Conf-910968--45

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OCTOBER 1991

GENERAL ATOMICS

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GA-A--20645

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This is a preprint of a paper presented at the 14th IEEE Symposium on Fusion Engineering, September 30 – October 3, 1991, San Diego, California, and to be printed in the *Proceedings*.

Work supported by
U.S. Department of Energy
Contract DE–AC03–89ER51114

GENERAL ATOMICS PROJECT 3466
OCTOBER 1991

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ACTIVE HEATER CONTROL AND REGULATION FOR THE VARIAN VGT-8011 GYROTRON

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Abstract: The Varian VGT-8011 gyrotron is currently being used in the new 110 GHz 2 MW ECH system installed on DIII–D. This new ECH system augments the 60 GHz system which uses Varian VA-8060 gyrotrons. The new 110 GHz system will be used for ECH experiments on DIII–D with a pulse width capability of 10 sec. In order to maintain a constant RF output power level during long pulse operation, active filament-heater control and regulation is required to maintain a constant cathode current.

On past DIII–D experiments involving the use of Varian VA-8060 gyrotrons for ECH power, significant gyrotron heater-emission depletion was experienced for pulse widths > 300 msec. This decline in heater-emission directly results in gyrotron-cathode current droop. Since RF power from gyrotrons decreases as cathode current decreases, it is necessary to maintain a constant cathode current level during gyrotron pulses for efficient gyrotron operation. Therefore, it was determined that a filament-heater control system should be developed for the Varian VGT-8011 gyrotron which will include cathode-current feedback. This paper discusses the mechanisms used to regulate gyrotron filament-heater voltage by using cathode-current feedback.

Introduction

Significant cathode-current droop, ~ 12%, has been observed on Varian VA-8060 series 60 GHz gyrotrons during RF heating experiments on the DIII–D tokamak for RF pulse widths > 300 msec. This droop in gyrotron beam current is significant enough to cause a considerable droop, ~ 15%, in total RF power delivered to the DIII–D vessel. The fall-off in beam-current is directly related to reduced cathode emissions due to cathode-cooling. Therefore, it was determined that an active filament-heater control system be developed which uses beam-current feedback for filament-voltage regulation on the new 110 GHz RF heating system. This new heating system is currently being installed at DIII–D to be used on the newly developed Varian VGT-8011 gyrotron.

Shown in Fig. 1 are the elements involved with maintaining the proper filament voltage: filament voltage and current monitoring, filament voltage control, and filament voltage regulation. These elements are located in both the ECH control room and the high voltage vault area. The feedback control circuitry and the receiving end of the filament voltage and current monitoring circuits are located in the control room. The regulator circuit and the transmitting end of the filament voltage and current monitor circuits are in the high voltage vault area. Fiber optic technology is used to provide maximum electrical isolation between the two areas.

Filament Voltage and Current Monitoring

It is important to properly monitor the filament ac voltage and current, along with the cathode current. These parameters are used, not only for viewing and fault control purposes, but are also used for feedback-control and regulation. The filament voltage and current are monitored on the primary side of a 110 kV filament isolation transformer. A potential transformer and a current transformer are used to sample the filament isolation transformer input. The resulting low-level ac signals are then directed to the true rms-to-dc conversion network and to the voltage regulating circuit; the regulating circuit will be discussed in the filament regulation portion of this paper. The true rms-to-dc convertor provides a dc signal directly proportional to the rms value of the ac voltage applied to the filaments. The dc signal is directed to a voltage-to-frequency/frequency-to-voltage network utilizing fiber optic links; it is also compared against a

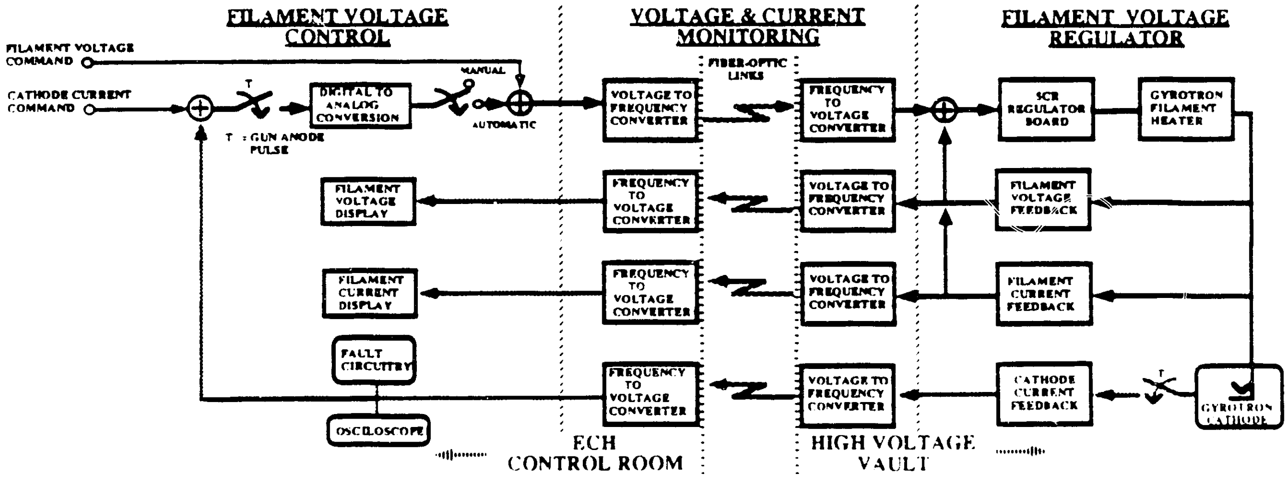

FIG. 1. Active filament heater control and regulation system.

preset level and the filament voltage is removed from the filaments if the preset overload values are exceeded. The cathode current signal is derived from a current shunt located in the high voltage tank. The signal from the shunt is also sent to the control room via a voltage-to-frequency/frequency-to-voltage fiber optic link.

Filament Voltage Control

The filament feedback and control circuit is contained in a single VME double slot width module located in the ECH control room. This module performs two functions. One function is to display actual filament voltage and current levels, along with the command settings. The display function is a digital meter readout using the signals from the fiber optic telemetry network discussed in the filament voltage and current monitoring section. The other major function performed by this module is to allow an operator to remotely control the heater voltage manually. After the filament voltage is within the proper operating range, the operator can place the unit into an automatic mode to properly regulate the filament voltage relative to the pulsed cathode current. The manual/automatic mode function is the primary and key function of the filament voltage feedback and control module.

With the feedback and control unit in manual, the operator dials in a desired filament voltage which will be the input command to the SCR regulator located in the ECH high voltage vault. In this mode, the system operates open loop with the SCR regulator being controlled by the voltage command sent by the operator. Once the filaments are up to their nominal operating temperature and the cathode current is within tenpercent of the desired level, the feedback control unit can be placed in automatic. The automatic feedback circuit consist of an error amplifier, phase detector, and a digital to analog convertor (DAC), yielding up to a ± 10% change in filament voltage to maintain a proper cathode current level during a gyrotron pulse.

The error amplifier produces an error signal proportional to the difference between the desired and the actual cathode current. There is also an offset adjustment at the input summing junction to compensate for any cathode current signal deviation due to telemetry drift. The output of the error amplifier is routed to both the absolute value rectifier and to the phase detector. The absolute value rectifier provides a signal to drive the error meter; the error meter is a bar-type meter and displays the degree of error between the actual cathode current and the requested cathode current. The other error amplifier output is sent to the phase detector which sets up the input conditions of the DAC.

The phase detector consists of a comparator and a D-Flip-Flop and controls the direction of the DAC output. Upon receiving the error signal, the comparator yields a TTL level; high for a positive error and low for a negative error. The comparator output provides an input to the flip-flop which is clocked at 400 Hz. The output of the flip-flop goes to a pair of NAND gates. Also, the Mod-Anode pulse command provides an input to the NAND gates; this permits regulation by the cathode current only when the gyrotron is pulsed on.

The input conditions sent to the DAC are derived by up/down counters controlled by the above-mentioned phase detector. Depending on the phase of error (±), one NAND gate will drive the up-counter and the other NAND gate will drive the down-counter. The up/down counter provides 4096 bits input to the DAC, with the most significant bit being the sign information. The output of the DAC is a ± 10 Vdc analog signal proportional to the amount of error between the desired cathode current and the actual cathode current. This output is then attenuated to ± 10% of the voltage commanded to the filament and then summed with the filament voltage command. The total voltage command is then sent to the regulator circuit via fiber optic telemetry.

Filament Voltage Regulation

The filament voltage regulator consist of three main components: an SCR regulator board, an SCR block, and a regulator control board. The regulator is a single-phase SCR firing circuit purchased commercially. The board controls the firing of a two-anti-parallel SCR block used to control the ac voltage supplied to the gyrotron filament. The regulator control board provides local feedback and control of the SCR regulator.

The SCR regulator is set up for two pulse gating and four quadrant operation. Using the reference voltage command from the filament feedback and control module, the proper SCR conducting angle is set to yield the desired filament voltage. Feedback information is received from a potential transformer and a current transformer located in the filament primary ac line. An instant inhibit feature is used to limit or shut off filament voltage when an over-voltage or an over-current exist. The card integrates into the system very well by using quick disconnect plugs.

Local regulation of the SCR regulator is achieved by the regulator control board. A sample of the filament-transformer primary voltage is essentially compared with the filament-voltage command. A span adjustment is provided to allow the full command signal range to be used along with a bias adjustment to compensate for inherent offsets within circuit components. The voltage error between input command and actual voltage is then sent to the error amplifier located on the SCR regulator board. The error amplifier output is fed to the phase-lock-loop summing filter on the SCR regulator which provides voltage control for the gate driver trigger network.

Conclusion

A 110 GHz ECH system has been completed and is operational using this active filament-heater control and regulation network. Future testing at longer pulse widths will fully test this new design. Manual control has been used primarily thus far since the gyrotron is in a short pulse operating phase. Preliminary tests have been performed in the automatic mode and beam current was maintained at the desired level. Once the gyrotron's pulse width is extended, a complete on line test of the filament-heater control network can be performed.

Acknowledgements

I would like to extend my appreciation and thanks to Trung Lam who initially laid the foundation for this project. Also, I would like to thank Arne Nerem and William Cary who conceptualized the idea of active filament control and allowed me the opportunity to see it through to its complete development and production.

This is a report of work sponsored by the U.S. Department of Energy under Contract No. DE-AC03-89ER51114.

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DATE FILMED

01/08/92