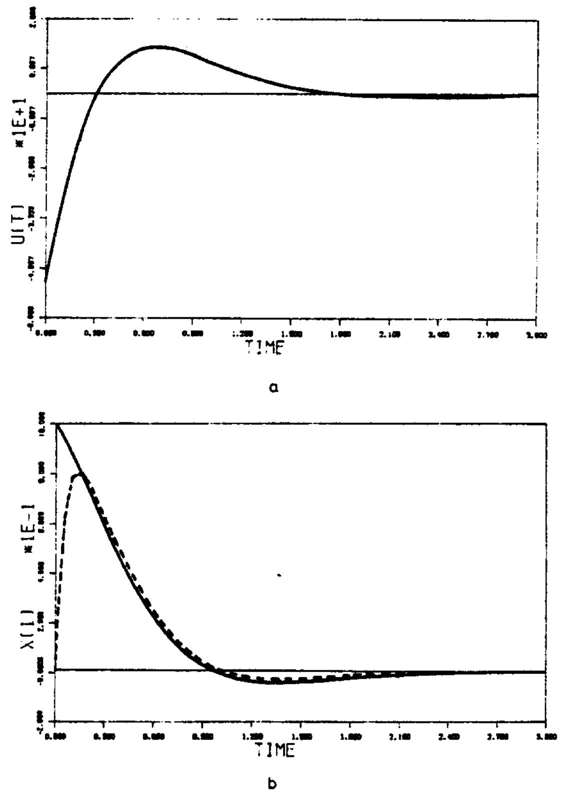

FIG. 9. (a) Control signal and (b) measured (——) and estimated (– – –) output signals.

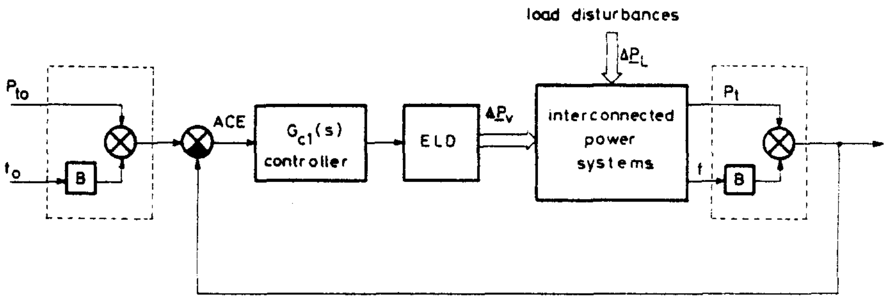

FIG. 10. Flowchart of the load-frequency control loop.

5. APPLICATIONS

ICONGRAPH has been used in basic and advance courses of control theory and process control at the Department of Automation. Beside education, it has been widely applied in several industrial problems as modelling and identifying a cement mill, a servowheel, an atomizer, a chemical reactor, power station and energy systems (Keviczky and co-workers, 1978). Some of the most important applications were the load-frequency control (LFC) of the Hungarian power system and the reactive power and voltage control (RPVC) in a power station (Vajta, Haber and Kovács, 1978, Vajk and co-workers, 1981).

Application 1

As a first application let us consider the LFC of the Hungarian power system. The task of the LFC is to adjust the actual frequency f and tie-line power P_t to their given reference values f_0, P_{t0} as close as possible. For this purpose the controller has to reduce the error signal ACE (area control error) to zero

$$\mathrm{ACE}(t) = \Delta P_t + B\Delta f = P_{t0} - P_t + B(f_0 - f)$$

where ΔP_t is the deviation in the tie-line power, Δf is the frequency bias and B is the bias factor of the power system. Figure 10 shows the flowchart of the control loop and Fig. 11 is the dynamic model of the interconnected power system. The Hungarian power system is modelled by n generator–turbine blocks (with second-order transfer functions $G_{1i}(s)$, $i = 1,\ldots,n$ and n gradient limiters with dead-time $\tau = 20$ s). $G_2(s)$ represents the dynamic behaviour of all the other parts of the interconnected power system. ΔP_1 and ΔP_2 are the actual power outputs of the subsystems. ΔP_{L1} and ΔP_{L2} are the load fluctuations acting on the system. The primary regulator performs a feedback from the frequency deviation, R is the drop, D is the load damping coefficient. The first task is to design a PI-type central controller to satisfy the performance criterion. Another very important task is the economic load dispatch (ELD). The design of ELD is outside the scope of this paper.

Two kinds of dispatching system were taken into account: parallel mode, in this case each block gets the same command, i.e. the power demand is uniformly distributed among the blocks; and serial

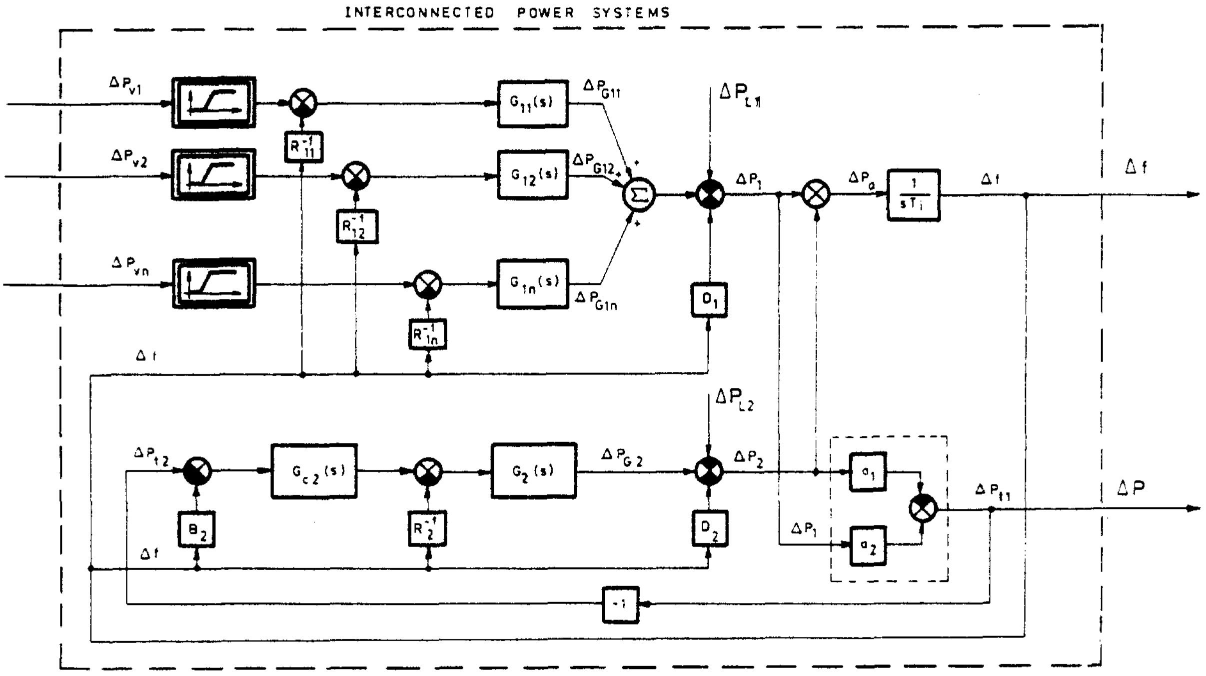

FIG. 11. The dynamic model of the interconnected power system.

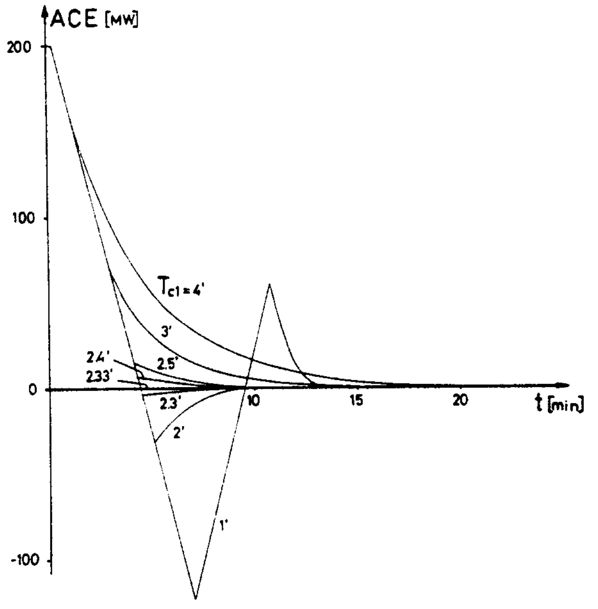

FIG. 12. Area control errors at different integration time constants.

mode, the demand is sent subsequently to the next block if the demand is greater than a given threshold.

The two dispatching modes have rather different effects on the behavior of LFC.

After investigating the dynamic behavior and the parameter sensitivity of the plant (i.e. the open loop) a reduced process model was developed (Vajta, Haber and Kovács, 1978) and an optimal I-type central regulator

$$G_{c1}(s)=\frac{1}{sT_{c1}}$$

was designed for the case of a parallel dispatching mode. In case of deterministic load-disturbance ($\Delta P_{L1}=200\,\mathrm{MW}$) overshoot σ and peak-time t_c of ACE(t) were calculated versus T_{c1}. Figure 12 shows the area control error and Fig. 13 contains σ and t_c. An optimal value of $T_{c1}\simeq 2.33$ min is seen to exist. In this case ACE(t) has no overshoot and the control time is of minimum value.

Finally let us note that an adaptive version of LFC was also developed using the results of the above-mentioned design method (Vajk and coworkers, 1981). The adaptive, self-tuning version of LFC was realized in a process control computer HIDIC 80 at the Power Control Centre and has been working since 1981.

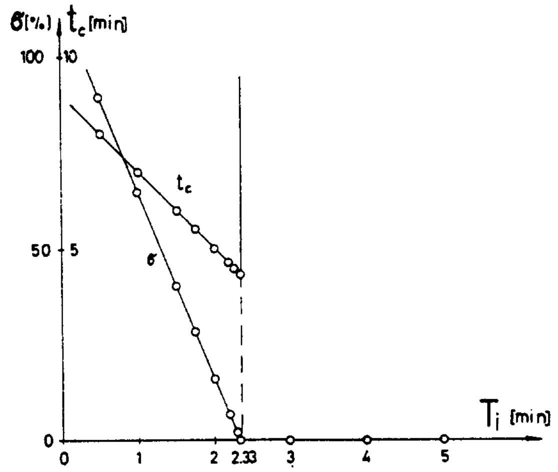

FIG. 13. Overshoots and peak-times of ACE(t) versus the integrating time constant.

Application 2

In the previous application only LFC was considered. But in an interconnected power system control of the reactive power Q and the voltage U can be very important. As a first step let us identify the parameters (the transfer functions) of a power station containing n generator–turbine blocks. Each synchronous generator has a magnetic-type voltage regulator. The scheme of the blocks is seen in Fig. 14. The blocks are connected to a common bus via transformators. The transfer functions to be identified are

$$G_{ij}(s)=\frac{\Delta Q_j}{\Delta I_{ai}},\quad i,j=1,2,\ldots,n$$

$$G_{i,u}(s)=\frac{\Delta U_{\mathrm{bus}}}{\Delta I_{ai}}$$

$$G_{i,Q}(s)=\frac{\Delta Q_{\mathrm{bus}}}{\Delta I_{ai}}$$

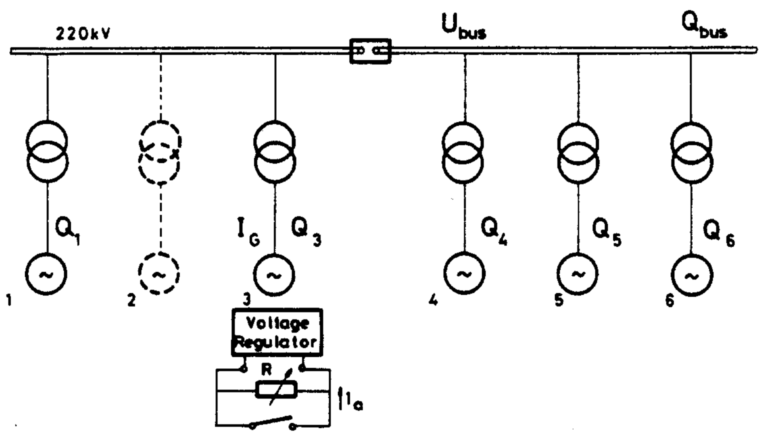

FIG. 14. Measurement configuration of blocks in the power station.

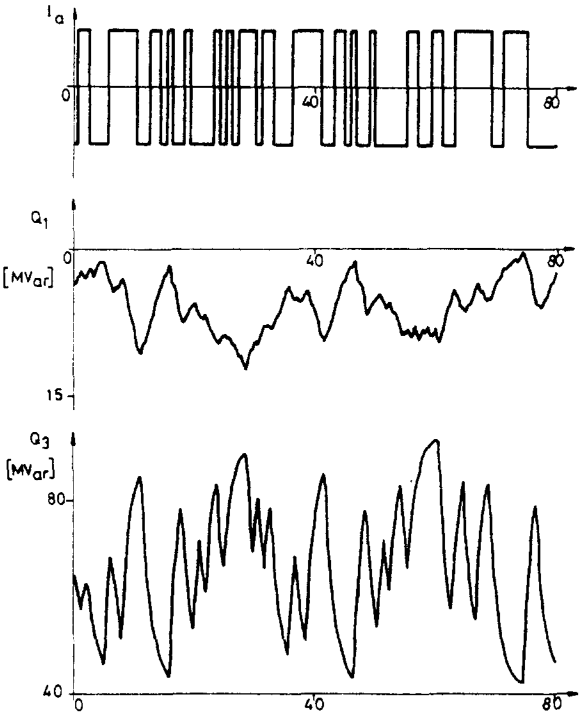

FIG. 15. Reactive power responses for PRBS input signal of generator's voltage regulator.

where ΔU_{bus} is the bus voltage, ΔQ_{bus} is the reactive power measured at the bus and

$$Q_{\text{bus}} = \sum_{i=1}^{n} Q_i$$

I_{ai} is the reference signal of the ith voltage regulator. The analogue signals were measured by a 14-channel Phillips tape recorder then sampled by a microprocessor with sample time of 25 ms. Figure 15 shows the reactive power of some blocks for a PRBS I_{a3} signal. The actual number of blocks was five. Figure 16 shows the 220 kV bus voltage.

Using IDENT program in ICONGRAPH, first a structure analysis of the transfer functions was carried out then the parameters were identified. Table 3 contains the identified parameters transformed from the discrete z-plane to the s-plane.

From Table 3 it appears that also the blocks have time lags and time delays. On the basis of the identified model parameters a multimicroprocessor real-time reactive power and voltage control system has been developed, now under construction for a power station.

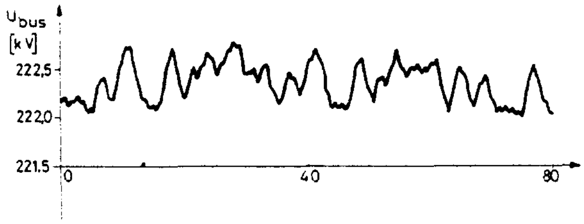

FIG. 16. Bus voltage response for PRBS input signal of generator's voltage regulator.

TABLE 3. IDENTIFIED PARAMETERS OF THE TRANSFER FUNCTIONS BETWEEN THE REACTIVE POWER AND THE BUS VOLTAGE

$$G(s) = \frac{K}{1 + sT}$$

	K	T(s)
$G_{i,1}(s)$	0.131	2.36
$G_{i,2}(s)$	—	—
$G_{i,3}(s)$	0.129	1.80
$G_{i,4}(s)$	0.130	2.21
$G_{i,5}(s)$	0.132	2.31
$G_{i,6}(s)$	0.130	2.26
$G_{i,u}(s)$	0.0045	1.51
$G_{i,Q}(s)$	0.48	1.48

6. CONCLUSIONS

A program package for CAD of control systems is briefly described. The package ICONGRAPH is interactive assuming the highest level in man–machine communication. It covers the most important problems which have arisen in research and development, furthermore in the educational tasks of automatic control. The time and frequency domain responses of the control system can be plotted during and after the design procedure.

The extended applications of the package both for academical and industrial design problems proved the correctness of the chosen CAD-system philosophy in current practice.

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APPENDIX: DESCRIPTION OF THE PROGRAMS

IDENT (IDENT*ification*)

IDENT is used for measurement data preparation, parameter estimation and model validity checking. It has several functional parts interconnected by a common data, parameter and structure field. The subsystems of IDENT are:

COPY	transmission of data
CORRECTION	correction of data
TRANSF.	transformation of data
FILTER	filtering of data
DRAWING	display by alphanumerical characters
PLOTTER	plotting on a digital plotter
CORRELATION	calculation of the cross-correlation function between files
PAR. EST.	parameter estimation by the extended least-squares method
DISCRETE/CONT. TRANSF.	discrete-continuous transformation
TEST-SIGNAL	generation of test signal.

STASIM (STA*te equation* SIM*ulation*)

The program simulates the transient responses of a continuous control system described by its state equations. The interactive CAD dialogue can help to give the optimal state-feedback matrix, different state initial conditions, the input signal, deterministic or stochastic disturbances. The program can also simulate the state reconstructor. The simulation step size can be chosen by the designer in an interactive way. All the simulated time functions (as state variables, estimated state variables, output signal) can be displayed or plotted on a digital plotter.

STAREC (STA*te space* REC*onstruction*)

STAREC is an interactive program for the reconstruction of the state-variables of a linear system comprising state and measurement excitation noises. The feedback gain vector of the optimal Kalman-filter is computed by solving the algebraic Riccati-equation using the Kalman–Englar iterative method. The algorithm was obtained from the Ruhr University in the frame of a scientific cooperation (Höfler and Grübel, 1976).

STACON (STA*te space* CON*troller design*)

The program STACON computes the optimal state feedback matrix of a linear control system by minimizing a quadratic function. Reading in the system matrix, the input and output matrices, the diagonal elements of control and state weighting matrices, the time increment and the upper limit of steps, the program lists the optimal-feedback matrix which is the solution of the matrix Riccati equation (Höfler and Grübel, 1976).

BLOCK (BLOCK-*oriented simulator*)

BLOCK computes the transient responses of dynamic, nonlinear systems. The system can be given similarly to analogue programming. The state equations are solved by the fourth-order Runge–Kutta method. Depending on the user's request the following tasks can be performed:

DATA	structure and parameters, as inputs
SIMULATION	simulation
PLOT	plotting of the transient response on a digital plotter
DOCUMENTATION	documentation of the system data under investigation
OPTIMIZATION	optimization of parameters
PARAMETER STEP	repeated simulation with different parameters

PODOM (PO*le*-DOM*ain design*)

The program calculates the root-locus diagram of a linear control system. The transfer function of the plant can be given in a polynomial form or by the pole-zero configuration. The root-locus method has been generalized for any parameter of the regulator hence it is possible to design a controller choosing different performance criteria. The root-locus can be plotted on CRT or by a digital plotter. The interactive dialogue is very efficient to design PI, PD or PID type controllers and to display the transient behavior of the system, as the program computes the step response.

FREDOM (FRE*quency* DOM*ain*)

The program FREDOM can be applied to design linear control systems in the frequency domain. The input data are parameters of the process and the feedback path, the prescribed static accuracy for the given input signal, the phase margin and the settling time. On the basis of the frequency characteristics the program determines both the type and the parameters of the controller of P, PI, PD or PID type satisfying the given prescriptions. The frequency and step responses of the process and the closed loop can be calculated and plotted.

TIDOM1 (TI*me* DOM*ain design 1*)

The program TIDOM1 determines the optimal control parameters of a linear control system with lumped parameters by minimizing the integral square of error. Reading in the Laplace transform of the error signal, the system polynomial coefficients, the starting values, the step increments and the accuracy for parameters to be optimized, the program gives the steps of optimization, the optimal control parameters and the optimum value of the quadratic integral criterion. The step response of the analysed system can be drawn on a digital plotter or displayed for the optimal and the starting parameters.

TIDOM2 (TI*me* DOM*ain design 2*)

TIDOM2 is an interactive program for simulation or/and optimization of a single-loop system with dead time. The structure of the closed loop, the parameters of the system and the controller, the type of the integral criterion, the saturation value, the type and magnitude of the input or the disturbing signal can be chosen by an interactive dialogue. The compensator may be of P, PI, PD or PID type. The integral criterion can be given as one of the following six possibilities

$$\int_0^\infty t^i |e(t)|^j \,dt, \quad i = 0, 1, 2, \quad j = 1, 2.$$

Here $e(t)$ is the error signal and t is the time. The input and the disturbing signal are step functions. The latter can be an exponential function, as well. The controller output is limited by a given saturation value. For simulation the fourth-order Runge–Kutta method is used. For optimization the adaptive simplex method is used.

SIFRED (SI*gnal* F*lowchart* RED*uction*)

The program calculates the overall transfer function of a multiloop control system. The system is given by its flowchart and the transfer functions of each branch. The algorithm is based on the node eliminating method. With knowledge of the overall transfer function it is possible to calculate its pole-zero configuration, and further simplification is possible by neglecting certain poles and zeros. It is also possible to reduce the system to four nodes.

TRAN(TRAN*sformation*)

The program TRAN performs transformations among continuous and discrete describing forms of a linear system. The designer may give the system in different forms, as

- transfer function given with the coefficients of the numerator and the denominator,
- transfer function given with the gain, the poles and zeros,
- transfer function given with partial fractions,
- state-space equations given in phase-variable form.

DISCON — DIS*crete* CO*ntroller design*

DISCON simulates the transient response of the discrete control of a single-loop continuous system with control action limitation. It calculates the impulse transfer function of the plant at a given sampling time and the operator can choose a controller in the knowledge of the discrete pole/zero configuration. The program also suits to simulate the DDC of a plant given in discrete form.