CONF-830609--25

CONF-830609--25

DE83 014314

EBR-II HIGH-RAMP TRANSIENTS UNDER COMPUTER CONTROL

by

R. J. Forrester, H. A. Larson, L. J. Christensen
W. F. Booty and E. M. Dean

Argonne National Laboratory
Idaho Falls, Idaho 83401

Submitted for the

American Nuclear Society Annual Meeting
June 12-17, 1983
Detroit, Michigan

*Work supported by the U. S. Department of Energy under Contract W-31-109-38

DISCLAIMER

EBR-II HIGH-RAMP TRANSIENTS UNDER COMPUTER CONTROL

by

R. J. Forrester, H. A. Larson, L. J. Christensen,
W. F. Booty and E. M. Dean

During reactor run 122, EBR-II was subjected to 13 computer-controlled overpower transients at ramps of 4 MWt/s to qualify the facility and fuel for transient testing of LMFBR oxide fuels as part of the EBR-II operational-reliability-testing (ORT) program [See J. D. B. Lambert et al., Operational Safety and Reliability Research at EBR-II, paper 81-JPGC-NE-11, Joint ASME/IEEE Power Generation Conf., St. Louis, Oct. 4-8, 1981, Amer. Soc. Mech. Eng. (1981) for an overview of plans for this program.]

A computer-controlled automatic control-rod drive system (ACRDS), designed by EBR-II personnel, permitted automatic control on demand power during the transients. Figure 1 is a schematic diagram of the system, which replaced the existing drive for a control rod with a servo-controlled DC motor. Figure 2 shows the controller electronics. During the transient testing, rod-velocity demand to the servo was set by a microcomputer in a reactor-power-feedback (from a linear power channel) configuration. The servo compared the computer generated velocity demand with the velocity feedback signal from a tachometer and generated the motor voltage based

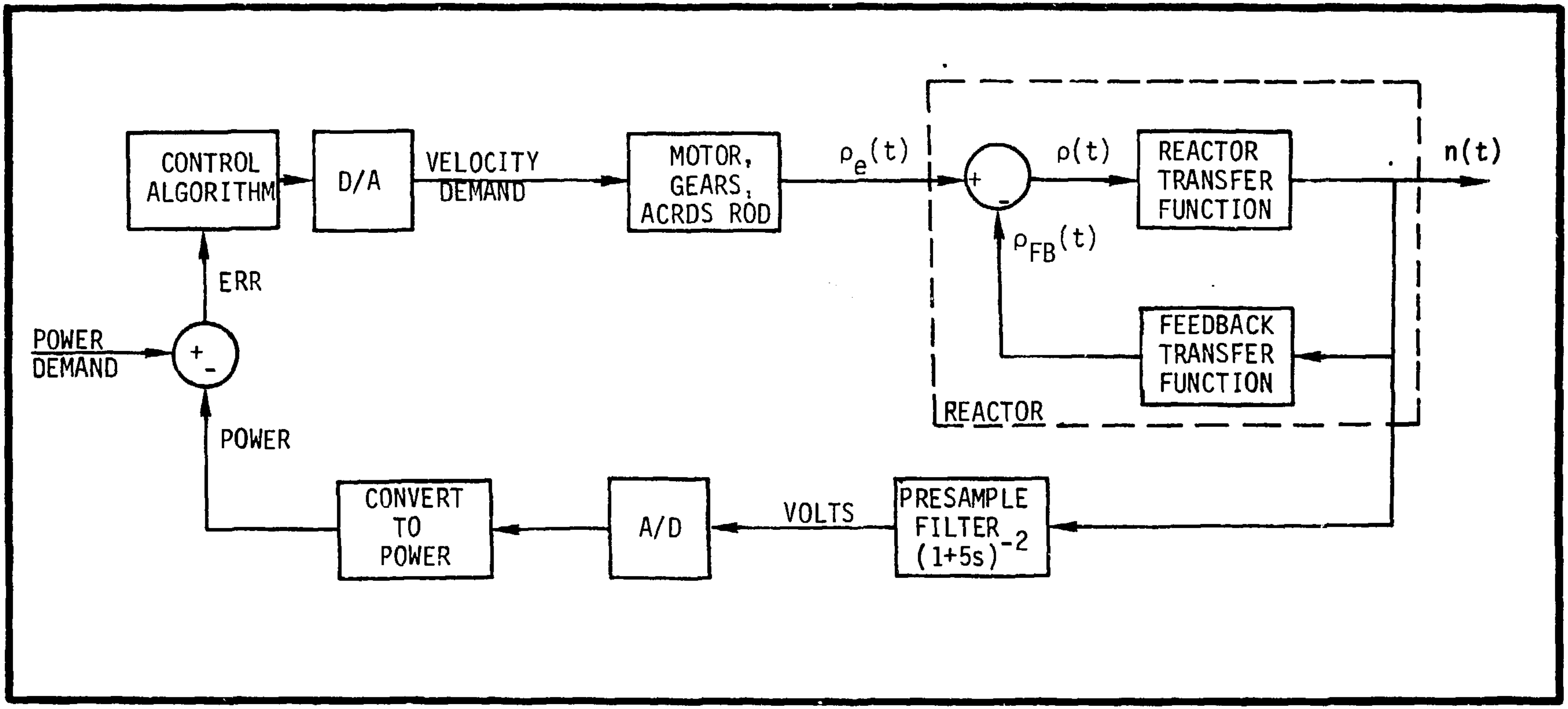
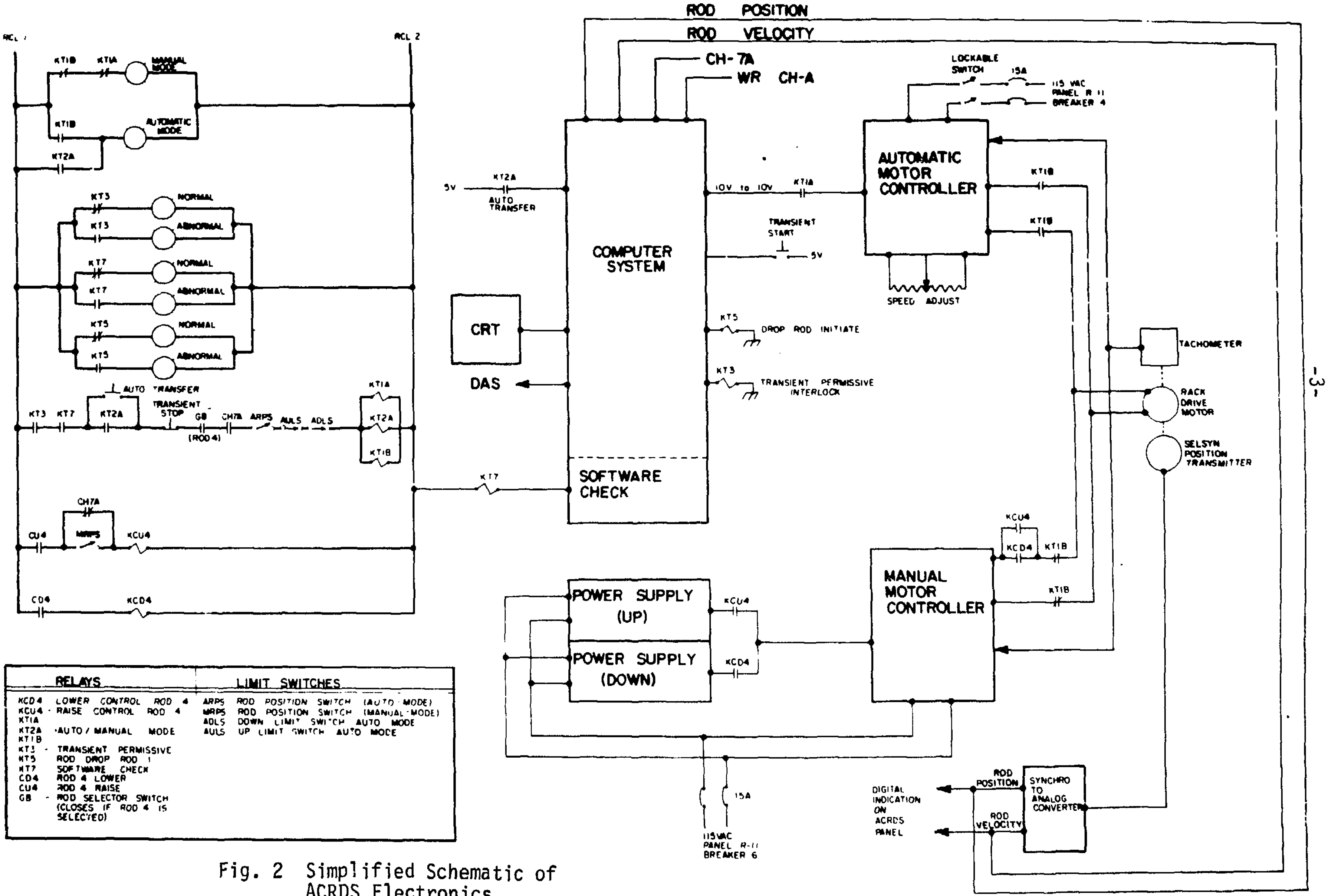


Fig. 1 Control System Block Diagram



RELAYS

KCD4	LOWER CONTROL ROD 4
KCU4 -	RAISE CONTROL ROD 4
KT1A	
KT2A	AUTO / MANUAL MODE
KT1B	
KT3 -	TRANSIENT PERMISSIVE
KT5	ROD DROP ROD 1
KT7	SOFTWARE CHECK
CD4	ROD 4 LOWER
CU4	ROD 4 RAISE
GB -	ROD SELECTOR SWITCH (CLOSES IF ROD 4 IS SELECTED)

LIMIT SWITCHES

ARPS	ROD POSITION SWITCH (AUTO MODE)
MRPS	ROD POSITION SWITCH (MANUAL MODE)
ADLS	DOWN LIMIT SWITCH AUTO MODE
AULS	UP LIMIT SWITCH AUTO MODE

Fig. 2 Simplified Schematic of ACRDS Electronics

on this difference. The drive system had both automatic and manual modes. In the automatic mode, rod velocity was controlled by computer. In the manual mode, rod movement was controlled through existing drive switches by a separate servo controller, and the speed corresponded to that of a normal control-rod drive. Rod-position feedback was available but used only for limiting the control-rod stroke. (See L. J. Christensen "Design of Automatic Control Rod Drive System for Transient Testing at EBR-II" paper to be presented a the ANL 11th Biennial Conference on Reactor Operating Experience "Plant Startup and Operation in the '80s," Aug. 1-3, 1983, Scottsdale, Arizona.)

Safety criteria (see Table I) developed for the ACRDS included the requirements that (1) a single failure should not result in a reactivity insertion rate greater than 0.12 $/s and (2) rod position would be interlocked so that sodium-boiling temperatures would not be reached upon failure of the ACRDS coincident with failure of the plant protection system (PPS). Limitation of the amount of rod worth inserted gave extra protective margin to (a) allow for uncertainties in parameters used in modeling postulated accident progressions and (b) provide extra protection in the manual mode at ranges of reactor powers where a protective function (reactor period) is ineffective.

The drive was also inherently limited to reactivity insertion rates of less than 0.50 $/s. Simulations using a continuous systems modeling program show that with a worst-case failure the rod would reach its upper limit before this rate could be attained.

TABLE I

SUMMARY OF MAJOR ACRDS SAFETY CRITERIA

Criterion	Basis
Criterion 24, 10CFR50, Appendix A "Separation of Protection and Control Systems"	Independence of control and protection system
Criterion 25, 10CFR50 Appendix A protection system "Requirements for Reactivity Control Malfunctions"	Assurance that fuel design limits are not exceeded for any single malfunction of the reactivity control system
Criterion 28, 10CFR50, Appendix A "Reactivity Limits"	Limits amount and rate of reactivity addition by control system so damage to reactor coolant boundary is no greater than limited local yielding and damage to internals does not significantly impair core cooling capability.
RDT C16-1 Para. 4.3.5	Reactivity addition rates limited so not beyond response capability of PPS
Inherent reactivity rate limit of $\leq$ 50¢	Within capability of RSS protection circuits
$\leq$ 12¢/s reactivity rate for any single failure	To classify failures at rates greater than 12¢/s as unlikely in terms of RDT standard C16-1.
Interlocks to prevent automatic operation below 40% reactor power	To assure that minor damage limit for EBR-II fuel clad was not exceeded in the unlikely event of failure of the primary protection circuit during a rod runaway event.
Interlock to limit available reactivity to rod (a function of power level)	To assure that sodium boiling would not occur in the event of insertion of all available reactivity at maximum inherent rate coincident with PPS failure

TABLE I (contd)

SUMMARY OF MAJOR ACRDS SAFETY CRITERIA

Criterion	Basis
Interlock ACRDS with other control rods to prevent insertion of reactivity by any other rod during automatic operation	To prevent violation of available reactivity limitation for a particular power level and to classify simultaneous insertion as unlikely.
Limit rod reactivity worth to 90¢	To meet the assumption of the safety analyses performed. (Bounds the normal range of rod worths.)
Provide software checks that the transient stays within predefined bounds and that rod velocity is within predefined limits, using sensors independent of the ones used for control	To prevent challenging the RSS
Key control of automatic mode and software controls	To prevent unauthorized transients.

Criterion 1 was met by limiting voltages available to the servo system and by providing software velocity checks. Criterion 2 was met by rod-position interlocks in software and hardware that would cause the ACRDS to revert from automatic to manual mode.

The EROS computer code [see E. M. Dean and H. A. Larson, EROS: An Experimental Breeder Reactor II Operational Safety Code, Nucl. Technol. 57(1), p. 7 (April 1982)] was used to show that both the primary (neutron channels) and the secondary (core outlet temperature or neutron level) protective functions were available to limit EBR-II metal-fuel-cladding temperatures to the technical-specification limits of 715°C for anticipated events and 815°C for unlikely events. Failure of the drive system to an insertion rate of up to 0.12 $/s was classified as anticipated. Failure of the drive coincident with failure of the primary protective function was classified as unlikely.

EROS calculations revealed that the response time of the secondary protective function (core outlet temperature) was inadequate to provide the required protective margin. Thus the response time of the outlet temperature channels was improved by a reactor modification before the transient tests. EROS calculations also showed that below 40% reactor power the core outlet temperature provided inadequate protective margin. Therefore, ACRDS interlocks were provided to cause control to revert to manual when the power dropped to 40%.

A summary of the fault progressions which were calculated and the resulting protective margins is given in Table II.

The limiting ACRDS design goal for this transient series was that the ramp be generated by 5% precision with allowance for a transition period at beginning and end of the ramp. This goal was easily met by the design except for a two-second period following the transition period when the rod was running at full speed.

Software development and checkout proceeded in several stages in cooperation with EG&G as shown in Table III. In a mockup of an ACRDS test assembly, the transfer function of the servo drive motor, gearing, and ACRDS rod was measured using a white noise source and Fourier Analyzer. EBR-II dynamic parameters and control-rod worths were used to design a preliminary controller algorithm. Final controller design and simulation tests were conducted in the EG&G hybrid computer lab, where the analog portions of the system (e.g., the reactor and servo controller) were simulated with an analog computer.

Parallel to this effort, an EBR-II dynamics and rod-worth simulator (portable analog device) was fabricated for use in preliminary algorithm testing on the ACRDS control computer with a mockup of a control rod at EBR-II. Final transient simulations were performed with an ACRDS control rod in the reactor while it was shut down. The resulting controller algorithm provided excellent response at all required power levels. After those simulations, the low-worth (about 0.02$) ACRDS rod was used for a

TABLE II

Calculated Response of EBR-II to Postulated Reactivity Transients using a Reduced Feedback

System Fault (Max. Ramp Rate)	Initial Power	Power Level Trip Setpoint %	Period Trip[1] Setpoint	Subassembly Outlet Temp. Trip (SOT) Setpoint	Peak Cladding Temperature[2] °C	Protective Margin[5] °C
Anticipated Fault						
ACRDS failure (0.12 $/s)	100%	115	BP[4]	S	661	54
	38%	115	BP	S	642	72
	0%	S	17	NR	371	344
Unlikely Faults						
ACRDS failure and failure of primary trip function (0.12 $/s)	100%	F	BP	115(S)	731	84
	38%	F	BP	115(S)	814	1
	0%	115	F	NR	639	176
ACRDS failure with concurrent 100% drive-in of a control rod (0.13 $/s)	100%	115	BP	S	661	154
	38%	115	BP	S	642	173
	0%	S	17	NR	371	444
ACRDS rod runaway at maximum inherent drive speed (0.50 $/s)	100%	115	BP	S	661	154
	38%	115	BP	S	637	178
	0%	S	17	NR	371	444

[1] Period trip bypassed at ∿ 50% power for normal startup. Bypassed at 38% power in the transient mode with operation of the ACRDS.

[2] Uncertainty factor has been applied to calculated temperature.

[4] RSS trip function status. BP - trip function bypassed F - trip function failure postulated S - secondary trip function NR - trip function not required.

[5] No credit is taken here for the ACRDS rod position interlock; margins were increased by the position interlock.

TABLE III

Development Steps for Control System

1. Definition of design criteria and selection of equipment.
2. Measurement of transfer function of controller, motor, gears, and mockup rod.
3. Simulations on hybrid computer to establish control algorithm simulate effect on analog portions of system (reactor, rod, servo, etc.).
4. Fabrication of EBR-II dynamics and rod worth analog simulator for use at EBR-II in shutdown condition.
5. Transient simulation with EBR-II in shutdown condition using
    - Portable simulator
    - Actual rod in the reactor
6. At-power transients (50-51 MWt) in EBR-II with a low worth rod, EBR-II reactor run 121.
7. At-power transients in EBR-II with high worth (∿ 0.83$) rod, at increasing power steps until desired qualification plant transient from 41 to 100% power had been verified.

test transient from 50 to 51 MWt. The results were in excellent agreement with those from the tests with the mockup of the control rod.

Starting in November, power transients were conducted with a high-worth (about 0.83$) ACRDS rod. Figure 3 shows the response and demand for one test; the power increase is from 40 to 100% of full power at 4 MWt/s. Demand sequence is an "up ramp" at 4 MWt/s, a hold for 12 min while a control rod is lowered to raise the ACRDS rod to a higher position, and a combination "down-step" and "down-ramp" demand to the original power level. The "down-step" accommodates a 0.20-$ drop by another control rod, required to reduce power at least as rapidly as the up-ramp power increase. Figure 4 plots the ACRDS rod motion and Fig. 5 shows a comparison of the demand and actual reactor power during an up-ramp.

The series of transients described above has qualified EBR-II for fuels transient testing under automatic control.

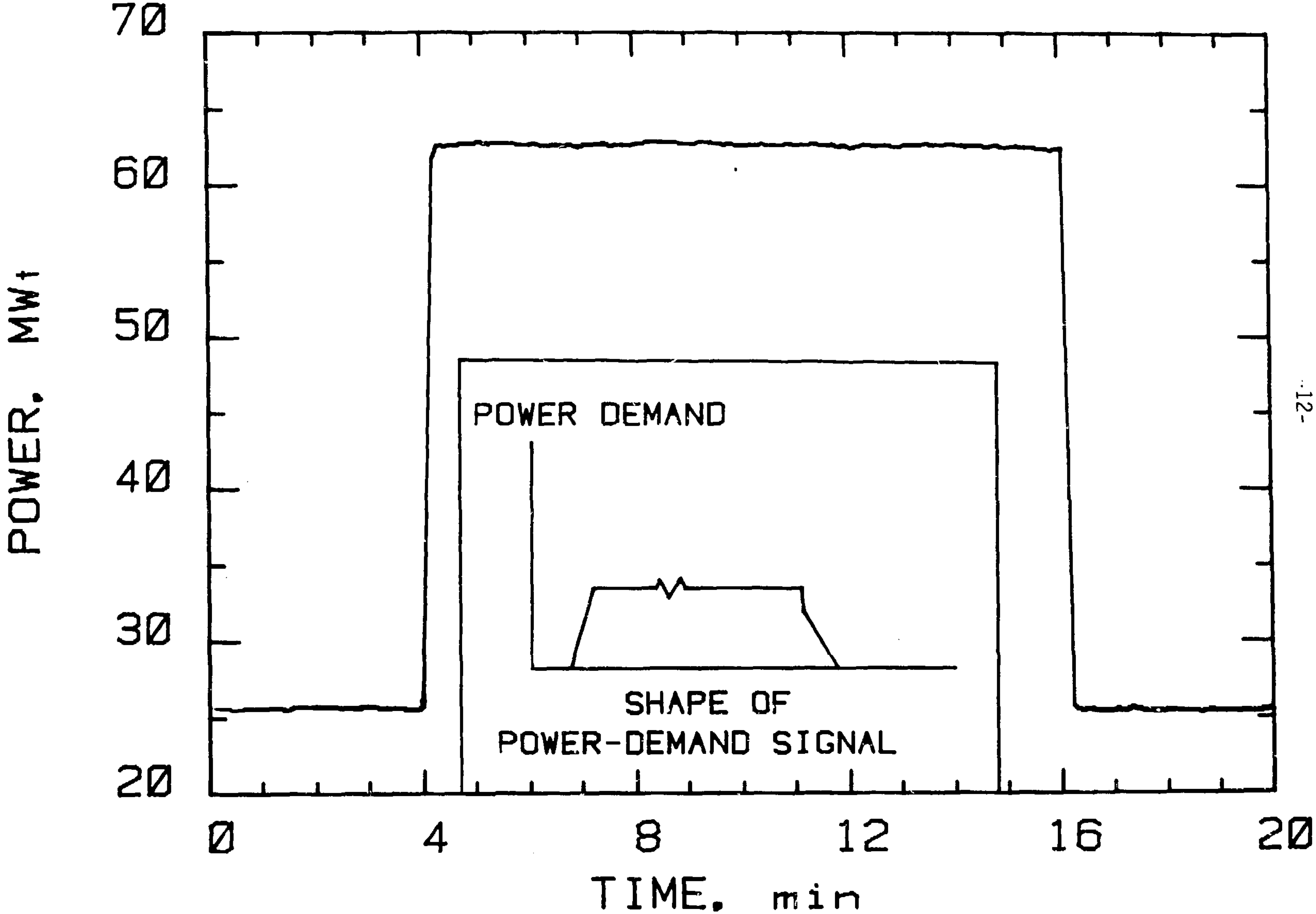


Fig. 3 Power Response and Shape of Power-demand Signal During ACRDS Transient.

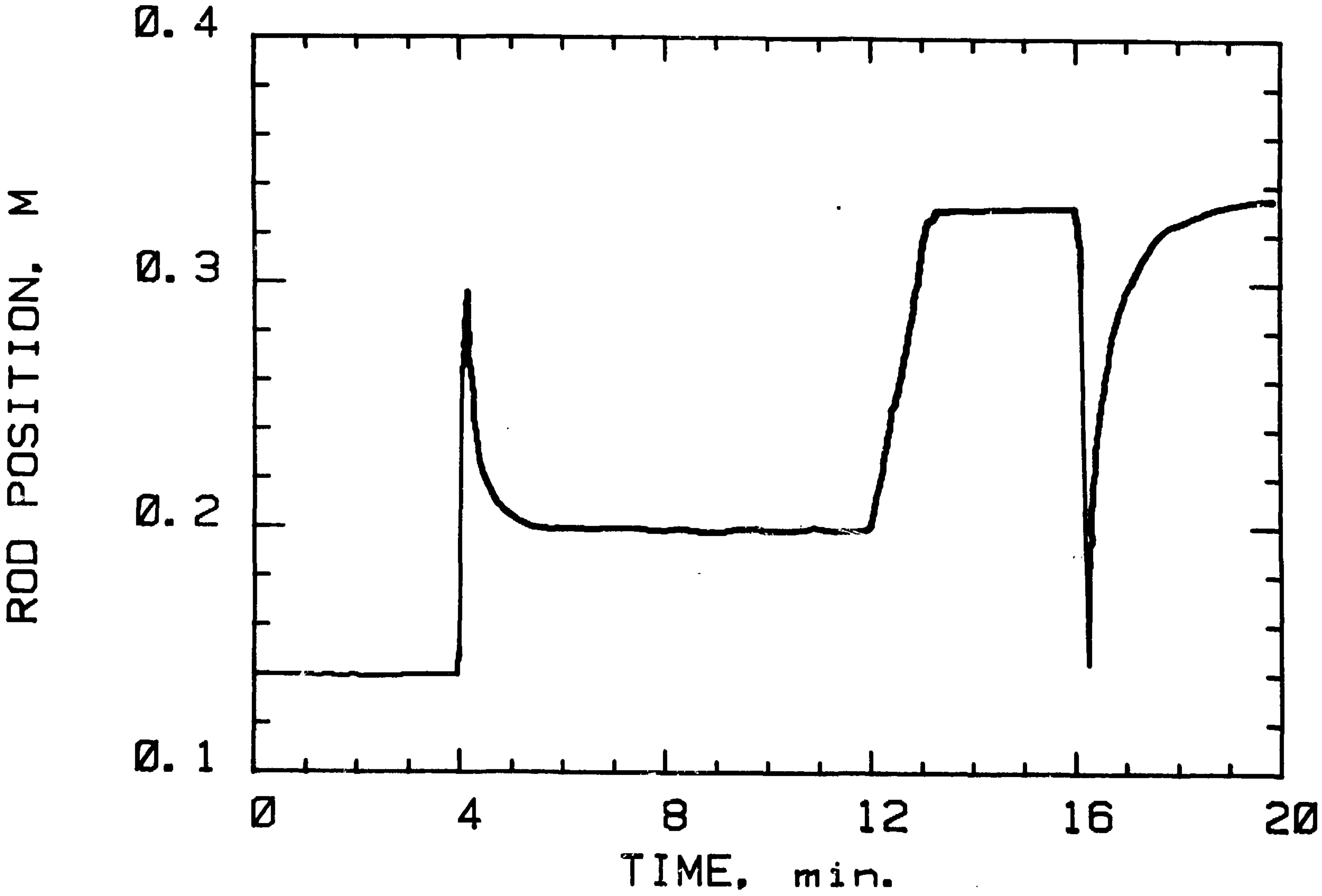


Fig. 4 Rod Position During ACRDS Transient

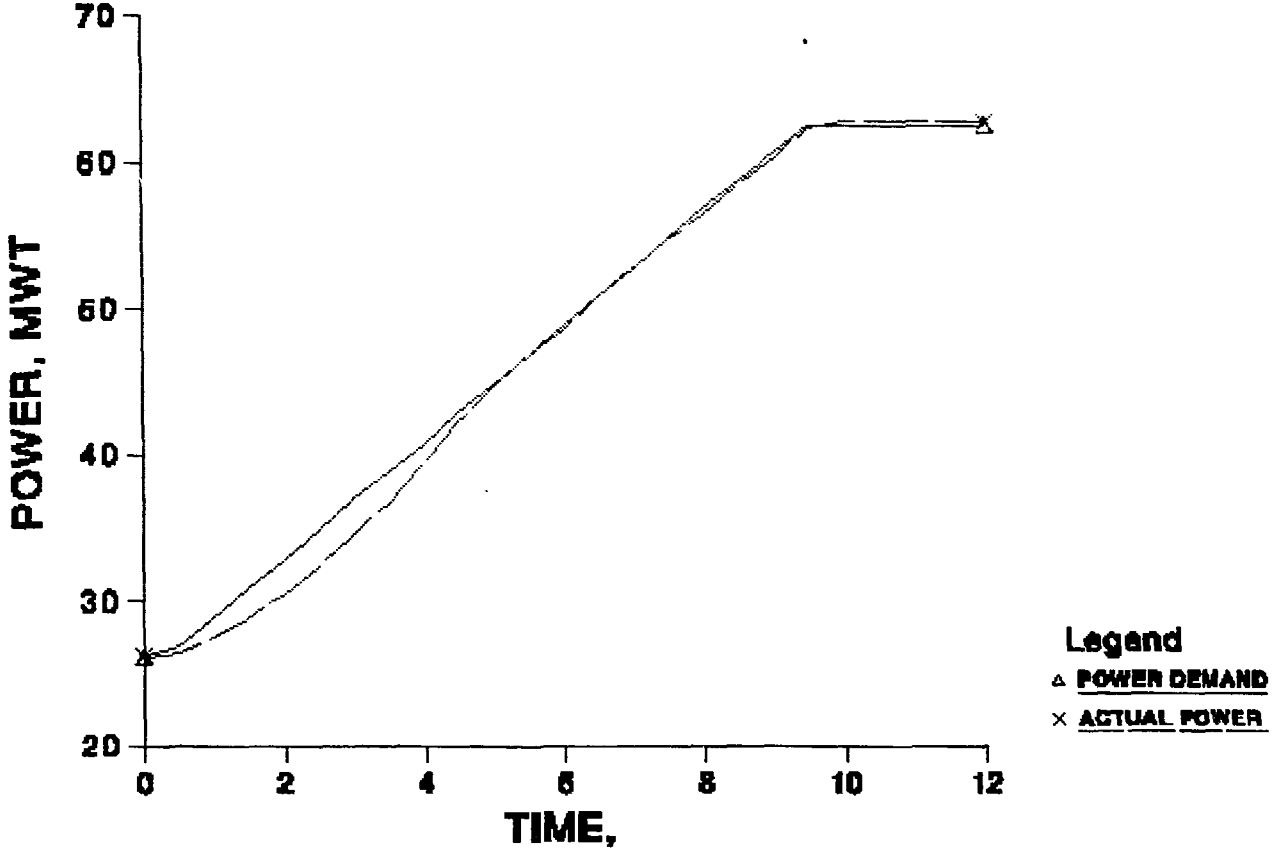


Fig. 5 Comparison of Power Demand and Actual Power During Transient