

Title:

DESIGN, CONSTRUCTION, AND FIRST OPERATIONAL RESULTS OF A 5 MEGAWATT FEEDBACK CONTROLLED AMPLIFIER SYSTEM FOR DISRUPTION CONTROL ON THE COLUMBIA HBT-EP TOKAMAK

RECEIVED
 JAN 16 1995
 O.S.T.I

Author(s):

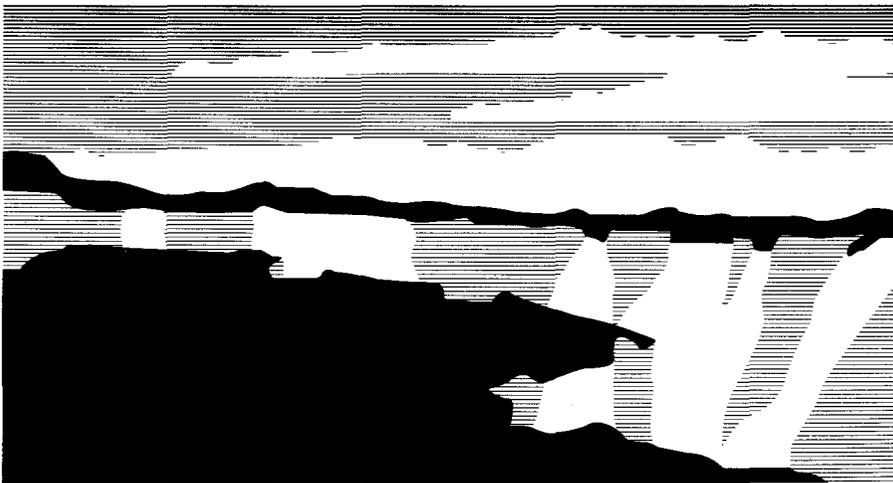
W. A. REASS, P-24
 H. A. ALVESTAD, P-24
 R. R. BARTSCH, P-24
 G. A. WURDEN, P-24
 T. H. IVERS, COLUMBIA UNIVERSITY
 D. L. NADLE, COLUMBIA UNIVERSITY

Submitted to:

IEEE PULSED POWER CONFERENCE
 Albuquerque, NM
 July 12 - 13, 1995

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.



Los Alamos
 NATIONAL LABORATORY

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the University of California for the U.S. Department of Energy under contract W-7405-ENG-36. By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Form No. 836 R5
 ST 2629 10/91

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

DESIGN, CONSTRUCTION, AND FIRST OPERATIONAL RESULTS OF A 5 MEGAWATT FEEDBACK CONTROLLED AMPLIFIER SYSTEM FOR DISRUPTION CONTROL ON THE COLUMBIA UNIVERSITY HBT-EP TOKAMAK

BY

W.A. REASS, H.A. ALVESTAD, R.R. BARTSCH, AND G.A. WURDEN
LOS ALAMOS NATIONAL LABORATORY
P. O. BOX 1663
LOS ALAMOS, NM 87545

AND

T.H. IVERS AND D.L. NADLE
COLUMBIA UNIVERSITY
500 WEST 120th STREET
NEW YORK, NY 10027

ABSTRACT

This paper presents the electrical design and first operational results of a 5 Megawatt feedback controlled amplifier system designed to drive a 300 μ H saddle coil set on the "HBT-EP" tokamak. It will be used to develop various plasma feedback techniques to control and inhibit the onset of plasma disruptions that are observed in high "B" plasmas. To provide a well characterized system, a high fidelity, high power closed loop amplifier system has been refurbished from the Los Alamos "ZT-P" equilibrium feedback system. In its configuration developed for the Columbia HBT-EP tokamak, any desired waveform may be generated within a 1100 ampere and 16 kV peak to peak dynamic range. An energy storage capacitor bank presently limits the effective full power pulse width to 10 mS. The full power bandwidth driving the saddle coil set is \sim 12 kHz, with bandwidth at reduced powers exceeding 30 kHz.

The system is designed similar to a grounded cathode, push-pull, transformer coupled, tube type amplifier system. The push pull amplifier consists of 6 each Machlett ML8618 magnetically beamed triodes, 3 on each end of the (center tapped) coupling transformer. The transformer has .1 volt-seconds of core and a 1:1 turns ratio. The transformer is specially designed for high power, low leakage inductance, and high bandwidth. Each array of ML8618's is (grid) driven with a fiber optic controlled hotdeck with a 3CX10,000A7 (triode) output. To linearize the ML8618 grid drive, a minor feedback loop in the hotdeck is utilized. Overall system response is controlled by active feedback of the saddle coil current, derived from a coaxial current viewing resistor.

The detailed electrical design of the power amplifier, transformer, and feedback system will be provided in addition to recent HBT-EP operational results.

INTRODUCTION

The Los Alamos ZT-P feedback amplifiers were originally designed to accommodate various amplifier and feedback topologies to provide a flexible physics experimental program. Each amplifier cabinet contains two rows of 3 ML8618 triodes. Each row has an independent driver

amplifier, feedback network, and control electronics. This will permit each row to be operated independently, in parallel, or push-pull. For the Columbia Tokamak, it was required to operate the amplifier systems in a push-pull configuration to provide a bipolar current output to more effectively suppress the M=2 plasma mode. To better optimize the amplifier system in a push-pull configuration, changes in the original feedback topology were made. A single feedback amplifier network was used to stabilize the system instead of using the two that were available. Gain and phase changes were necessary (as expected) in both the forward and feedback loop to ensure unconditional stability. Initial testing on the Columbia Tokamak went very smoothly. One of the initial concerns related to the induced voltages on the amplifier system during plasma start-up or disruption. Another concern was the effect on system diagnostics and induced noise when the amplifier system was operational. Fortunately, neither problem were of significance. The plasma start-up and disruptions does not affect the amplifier in any detrimental manner or induce any observable amplifier (output) current. As expected, the amplifier does induce waveforms in the plasma magnetic pick-ups. The induced waveforms are exactly those reproduced by the amplifier. Other diagnostics do not seem to be affected by the high-power waveforms.

SYSTEM CONFIGURATION

The simplified system block diagram is shown in figure 1. The major system components consist of the energy storage capacitor bank, amplifier module, coupling transformer, and the HBT-EP saddle coils. Important subsystems are the feedback networks, interlock, and the amplifier fast protect system. The 100 μ F energy storage capacitor bank has a maximum voltage rating of 20 kV (100 kJ). A constant current charging supply of Los Alamos design is remotely sequenced from the HBT-EP control room. The amplifier module is 4' wide, 6' high, and 7' deep and in addition to the high-power tubes, contains the majority of systems complex electronics. The module has the fast crowbar systems, feedback electronics, hot deck driver controls, 8618 filament controls, high power grid drivers, and its own equipment interlock system. A simplified diagram of the

INTERNAL HOTDECK

The use of a hotdeck within a hotdeck is energy efficient, it avoids the use of power hungry, high voltage level shifters and cathode followers. This design, as shown in figure 4, provides a solid state interface to the high power vacuum tube stages with the added benefit of a simple feedback topology. A voltage divider between the internal hotdeck and main hotdeck provides a signal for minor loop feedback. Error signals from the system's main feedback networks are received by amplitude modulated fiber optic links. This signal and the minor loop signal are combined, amplified, and then buffered by a T-Mos output FET. Photograph 1 shows normal 3CX10,000A7 (gated) grid drive (~400 Vp-p) when input through the fiber optic link (~4 Vp-p). With the minor loop disconnected, grid drive becomes unstable and easily saturates at either supply rail, as shown in photograph 2. The overall closed loop frequency response exceeds 200 kHz and loop parameters are not affected by tube Miller capacitance. The T-Mos output FET can provide over 2 kW of linearized grid drive to the 3CX10,000A7.

FEEDBACK

This amplifier system closes the feedback loops at ground potential, and fiber optically couples error signals to the hotdecks. This topology permits measurement and adjustment of loop parameters during machine operation. By utilizing AM links for error signals, wide bandwidth, first order response is easily attained with excellent signal to noise ratio. Drift and gain changes are of minor consequence as those errors are corrected by the overall feedback network. Figure 5 shows the loop compensation circuitry that stabilizes the overall system response. The saddle coil current signal is amplified by U1 and its frequency response tailored by U2. The difference (error) signal between the reference signal and the feedback signal is derived by U3. The forward loop gain and dominant pole-zero are controlled by U4 and U5. U5 and its complementary signal drive amplitude modulated fiber optic transmitters that output to each hotdeck's internal hotdeck.

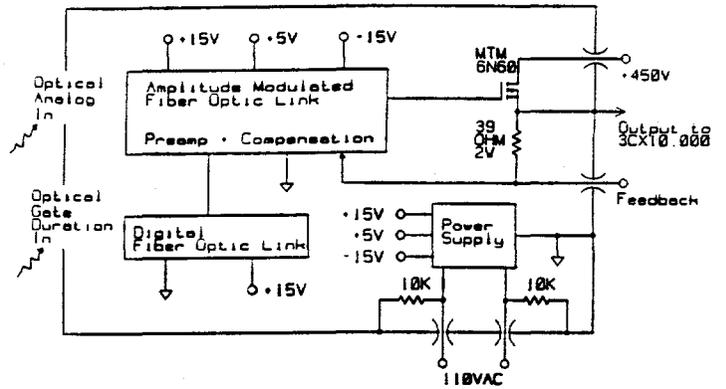


FIGURE 4: INTERNAL HOTDECK

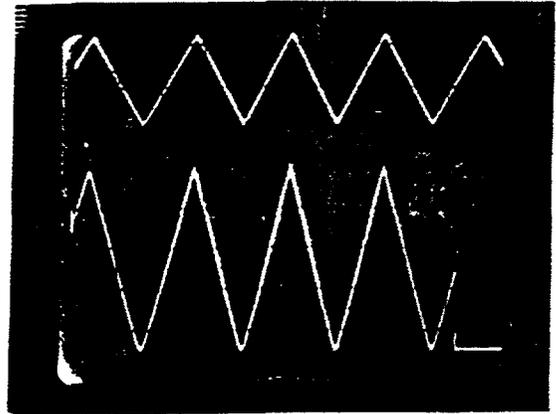


Photo 1. Internal Hot Deck with Closed Loop

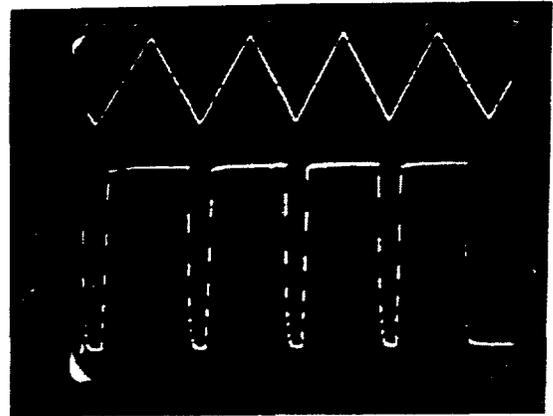


Photo 2. Internal Hot Deck with Open Loop

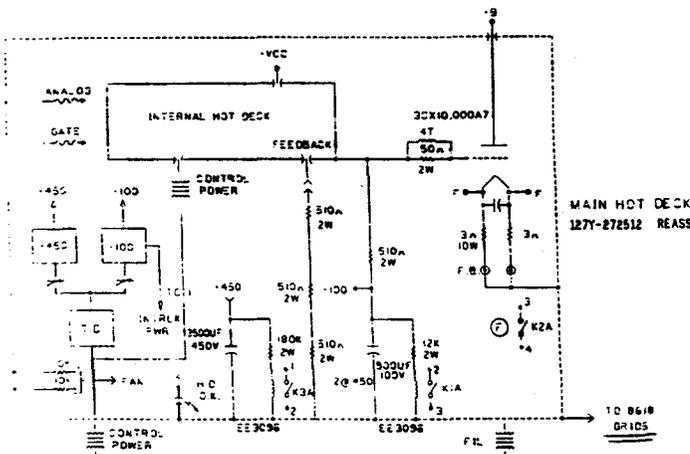


FIGURE 3: MAIN HOT DECK

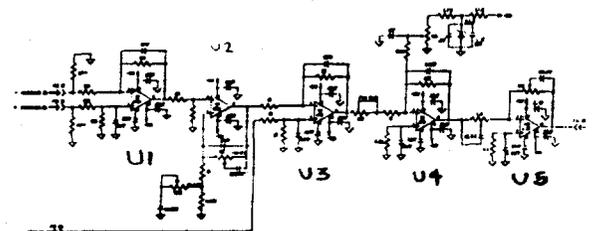


Fig. 5. Loop Compensation Circuits

The initial HBT-EP installation and debug required a few system modifications and adjustments. The truck shipping from Los Alamos to New York rattled many components and screws that caused additional trouble shooting and repair efforts. An error in the 3Ø power feed wiring resulted in a discontinuous neutral that resulted in arcing in the building power conduits and excessive ground loop noise. The most problematic effort was caused by a defective (noisy) bias potentiometer in one of the fiber optic receivers, which resulted in random bias level shifts of the hot deck driver. These initial start-up headaches have been corrected and an exciting experimental program has been initiated. The saddle coils have been driven with a variety of waveforms with photograph 3 showing a typical high power sine wave pulse. The amplifiers are calibrated with a transconductance of 125 mho. Early results show that the plasma can lock into the saddle current waveform track the excitation. Figure 6 shows a increasing frequency sweep of the saddle coil current. After a few cycles, the plasma locks in, and tracks the waveform. After the pulse is terminated, the plasma continues to free-wheel. These results are very exiting from a plasma physics view, but also indicate stable amplifier control under varying dynamic conditions without spurious response or system instabilities.

CONCLUSION

A high-power, high-fidelity feedback amplifier system has been installed on the Columbia HBT-EP Tokamak. The amplifier replicates any input waveform with an output to 1,100 Amperes and 16,000 Volts, peak to peak. The amplifier is not affected by changes in plasma parameters, start-up, or disruption. Early experimental results show plasma response and tracking to the amplifier waveforms. These results encourage a more complicated system feedback topology such that control of plasma disruptions may be obtained. Another identical amplifier system is under construction, for delivery in 1996, that will provide additional experimental opportunity.

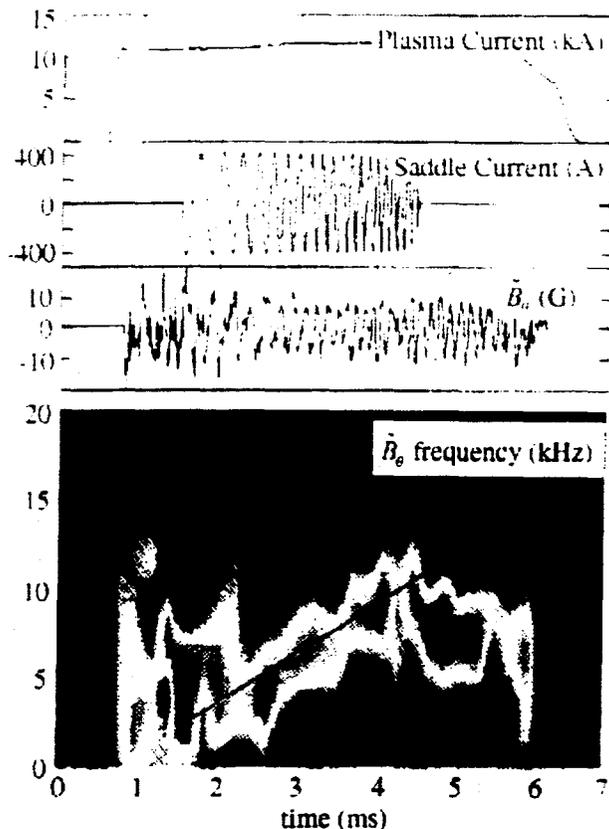
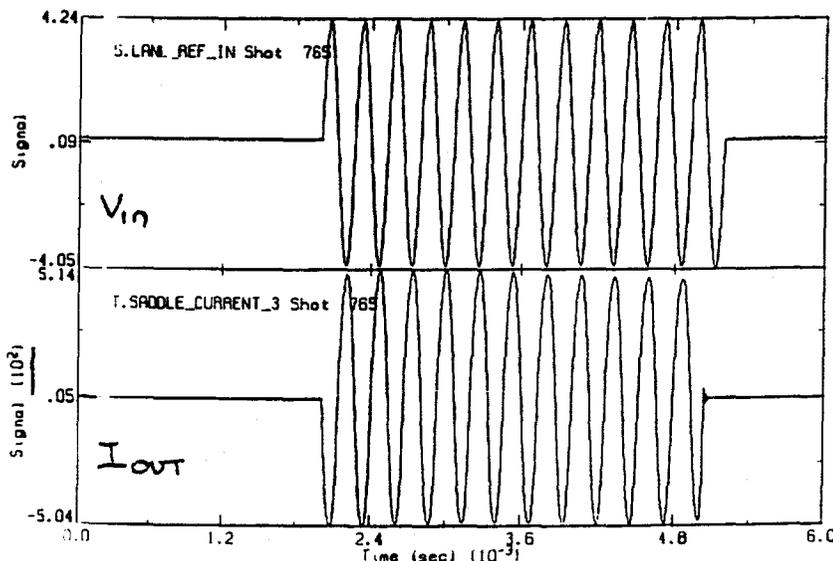


Fig. 6. Control of mode rotation via application of a frequency-ramped resonant magnetic perturbation. Mode frequency locks to the applied field (as shown with dotted line) over the range 4-11 kHz.



PHOTOGRAPH 3: 1000 AMPERE TEST WAVEFORM