THERMEX THERMATRON®

OPERATING AND MAINTENANCE MANUAL

100 kW Microwave Generator
And Continuous Applicator
Thermatron Model TM100P

Manufactured by

Thermex Thermatron LP.

2017

THERMEX THERMATRON®

100 kW Microwave Generator and Continuous Applicator

Thermex Thermatron, LP.

10501 Bunsen Way, Suite 102

Louisville, KY 40299

U.S.A.

Telephone (502) 493-1299

Equipment Sales …………………Ext 202

Parts Sales……………………..….Ext 208

Technical Support..…. Ext 215 & Ext 207

Fax (502) 493-4013

E-mail:

Sales1@thermex-thermatron.com

Service@thermex-thermatron.com

Website

Thermex-Thermatron.com

Table of Contents

1.0) GENERAL INFORMATION

This manual has been prepared to assist the Customer in the operation and maintenance of this system. All information presented in this manual should be given careful consideration for optimum performance and service of the equipment.

WARNING!! VOLTAGES INSIDE THE EQUIPMENT CABINET(S) ARE LETHAL. PAY STRICT ATTENTION TO WARNINGS AND CAUTIONS IN VARIOUS LOCATIONS WITHIN THIS MANUAL. FOLLOW ALL APPLICABLE SAFETY CODES, REGULATIONS, AND RULES WHILE OPERATING OR SERVICING THIS EQUIPMENT.

This equipment must be operated and serviced only by personnel completely trained in safe operating procedures, practices, rules and regulations regarding Conveyors, Motors, Pumps and Power Transmission Devices, Pneumatically Activated Machinery, MW Ovens, MW Generators, Industrial Programmable Logic Controllers, Operator Interfaces, High Voltage electrical circuits, and application of High Microwave Power.

THE PURCHASER OF THIS SYSTEM IS RESPONSIBLE FOR THE COMPLETE SAFETY EDUCATION OF ALL OPERATING AND MAINTENANCE PERSONNEL IN ITS EMPLOY.

The instructions contained in this manual are intended to provide the user with necessary information for the efficient operation of the equipment and for normal adjustments to the equipment for which this manual is intended.

The directions should be followed carefully and no other adjustments or modifications should be attempted except under the supervision of or as authorized by Thermex Thermatron, LP or its authorized representative. Failure to observe these directions or to take precautions to avoid mishandling or misuse of this equipment voids the guarantees and warranties for either a specific component or the entire equipment.

The Thermex Thermatron Technical Service Department is available for advice or assistance in the event of any difficulty in the operation or maintenance of the equipment.

1.1) EXTRACT FROM OSHA STANDARD 1910.97

"For normal environmental conditions and for incident electromagnetic energy of frequencies from 10 MHz to 100 GHz, the radiation protection guide is 10 mW/cm2 (milliwatt per square centimeter) as averaged over any possible 0.1-hour period. This means the following:

- ***Power density: 10 mW/ cm2 for periods of 0.1-hour or more.***
- ***Energy density: 1 mW.-hr. / cm2 (milliwatt hour per square centimeter) during any 0.1-hour period.***

This guide applies whether the radiation is continuous or intermittent."

1.2) REQUIRED PERIODIC TESTING

Compliance with Title 47 of the FCC Code of Federal Regulation (CFR) Part 18 – Industrial Scientific and Medical Equipment is required. This Thermex MW generator was manufactured, tested, and found to be in compliance with applicable OSHA Standards in effect at the date of manufacture. **To ensure that the MW generator is maintained and operated in compliance with the above safety standards, the user is required to do periodic test and measurement of the level of MW emission from the generator.**

IMPORTANT! For a detailed description of the recommended test equipment please refer to Section 6.0.

2.0) SAFETY FIRST

It is imperative that anyone working with this equipment reads and understands those portions of the operating and maintenance manual relevant to the work to be performed. Personnel performing work must be properly trained and use all safety precautions and procedures for working with high voltages at high power levels. Failure to do so will result in damage to the equipment, serious injury or **DEATH**.

If at any point during operation, maintenance or servicing, difficulty is encountered, **STOP AT ONCE** and refer to the operation and maintenance manual. If you are uncertain how to proceed, contact your supervisor and/or Thermex Thermatron.

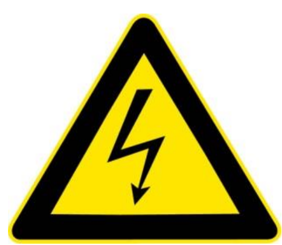
Equipment **MUST NOT** be modified or altered in any way. Changes deemed necessary must be fully documented, submitted to, and approved by Thermex Thermatron, LP, in writing, prior to implementation.

HAZARD ASSESSMENT

Prior to performing any service or maintenance, a hazard assessment must be made in order to ensure that the proper safety procedures are used and that the intended work may be performed safely.

Some of the inherent hazards associated with the equipment are listed below. There may be additional hazards related to external factors such as how the equipment is utilized, the materials processed, etc.

THE OWNER OF THIS EQUIPMENT IS RESPONSIBLE FOR THE COMPLETE SAFETY EDUCATION OF ALL OPERATING AND MAINTENANCE PERSONNEL AS WELL AS IDENTIFYING ALL HAZARDS AND TAKING THE NECESSARY STEPS TO PROTECT THE HEALTH AND SAFETY OF PERSONNEL IN ITS EMPLOY.



☠ WARNING ☠

HIGH VOLTAGE: ELECTROCUTION HAZARD

LETHAL VOLTAGES **ARE CONTAINED INSIDE THE ELECTRICAL COMPARTMENTS OF THIS EQUIPMENT. REVIEW AND FOLLOW ALL SAFETY PROCEDURES PRIOR TO PERFORMING ANY MAINTENANCE OR SERVICE. Under NO circumstances shall personnel place any part of the body inside the generator until electrical power to those systems have been DISCONNECTED AND LOCKED OUT.**

DO NOT ATTEMPT TO DEFEAT ANY SAFETY INTERLOCKS.

The warning sign above indicates specific hazards and provides specialized instructions to protect personnel.

2.1) GENERAL SAFETY REQUIREMENTS

Operation of this equipment involves the use of potentially dangerous high frequencies and voltages. At a minimum, operating and maintenance personnel must be familiar with and observe the appropriate safety rules and regulations at all times. These rules and regulations have been established by the Occupational Safety and Health Administration (OSHA), the National Fire Protection Association (NFPA), the National Electric Code (NEC), and their state and local organizations. The recommendations of the appropriate industry safety committees should also be observed.

2.2) SPECIFIC ELECTRICAL SAFETY REQUIREMENTS

Although every practicable safety precaution has been incorporated into the equipment, in addition to the above, the following rules must be strictly observed!

DO NOT ADJUST OR SERVICE ALONE!

Under no circumstances should any person reach within an enclosure for the purpose of servicing or adjusting the equipment without the immediate presence or assistance of another person capable of rendering aid.

KEEP AWAY FROM LIVE CIRCUITS!

Under no circumstances should any person be allowed to reach within, or in any manner gain access to any electrical enclosure by extending an arm or hand or by use of a stick, pole, pipe, rod, shaft etc., when the electrical power switches, disconnects, and breakers to the equipment are closed, or if the interlock switches are closed.

NEVER CONNECT any test apparatus, such as meters, oscilloscopes, and other similar devices external to the enclosure to circuits.

DO NOT CHANGE the tube or make any adjustments inside the equipment enclosure with the High Voltage Power Supply ON.

ENSURE THAT THE ELECTRICAL POWER cannot be switched on accidentally.

The shutdown button or activation of the EMERGENCY STOP will not disconnect all of the electrical power. Electrical power continues to go to the control circuit. It is possible that a defective component could activate one of these circuits. If you must enter the equipment enclosure, turn the electrical power switch OFF and turn the electrical disconnect which supplies electrical power to the equipment OFF and LOCK IT OUT.

UNDER CERTAIN CONDITIONS dangerous voltages may exist in the circuits, even with power switches in the OFF position, due to an electrical charge retained by the capacitors or power transformers. To avoid possible danger, always disconnect the electrical power, and then ground circuits before physically touching them.

NEVER CHECK FOR CONTINUITY OR RESISTANCE if the electrical power is on or if the circuits have not been grounded.

DO NOT TAMPER WITH INTERLOCKS. Under no circumstances should any interlock switch or other safety device be removed, short circuited, or tampered with in any way or its purpose defeated except by authorized personnel.

DO NOT DEPEND UPON THE ACCESS DOOR INTERLOCK SWITCHES FOR PROTECTION. Before removing the covers or other protective devices, always remove the electrical power from the equipment by turning the MAIN DISCONNECT OFF and LOCKING IT OUT

In some cases, THE INTERCONNECTING WIRES MIGHT BE LIVE, even when the main disconnect is OFF. Make sure the disconnect switches are turned OFF for all the equipment that is interfaced with the unit to be serviced.

WAIT at least 5 minutes (and in some cases even more time) after the power has been disconnected for the equipment and its components to cool off before servicing or troubleshooting

3.0) IMPORTANT OPERATING AND ENVIRONMENTAL REQUIREMENTS

The Main Control Panel, MW Generator, and Applicator (also called an “Oven”) consist of a variety of electrical and mechanical components, whose performance depends on the environmental and operating conditions to which these components are exposed during their operation. The quality and temperature of the air and water that cool these components, as well as humidity and level of contamination (cleanliness) inside the Main Control Panel, MW Generator, and Applicator must be kept within strict limits. The Main Control Panel and the MW Generator are designed and built to maintain the required clean and dry operating conditions inside the compartment if operated and maintained properly.

IMPORTANT! Operating and storing (warehousing) the Main Control Panel and the MW Generator where the ambient air temperature outside the generator cabinet is above 122 degrees F (50 degrees C) or below 40 degrees F (5 degrees C) will result in serious damage of key components. Operating the system when the air temperature inside the generator compartment exceeds 113 degrees F (45 degrees C) or drops below 40 degrees F (5 degrees C) may result in damage of the electronic circuits and components.

The PLC, MW control modules and transducers are designed to operate in a clean environment at an air ambient temperature between 40 to 122 degrees F (5 to 50 degrees C). Air temperature outside this limit will seriously affect and may even damage these components. Humidity must be kept **below condensation level** even within the above specified temperature limits.

Proper **cooling of the magnetron** is very important. The temperature of the various parts of the magnetron must never exceed the values specified in the Magnetron Specification Data (see Section 7.3). Starting the flow of distilled water and cooling air to the magnetron before applying high voltage, as well as maintaining the cooling for several minutes after the removal of the high voltage, is mandatory.

The **distilled water** and air must be clean to prevent system contamination or corrosion. Changing the distilled water from the cooling tank **at least twice a year** is required (more often if the plant conditions require).

The distilled water temperature cooling the anode of the magnetron must be kept above 80 degrees F (27 degrees C) at maximum 100 psi (6.9 bars). The water temperature returning from the anode of the magnetron shall be kept below 160 degrees F (70 degrees C) at all times during operation.

The magnetron’s output ceramic dome and filament ceramic stem require forced air cooling. The manifold from the cooling blower directs the air to the filament stem and the dome. The filament connector incorporates a manifold to direct air cooling at the filament stem.

Periodically check the **water and airflow** interlock **switches** to ensure proper operation to prevent tube damage in case of water or air flow failure. **The temperature of the metal and ceramic surface of the magnetron must be kept below 300 degrees F (150 degrees C) at all times during operation.**

All high voltage and power components are built using various insulating materials which maintain separation of the high voltages from the chassis or ground. Excessive humidity along with contamination from the air (dust, fumes, solid particles, etc.) are conducive to surface degradation of these insulating materials, thus reducing their insulating and cooling capacity. This may result in short circuits and component failure. Maintaining a dry and clean operating condition inside the cabinet, combined with periodic inspection and cleaning inside the MW Generator, provides a more efficient operation and extends the life of each component.

Never operate the MW Generator with the doors open. Periodically check the condition of the door seals to keep the inside free from contamination caused by humidity, fumes, dust, and other airborne particles. Check and ensure that the **MW Generator cabinet is always operated at positive pressure,** provided by the supply of <u>clean, dry, and oil-free compressed air</u>.

The waveguides carry large amount of power at high frequency and voltage. Thermex MW applicators are provided with vapor barriers that **prevent dust, fumes, and vapors from entering the waveguides.** Contamination in the waveguide will cause serious arcing and damage to the magnetron and other major components. Periodically check the condition of the vapor barriers and the seal between the applicator wall and the vapor barriers for any potential leak. Check and ensure that the waveguides are always **operated at positive pressure,** provided by the supply of <u>clean, dry, and oil-free compressed air.</u>

Insulating materials inside the MW applicator (such as the conveyor belt, the belt support system, vapor barriers, carriers, door seals, etc.) are exposed to continuous MW power. **Surface contamination of these components may lead to overheating and cause permanent damage.** Specifically, plastic materials exposed to contaminations from metal shavings, carbon particles, or ionic substances that are conductive of electricity are subject to excessive heating in MW fields. Contaminated plastic components are subject to excessive arcing, overheating, and/or burning, and will cause a fire in the MW applicator. **<u>Inspection and cleaning of these components on a regularly scheduled basis is</u>**

required to insure proper operation of the MW. Development of operating procedures and implementation of measures to reduce contamination is conducive to more efficient operation of the MW and extends the life cycle of each component. This schedule must be developed individually for each MW based on the specific environmental and operating conditions of the plant, reviewed regularly, and revised, if conditions change.

The maximum weight of material plus carriers loaded on the main belt must not exceed the rated capacity of the belt. The MW is designed to handle a load of up to 5,700 lbs. at a maximum air temperature of 160 degrees F. The main belt driving shaft is supplied with sprockets having stainless steel teeth to reduce wear at heavy loading conditions.

4.0) OUTLINE OF THE MW GENERATOR

4.1) GENERATOR CABINET

The MW Generator is a complete self-contained microwave source used for industrial heating processes. The generator uses a water-cooled magnetron to generate the microwave energy. Varying the current of the electromagnet controls the output power. This variable magnetic field provides continuous control of the output power manually or automatically by using a standard PLC.

The generator is housed in a NEMA 12 type enclosure that measures approximately four feet wide, six feet long and six and one-half feet tall. The generator cabinet is designed for free standing, bolting to the floor.

The major components located in the generator cabinet such as the magnetron, circulator, and water load are water-cooled. A closed-loop distilled water system cools the magnetron, electromagnet, and circulator. Plant water is used to cool the water load and the cabinet. The distilled water is cooled by a water-to-water heat exchanger using plant water.

The cabinet has two (2) large hinged access doors on the front that allow complete access to the interior for ease of inspection, installation, and maintenance. All necessary controls and indicators are mounted on the Main Control Panel located on the front door of the cabinet.

The water section is completely isolated from any high voltage components, located in a separate compartment, at the rear of the main cabinet. This compartment is also provided with two (2) doors for ease of inspection, installation, and maintenance. The bottom of the magnetron compartment is watertight and is provided with a drain port through the generator outside wall.

4.2) TM100P MW GENERATOR SPECIFICATIONS

- Power Input: 480 VAC, 3-phase, 60 Hz, and approximately 250 Amps
- Power Output: maximum 100 kW continuous in an ideal MW Load.
- Operating Frequency: 915 MHz $\pm$ 15 MHz
- Power Control Range: Continuous from 20 to 100 kW Intermittent from 0 to 20 kW
- Magnetron Protection: A 3-port circulator with water load protects the magnetron during high-reflected power periods.
- Arc Detection: Photoelectric Arc detection to protect magnetron and wave guides.
- A polyphase anode transformer is installed to reduce DC power supply ripple and minimize potential anode breaker trips.
- Output Fitting: WR-975 Waveguide Flange
- Cooling: Filtered, clean plant water maximum 65 degrees F, minimum 8 GPM
- A cooling system with a capacity of 80,000 BTU/hour per generator is required when the generator is fully loaded into a matched microwave load. An unmatched load may require more cooling capacity.
- Overall Size: 48 inches wide x 72 inches long x 78 inches tall.
- Weight: Approximately 6,000 lbs.

4.3) GENERATOR CONTROLS

The following controls and indicators are provided with the TM100P Microwave Generator:

The Generator Control Panel with the PanelView Operator interface is shown above.

Switches and Push Buttons:

Shutdown Push Button
Reset
Start Microwave Push Button
Start Up Push Button
Stop Microwave Push Button
E-Stop

Indicator Lights:

System Start-up
Applicator Ready
Anode Over Current
System Fault
Generator Ready
Microwave “ON”
Reflected Power

Internal Interlocks:

High Reflected Power
Water Temperature
Air Flow
Water Level
Water Flow
Cabinet Air Temperature

Analog Panel Meters:

Microwave Output Power

4.4) PLC CONTROL UNIT

An **Allen Bradley CompactLogix PLC** controls the microwave generator. This allows for easy connection of each generator to the plant network. Each generator is capable of operation as a standalone piece of equipment.

This design simplifies the installation by allowing each generator to be built to a standardized design and to be tested individually. Only a small number of interconnecting wires are required with this design greatly simplifying the project complexity and reducing project installation time.

An Allen Bradley **PanelView Plus 700 color touch screen** operator interface is installed on the control panel of each generator to display and access information regarding the operation and calibration of the MW generator. A fault diagnostics screen is provided to indicate any fault conditions. All of the direct metering signals are displayed on analog panel meters and on the PanelView for ease of calibration and troubleshooting purposes.

A closer look at the Generator Control Panel with the PanelView Operator interface is shown above.

There are initial setup and calibration screens provided for the microwave technician to calibrate the analog signals displayed on the PanelView.

The **filament current** is regulated by the **Filament Control Module** which is controlled by the PLC. PLC controlled regulation of the filament current reduces filament current surges during warm up and includes a filament test sequence during start up to test the integrity of the filament circuit and the filament current regulation system. If the Filament Control Module should fail, the PLC will indicate a fault condition describing the problem encountered. A set up and calibration screen allows calibration and tuning of the filament control circuit.

The **Magnet Control Module** supplies a filtered DC **magnet current** required to control the microwave power output. A magnet current test sequence will automatically occur during system warm up. If the Magnet Control Module should fail, the PLC will indicate a fault condition describing the problem encountered. A setup and calibration screen allows calibration and tuning of the magnet current circuit. A manual power control pot is also included for use when the manual power control mode is selected.

Power output is calculated by the PLC based on anode voltage and current. To compensate for fluctuations in line voltage, the PLC automatically makes the necessary adjustments to maintain a constant microwave power output.

All adjustments and calibrations are performed through the PanelView interface; there are no other pots to adjust inside the MW Generator.

There is an initial set up and calibration screen for output efficiency of the generator. The efficiency of the generator can also be adjusted on the PanelView screen to match the Calorimeter tests.

For easy troubleshooting and maintenance, all major test points are indicated in the Electric Circuit Diagram (included with this manual) and mounted in a test panel, accessible inside the MW generator. For detailed description of the MW generator, refer to Section 7.0.

4.5) WAVEGUIDE PRESSURIZING UNIT

The waveguides are pressurized using an instrument-grade clean, dry, oil-free compressed air. The compressed air provided by the user must be reduced to 5-10 psi using a manual pressure regulator installed at the MW generator. The air travels through the waveguide and is exhausted through the ports provided on the side of the leaky waveguide applicators. The positive pressure inside the waveguide is required to keep the waveguides free of contamination from vapors or fumes in the event of any leakage through the vapor barriers.

The main disconnect is shown above.

5.0) UTILITIES REQUIRED FOR OPERATION

The general layout drawing for the MW generator is found in Attachment A and shows all the connections for the utilities required for the operation of the system.

5.1) CONNECTION TO THE UTILITIES

Thermex supplies the necessary cables required to connect the MW generators with the applicator. The customer is responsible for providing external services such as electric power, cooling / process water and compressed air if required.

The customer is responsible to insure that all provisions of national and local codes are strictly followed when the MW system is connected to the utilities.

5.2) UTILITY SPECIFICATIONS

5.2.1) ELECTRIC POWER

The MW Applicator is to be supplied with **electric power** in two (2) locations; one (1) for the MW Generator and one (1) for the conveyor Main Control Panel. The location of the electrical power input is indicated on the layout drawing.

- MW Generator: 480 VAC, 3 Phase, 60 Hz, 250 Amps
- Applicator (oven) and conveyor: 480 VAC, 3 Phase, 60 Hz, 30 Amps

5.2.2) COOLING WATER

The MW Generator is to be supplied with clean and filtered cooling water, at minimum 60 psi maximum 65 degrees F, minimum 6 GPM, 3/4” NPT

The location of the cooling water input and drain are indicated on the layout drawing.

6.0) RECOMMENDED TEST EQUIPMENT

Thermex Thermatron recommends the following test equipment be used for troubleshooting, testing, and calibrating MW systems operating at 915 MHz.

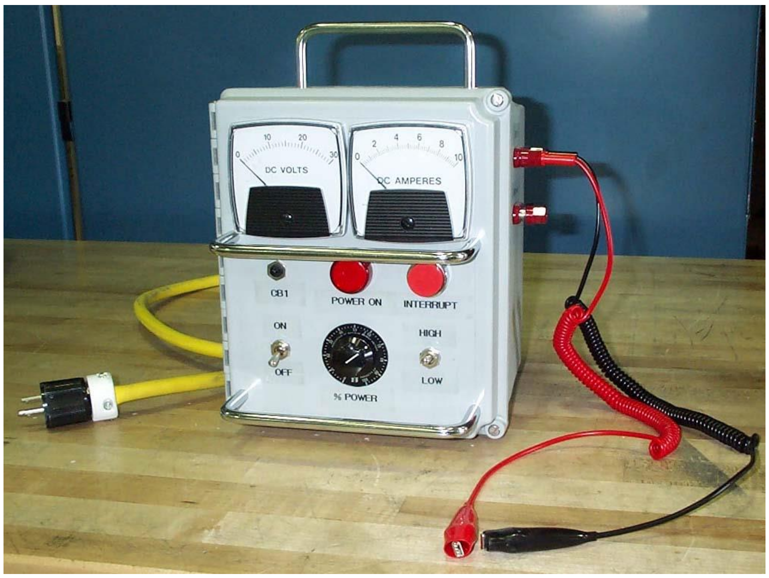
IMPORTANT! Before using any Test Equipment please read and follow carefully all Safety and Operating Instructions supplied with each test equipment.

6.1) MICROWAVE GENERATOR CALIBRATOR

This multipurpose testing equipment is used for conveniently testing and calibrating the following Microwave Generator devices and circuitry:

- Anode circuit continuity testing, including the following devices: anode overload relay, anode meter, anode shunt, and metering circuit.
- Calibrating the anode overload relay and magnet undercurrent relay.
- Calibrating the anode meter and its circuitry
- Simulate load and set the filament turndown for the magnetron
- Calibrate the signal conditioners: filament current and reflected power circuit.

Power Requirement: 115 VAC, 15 Amps.



The above picture shows the Thermex Model MW-CAL100 Microwave Generator Calibrator.

6.2) CLAMP-ON AMP METER

This true RMS clamp-on meter is used to measure and calibrate the filament current applied to the magnetron. The filament current is a very important parameter that determines the performance and the life of a magnetron. This unit is also commercially available.

The above shows a Clamp-On Amp Meter –
Model 36 and its carrying case.

6.3) MULTIMETER WITH HIGH VOLTAGE PROBE

This multimeter is used for troubleshooting the electrical circuit, as well as measuring and calibrating various control components. With the 40-kVDC high voltage probe attached, it can be used to measure the DC Voltage applied to the magnetron from the High Voltage Power Supply. The value of the DC Voltage applied to the magnetron affects the performance and efficiency of the magnetron, as well as the efficiency of the entire MW generator.

The above picture shows a Multimeter with High Voltage Probe – Model 79

6.4) MW RADIATION SURVEY METER

OSHA and the FCC strictly regulate the amount of MW energy radiated into the environment by any MW source. The Microwave Survey Meter shown below is a simple instrument, used to measure the amount of MW power radiated from the MW source in any given place. It is calibrated for both the 915 MHz and the 2450 MHz microwave frequencies used in industrial applications.

The above picture shows a Microwave Oven Survey Meter – Model HI-1600 and its carrying case.

6.5) MW CALORIMETER TESTER

This unit is used to test the output power of a 915 MHz MW power source up to 100 kW. It is designed to be installed at end of the waveguide at the output end of the power source. A calibrated water load absorbs the microwave energy. The water flow, as well as the input and outlet temperature of the water, is measured and displayed accurately by three (3) digital metering units. Based on the values displayed, the effective microwave energy generated by the power source can be calculated using the following formula:

English System:

$$P = 0.147 \times G \times (\text{Temp out} - \text{Temp in})$$

Where: P - is the effective Power Generated, in kW

G - is the water flow measured in GPM

Temp - is the water temperature in and out, measured in degrees F

Note: The amount of city water required for testing a power source up to 100 kW is minimum 8 GPM at 50-80 psi.

SI System:

$$P = 0.07 \times G \times (\text{Temp out} - \text{Temp in})$$

Where: P - is the effective Power Generated, in kW

G - is the water flow measured in liters per minute

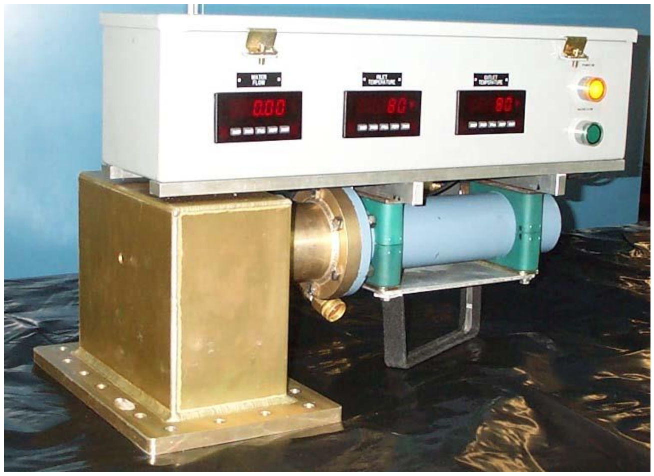
Temp - is the water temperature in and out, measured in degrees C

Note: The amount of city water required for testing a power source up to 100 kW is minimum 8 GPM (30.3 l/min) at 50-80 psi (3.5-5.6 kg/cm2).

Power Requirement: 115 VAC, 50/60 Hz, 1 Amp

Output: Interlock signal to MW Generator which allows MW power to be applied only when the water is on.

This unit can be also calibrated in SI measuring system.



The above picture shows the MW Calorimeter Tester – Thermex Model MW-CT100A
Note that some units may have a slightly different configuration.

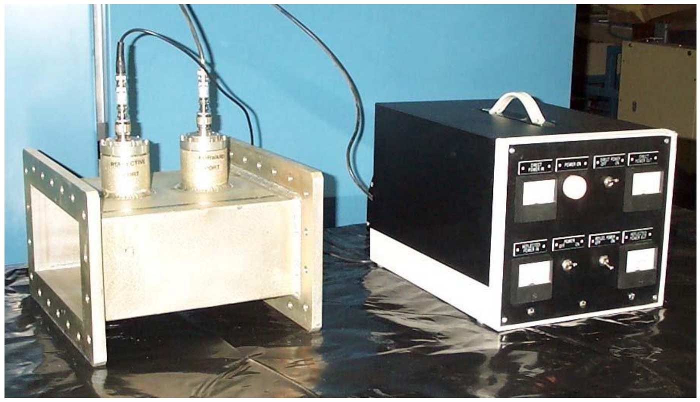
6.6) PORTABLE MICROWAVE POWER METER

The Microwave Power Meter measures the effective direct and reflected power in any section of waveguide. This instrument is very useful to determine the efficiency of load matching with the microwave power source by measuring the amount of power directed toward the load and the amount of power reflected by the same load. Also, it can measure the amount of power distributed between various branches of a waveguide system when a wave splitter or tee is used to direct microwave energy into the load using multiple ports. It is also used to calibrate the direct and reflected power meter of a MW generator.

The Microwave Power Meter consists of a dual directional coupler with special connections for the direct power and reflected power meter. The directional coupler is approximately 12 inches long and can be installed in between the flanges of any WR975 standard waveguide, with EIA flanges.

Power Requirements: 115 VAC, 60 Hz, 0.5 A.

Output: Two (2) coaxial analog output, 0-5 VDC can be connected to a PLC card.



The above picture shows a Portable Microwave Power Meter.

7.0) DESCRIPTION OF THE MW GENERATOR

7.1) GENERATOR LAYOUT

The microwave generator converts the electric power from a three-phase line voltage of **480 volts AC** operating at a low frequency of 60 Hz to a microwave power at 915 MHz. This conversion occurs in three (3) stages:

Step 1: The line voltage is stepped up to a high voltage AC by using the anode transformer.

Step 2: The high voltage AC is converted into a high voltage DC of **approximately 20 kVDC** by a three (3) phase full bridge rectifier assembly.

Step 3: The high voltage DC is converted into a very high frequency (microwave frequency) using a vacuum tube device called magnetron.

The MW Generator cabinet is divided into four compartments/sections:

- The Control section located above the shelf in the main compartment.
- The enclosed magnetron compartment located behind the right hand door.
- The power supply section located on the bottom of the main compartment.
- The cooling section located on the rear of the cabinet.

Front view of the MW generator cabinet.

The above picture shows the front of the generator with the doors open. Both the front side and the rear of the generator compartment are provided with two access doors for service.

7.1.1) CONTROL AND PROTECTIVE CIRCUIT

The MW generator contains a Control and Protective Circuit consisting of relays, contactors, transducers, switches, indicator lights, push buttons, etc. and a PLC with operator interface. All these devices are used to control the application of the proper filament current to the magnetron, control of the electromagnet current and control the high voltage applied to the magnetron.

The DC current applied to the electromagnet surrounding the magnetron controls the power generated by the magnetron. For proper operation of the magnetron the filament current has to be tightly controlled as a function of the output power. As the output power increases the filament current must be reduced to maintain constant filament temperature.

A main disconnect switch connects the MW generator to the electric power. The Control Breaker “CB2” protects the control circuit and its components; the Anode Breaker “CB3” protects the power circuits and the power components.

The major areas of the Control and Protective Circuits are as follows:

- Operator Interface with indicator lights, switches, push buttons, and meters installed on the left front door of the MW generator cabinet.

- Control Relay Board with the PLC installed inside the left side of the control section of the generator cabinet

- The **Magnetron Control Module** (includes the magnet and filament control modules) and the transducer section installed on the right side of the control section of the generator cabinet

- Arc Detector, Overload, Temperature and Flow Controls, and other interlocks are located in the power supply and cooling section of the MW cabinet

The above pictures show the rear of the Main Control Panel on the left and the PLC and Control Relay Panel on the right.

The magnetron control module is shown above.

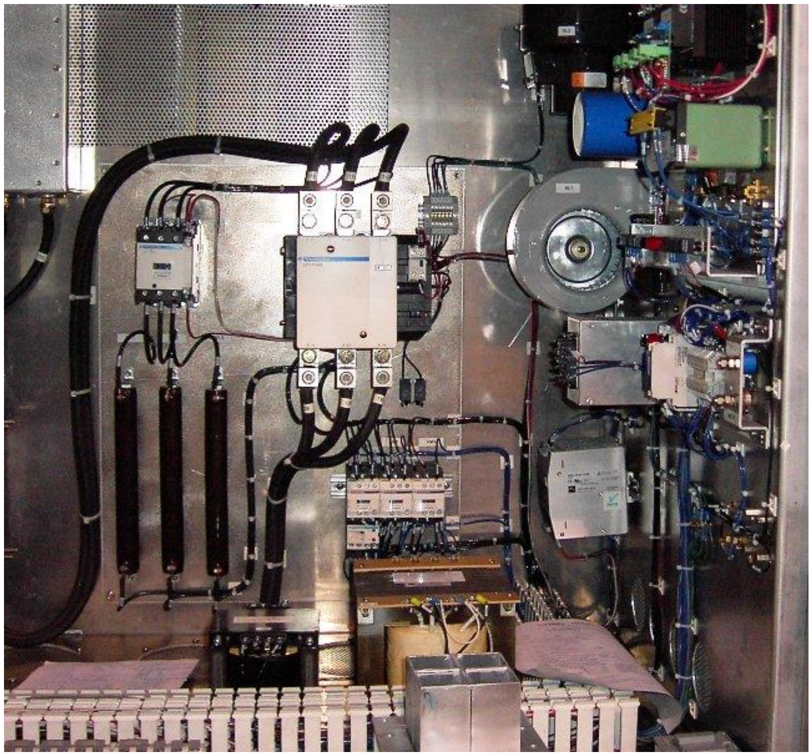
7.1.2) HIGH VOLTAGE POWER SUPPLY

The High Voltage Power Supply section contains the anode transformer, the high voltage rectifier stack, the high voltage filter network, the high voltage meter multiplier assembly, and the spark gap. All of these devices (except the contactor) are installed on the bottom section of the main generator cabinet.

Danger! High Voltage! The High Voltage Power Supply section is protected against accidental contact with maintenance personnel by a transparent Plexiglas panel. This panel is also interlocked with a limit switch that prevents application of high voltage in case the panel would be removed. **Do not attempt to operate the generator with this panel removed!**

The above picture shows the High Voltage Power Supply section (with the protective cover removed). The anode transformer and rectifier assembly are visible on the front plane.

The picture above shows the high voltage rectifier stack, high voltage filter, and spark gap.



The picture above shows the Soft Start and the Main Contactor.

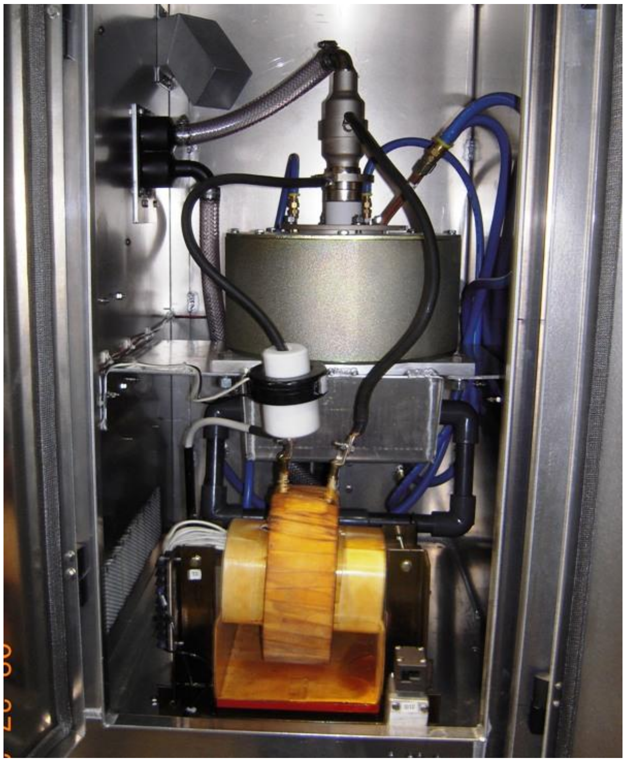
7.1.3) MICROWAVE

The microwave section consists of the launcher, electromagnet, magnetron, and filament transformer housed in a sealed and closed magnetron compartment located next to the control section. This section also includes the circulator, coupler, and arc detector with the connecting waveguides installed in the cooling section of the generator cabinet. All the wires connecting to the filament transformer, electromagnet, and filament current transducer are filtered to prevent leakage of microwave energy into the generator compartment.

The magnetron is installed in a special socket located in the center of the electromagnet. An RF gasket is placed between the magnetron and the socket to insure that good electrical contact is maintained between the anode of the magnetron and the tube socket.

The tube socket is bolted to the electromagnet and the launcher. The launcher is a section of waveguide where the antenna of the magnetron releases the microwave power generated. A ceramic dome, sealed to the anode by a metal to ceramic seal, encloses the magnetron antenna.

Special care should be taken when handling the magnetron. If the dome is broken, the vacuum inside the magnetron is lost resulting in permanent tube damaged. The same high pressure blower used for the filament cooling also cools this ceramic dome. The air is introduced in the launcher by a plastic manifold.



The picture above shows the magnetron compartment. The magnetron compartment houses the launcher, electromagnet, filament transformer and the magnetron.

The filament transformer shown on the lower part of the picture feeds the magnetron through heavy leads. A special current transformer is installed on the filament lead to monitor the filament current applied to the magnetron. The magnetron is also provided with special filament connectors. The air supplied from the high pressure blower cools the top filament connector.

The magnetron and the electromagnet are water cooled. Special silicone hoses that connect the magnetron and the electromagnet to the distilled water circuit are also located in this compartment. Special care is to be taken when replacing the magnetron to insure the magnetron water inlet and outlet line are properly connected to the water supply and discharge hose. Reversing these connections might result in overheating and permanent damage to the magnetron.

The magnetron, electromagnet, dummy load, circulator, and generator cabinet are all water cooled. The cooling section contains the distilled water and cooling water circuits that make up the cooling system. Attachment B shows a schematic of the water circuit.

A closed loop distilled water circuit cools the magnetron, electromagnet, and circulator. The distilled water is cooled by plant water using a water-to-water heat exchanger. The generator cabinet is an environmentally sealed enclosure and is cooled by plant water using an air to water heat exchanger. The plant water also cools the dummy load.

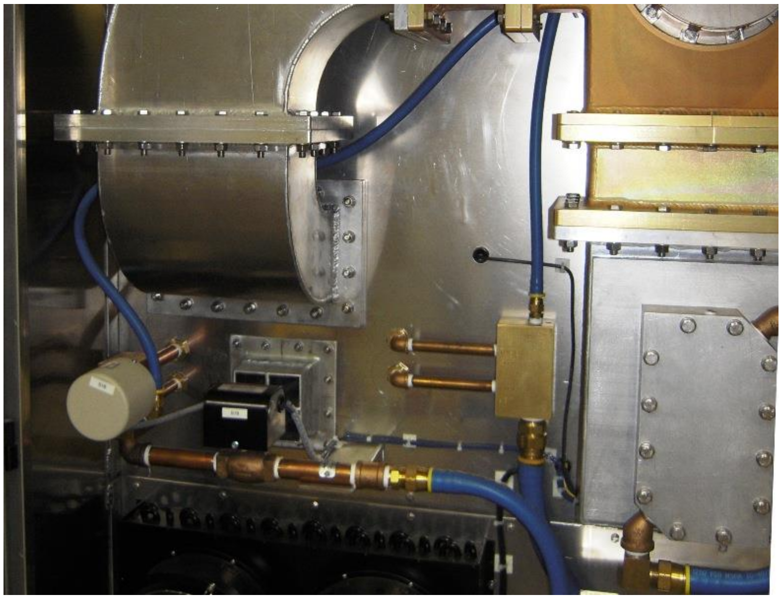
IMPORTANT! Use clean, filtered cooling water in order to prevent buildup of deposits on the wall of heat exchangers, or clogging the orifices of valves and flow meters. The water inlet and outlet ports are located at the bottom of the generator cabinet, under the main disconnect switch.

The following pictures show details of the cooling compartment located on the rear of the generator cabinet. The cooling section is completely isolated from the high voltage power supply to prevent damage from any potential water leak that might develop in the water circuit. The high power circulator as well as the arc detector and reflected power pick-up are also located in this section.

The air is moved through the generator compartment by four high efficiency fans installed on the water-to-air heat exchanger and air is cooled when passing thru the fins of the radiator.

IMPORTANT! Do not operate the MW Generator with the front or rear access doors open. The cooling air circulation is disrupted when these doors are open, resulting in inadequate cooling of the generator components.

The picture above shows the cooling section.

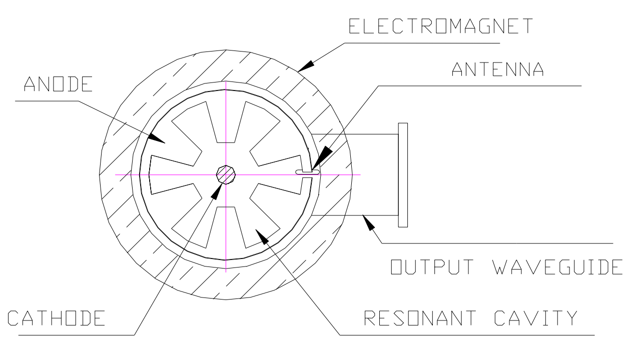


The picture above shows the connections to the magnetron compartment.

Above is the distilled water tank, water pump, and cooling water inlet and outlet connections.

7.2) MAGNETRON OSCILLATOR

The magnetron is a high vacuum electronic valve, just like the triode, consisting of a hollow copper anode incorporating a resonant microwave structure. A permanent magnet or electromagnet depending on the type and size of the magnetron surrounds the anode. At the center of the magnetron is an electron-emitting cathode (filament) as shown below.



MAGNETRON OSCILLATOR DIAGRAM

The anode has a set of vanes projecting inward forming slots between them, which are approximately ¼ λ deep and, therefore, they are resonant at the operating microwave frequencies. The slots are mutually coupled via the fringing field at their open ends and the whole structure forms a resonant circuit. When the filament is heated, a cloud of electrons is formed around the cathode. When the anode is supplied with high voltage DC, these electrons travel from the cathode to the anode.

The permanent magnet or electromagnet installed outside the anode provides a strong magnetic field that changes the path of these electrons. Since the field lines are parallel to the axis of the anode and perpendicular to the electron path, the electrons are forced to travel in a quasi-circular path around the cathode.

By increasing the DC anode voltage or decreasing the magnetic field, some of the electrons travel on a path closer to the anode, reaching the anode cavities where they generate a resonant microwave field. The microwave power generated is extracted in one of the cavities by using an antenna that then is connected to a launcher. The launcher is connected to the circulator and then to the oven by the waveguides.

The picture above shows an assembled 100 kW magnetron.

Shown above is the anode of the magnetron with its resonant cavities.

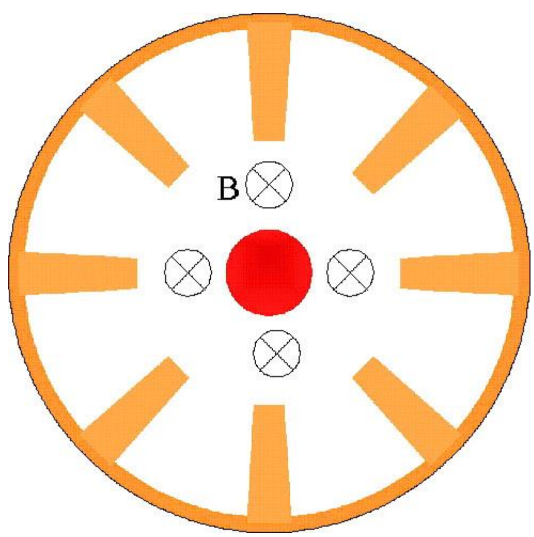
Above are the filament and its internal support structure.

Ceramic insulation with metal seals.

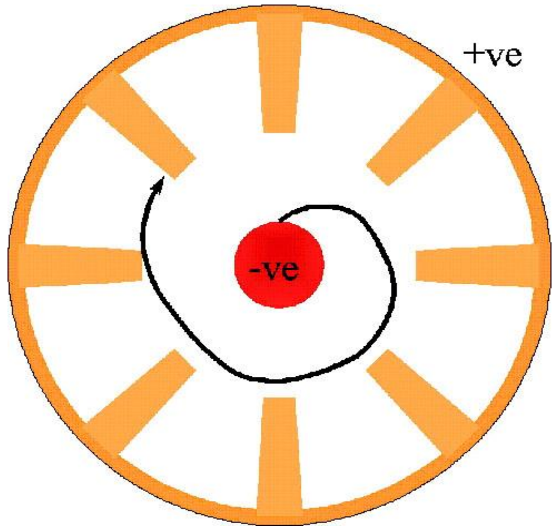
The filament and the anode components are insulated with a special ceramic material. This material is joined with the anode and filament structure with a “ceramic-to-metal” seal, capable of maintaining the high level of vacuum inside the magnetron.

The antenna shown above carries the MW energy into the waveguide launcher.

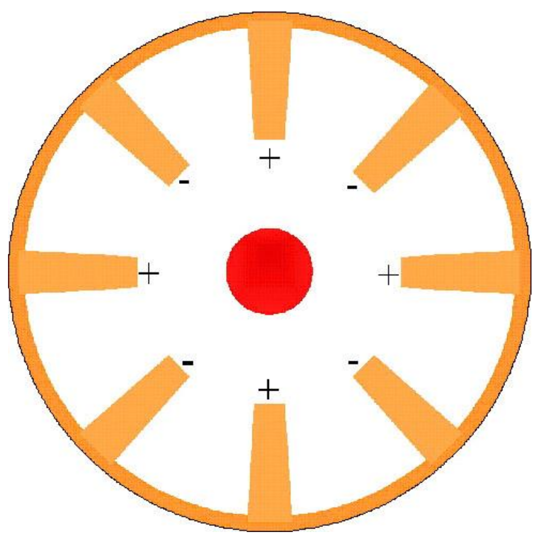
The antenna is protected by a "ceramic dome" (shown above)
that also closes the vacuum chamber of the magnetron.



The electromagnet supplies the
magnetic field that is set up parallel to the cathode.

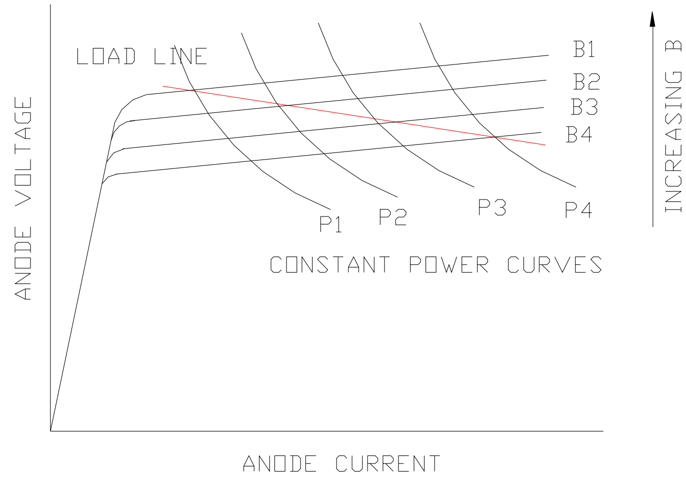


The electric power supplied by the high voltage power supply of the generator provides the electric field between the cathode and anode. Electrons leave the cathode due to the electric field, and spiral to the anode under the influence of the magnetic field.



Electrons rotating around the cathode reach the resonant cavities and set up an oscillating RF field. The RF field is symmetrical and power is coupled to the output by the antenna. This is called the PI mode.

The most important characteristics of the operating parameters of a magnetron are shown on the following diagram.



MAGNETRON TYPICAL OPERATING DIAGRAM

The anode voltage-current characteristic shows some peculiar features of the magnetron. On raising the anode voltage from zero at fixed magnet field, very little current flows until a specified voltage is reached (called the π - mode voltage) when the outermost electrons reach the anode. Thereafter, the anode current rises very rapidly reaching its maximum rated value with further voltage increase of only 3-8%. **It is essential that the generator is connected to a stable power source to prevent unacceptable changes in power from the magnetron due to fluctuations of the incoming voltage.**

A change of the magnetic field produces similar changes in the anode current, except at different π - mode voltage, increasing magnetic field giving proportional increase in π - mode voltage. This feature makes it possible to control a magnetron with an applied magnetic field. This technique is commonly used for high power magnetrons with electromagnets as only a low power adjustable supply is needed to energize the electromagnet. Low power magnetrons usually have permanent magnets and are controlled solely by adjustment of anode voltage.

It is important to notice that:

- The power output rises with the increase of applied anode voltage since more electrons are attracted to the anode whereby increasing the anode current.

- The power output increases with the decrease of the magnetic field. Reducing the magnetic field allows the electron path to extend further and further from the cathode, when the outermost electrons reach the anode, anode current starts to flow.

See Attachment C for the principles of power control using a magnetron with permanent magnet and with electromagnet.

7.3) MAGNETRON SPECIFICATION DATA

Thermex 100 kW CW L-band Magnetron Specification Data – Model CWM-100L

Operating frequency – 915 MHz
Maximum Output Power – 100 kW
Efficiency – 88% - typical
Water-cooled anode, minimum flow – 4 GPM
Air-cooled cathode – minimum flow – 10 CFM
Air-cooled dome – minimum flow – 40 CFM
Coaxial launch into WR-975 waveguide
External Electromagnet type

Specifications:

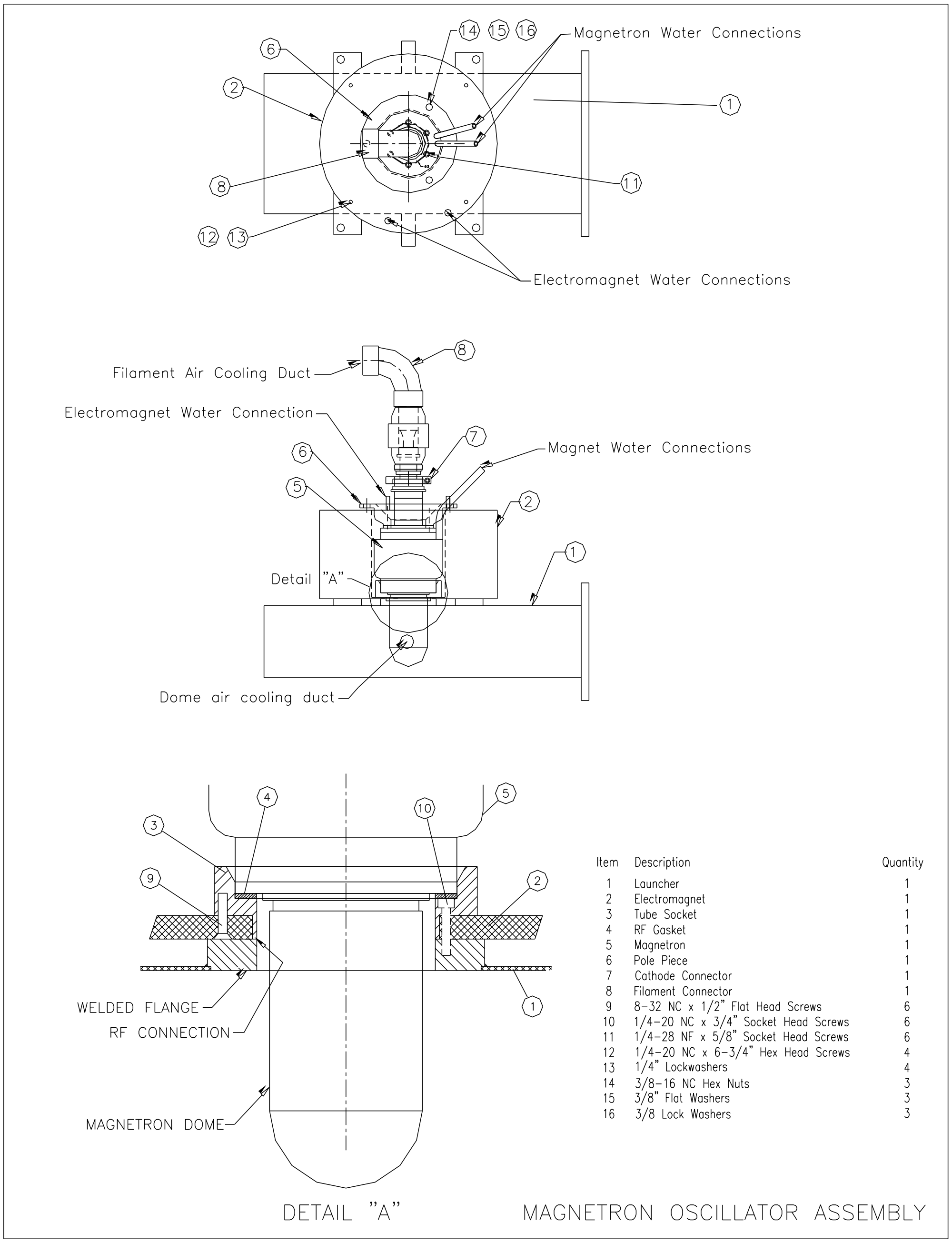
Characteristics	**Specification**	**Typical**
Frequency of operation	915MHz $\pm$ 10MHz	915MHz $\pm$ 5MHz
CW Power Output, minimum	100 kW	100 kW
Anode Voltage	21 kV Max.	18.5 kV
Anode Current	6.0 A	6.5 A
Efficiency	83%	88%
Filament Voltage (Standby)	12.6 V	12.0 V
Filament Current	115 A	112 A (see filament current back down schedule)
Load VSWR, Maximum	1.1:1 (circulator required)	1.5:1 (circulator required)

7.4) MAGNETRON INSTALLATION AND OPERATION

Please also refer to the L3 Services Magnetron Installation information included with this manual.

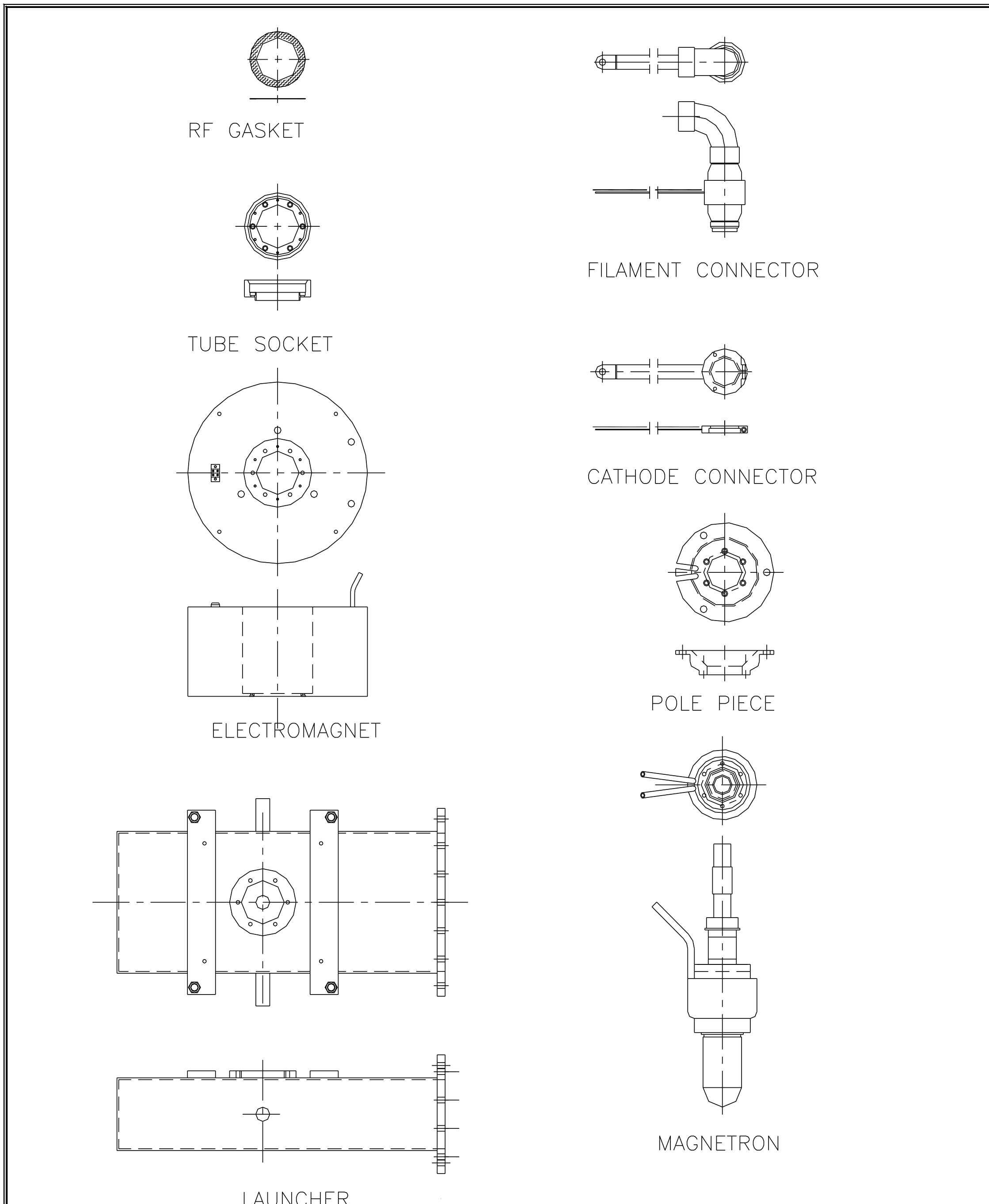
7.4.1) MAGNETRON OSCILLATOR ASSEMBLY

The magnetron used for the microwave generator uses an electromagnet to control the power delivered to the load. The magnetron oscillator assembly is shown below:



Item	Description	Quantity
1	Launcher	1
2	Electromagnet	1
3	Tube Socket	1
4	RF Gasket	1
5	Magnetron	1
6	Pole Piece	1
7	Cathode Connector	1
8	Filament Connector	1
9	8-32 NC x 1/2" Flat Head Screws	6
10	1/4-20 NC x 3/4" Socket Head Screws	6
11	1/4-28 NF x 5/8" Socket Head Screws	6
12	1/4-20 NC x 6-3/4" Hex Head Screws	4
13	1/4" Lockwashers	4
14	3/8-16 NC Hex Nuts	3
15	3/8" Flat Washers	3
16	3/8 Lock Washers	3

The major components that make up the magnetron oscillator assembly are the launcher, electromagnet, tube socket, RF gasket, magnetron, pole piece and cathode, and the filament connectors. These components are shown separately below.



MICROWAVE OSCILLATOR COMPONENTS

The launcher is special section of waveguide that supports the magnetron and its accessories that makes the connection between the magnetron and the waveguide system. The anode of the magnetron and the electromagnet are water cooled. Cooling air from a blower cools the filament and the antenna (dome).

The electromagnet is installed on the launcher and is secured to the mounting brackets by four (4) ¼-20 bolts, 6-3/4" long. The tube socket is secured to the bottom of the electromagnet with six (6) 6-32 flat head screws. The tube socket is also secured to the launcher with six (6) ¼-20 x ¾" long socket head screws. The contact between the tube socket and the welded flange of the launcher has to be clean in order to carry a large amount of current associated with the power transferred from the magnetron to the waveguide.

7.4.2) MAGNETRON PREPARATION AND INSTALLATION

The following steps are recommended when replacing a magnetron.

IMPORTANT! Step 1 is required only if the magnetron is not shipped with the pole piece installed. For item numbers, refer to the "Magnetron Oscillator Assembly" diagram in Section 7.4.1. If the magnetron shipped with the pole piece installed, proceed to Step 2.

Step 1: Assemble the Pole Piece (Item 6) to the magnetron by carefully slipping it over the filament end. It may be necessary to bend the copper tubing slightly to align the Pole Piece slots with the tubing. Make certain that the coolant pipes fit inside the smallest slotted Pole Piece outer diameter. If this is not done, the magnetron will not slip into the electromagnet in subsequent steps.

Secure the Pole Piece to the tube with the screws provided. Holding the completed tube-pole piece assembly by the pole piece, lift the assembly clear of the plastic bag. Care should be taken to avoid touching the ceramic parts with hands contaminated with oil or grease. Use of clean gloves is recommended to avoid damage to the magnetron from contamination.

Step 2: If the RF gasket (Item 4) is not already attached to the tube, slip it down over the output ceramic dome and position it on the RF contact surface of the tube as shown on the assembly outline. Avoid contacting the ceramic dome with the RF gasket.

If the gasket was previously used with a tube in place, examine the gasket carefully for evidence of burning, oxidation, contamination, deformation, or deterioration in any way. Replace if any damage is observed. The RF gasket can be fastened in position by observing the instructions enclosed with the spare RF gasket received with the tube.

Step 3: With the RF Gasket properly secured in position on the tube, hold the tube pole piece assembly by the pole piece and insert the tube with dome end first and the anode coolant tubing at the preferred position carefully into the electromagnet. Seat the tube squarely in the socket. Thread the three (3) nuts on the studs protruding through the pole piece from the electromagnet using one (1) of the three (3) lock washers provided on each stud. The nuts should be turned by hand as tight as possible. Hand tighten the nuts before checking distance between pole piece and magnet. The distance between the edge of the pole piece and the electromagnet, as checked at several points around the circumference, can be used as a valuable aid in assuring that the tube is seated squarely.

Note: The following instructions pertaining to the degree of tightening apply only if the lock washers are used as directed above. If for any reason the lock washers are not used, the prescribed 2/3 turn discussed below would be excessive.

After hand tightening, the nuts should be turned an additional 2/3 of a turn (approximately) by wrench. This is done in four (4) steps, each step being a 60-degree rotation or "one flat around" in turn, of the hexagon-shaped nuts. Marking of nuts with respect to the pole piece can be an aid in determining the completion of 2/3 turns (240 degrees or "four flats around"). This is equivalent to compressing the gasket by 0.015- 0.017 in (0.38 -0.43 mm). The torque on each nut will now be between 20-30 in-lb. (2.26-3.39 N-m).

If the RF gasket is not making a good RF connection between the tube and the electromagnet seat around the entire circumference, burning, arcing, and probable loss of the magnetron tube will result.

Step 4: Make certain that the contact surfaces of the tube and the filament current carrying connectors are "clean". Position the Filament Connector (Item 8) and the Cathode Connector (Item 7) squarely against the shoulder of its respective tube terminal. Tighten the connector screws to give a good electrical contact to the tube terminals.

Step 5: Cooling connections are made in the following manner:

a. Connect and clamp air hoses to the Filament Connector (Item 8) and to the Air Inlet on the launcher (Item 1).

b. Connect and secure water hose to the anode of the magnetron as shown on the drawing in Section 7.4.1. The coolant pipes must be bent away from the magnetron filament so that the spacing between the coolant pipes and filament (or all objects at high voltage) are greater than two (2) inches (50 mm).

c. Connect and secure water hose to the electromagnet coolant ducts. Direction of water flow may be in either direction.

d. Turn only the Control Power ON and check the distilled water pump rotation. Check the water pressure and water flow. Turn the power OFF and check for any potential water leaks around the magnetron and the electromagnet. Run the generator with the High Voltage OFF for approximately ten (10) minutes and check again for water leaks.

e. While the control power is ON check the blower for the filament and launcher for proper airflow. Also, check the cabinet cooling fans to ensure they are operating correctly.

See Magnetron Specification Data in Section 7.3 for the cooling requirements, the minimum water, and the air flow.

7.5) MAGNETRON OPERATING CONDITIONS

Safety Precautions!!! **Protective circuits serve a threefold purpose: safety of operating and maintenance personnel, protection of the magnetron and other major components in the event of abnormal circuit operation, and protection of the power circuits in the event of abnormal operation.**

7.5.1) MAGNETRON PRECAUTIONS

7.5.1.1) Precautions to Observe

1. Filament power must not be applied in the absence of cooling water or cooling air flow to the magnetron in the quantities required.

2. The filament voltage must be applied as described in the Magnetron Specification Data (see Section 7.3). See also the Filament Turndown diagram in Section 9.1.1.

3. The electromagnet power supply must not be energized in the absence of cooling water to the electromagnet.

4. The high voltage anode supply must not be energized unless:
   a. The electromagnet current is sufficient to keep the magnetron anode current cut off;
   b. The filament temperature has had sufficient time to stabilize; and
   c. Cooling water and cooling air are adequate.

5. The anode supply must be de-energized if:

   a. Electromagnet current drops below the value needed to prevent π-1 modes operation;
   b. The anode current exceeds maximum operating value;
   c. Internal tube arcing;
   d. Reflected power exceeds 10.0 kW; or
   e. Air or water flow becomes inadequate or temperature becomes too high.

6. The internal impedance of the anode supply must restrict the peak short circuit current to 30 A or less.

7. The filament power must be within the limits specified on the magnetron manufacturer's data sheet (available on request).

7.5.1.2) Filament Considerations

The magnetron filament is a vertically mounted, spiral-wound tungsten wire designed to give adequate emission when operated at about 2300K

It is of extreme importance that the filament is held at or as near as possible to this temperature. If the filament temperature is too low, the tube will cease to operate in the π-mode but can operate in the π-1 mode if the magnetic field strength is low enough. Operation in the π-1 mode is possible at a lower filament temperature than that required for π-mode operation.

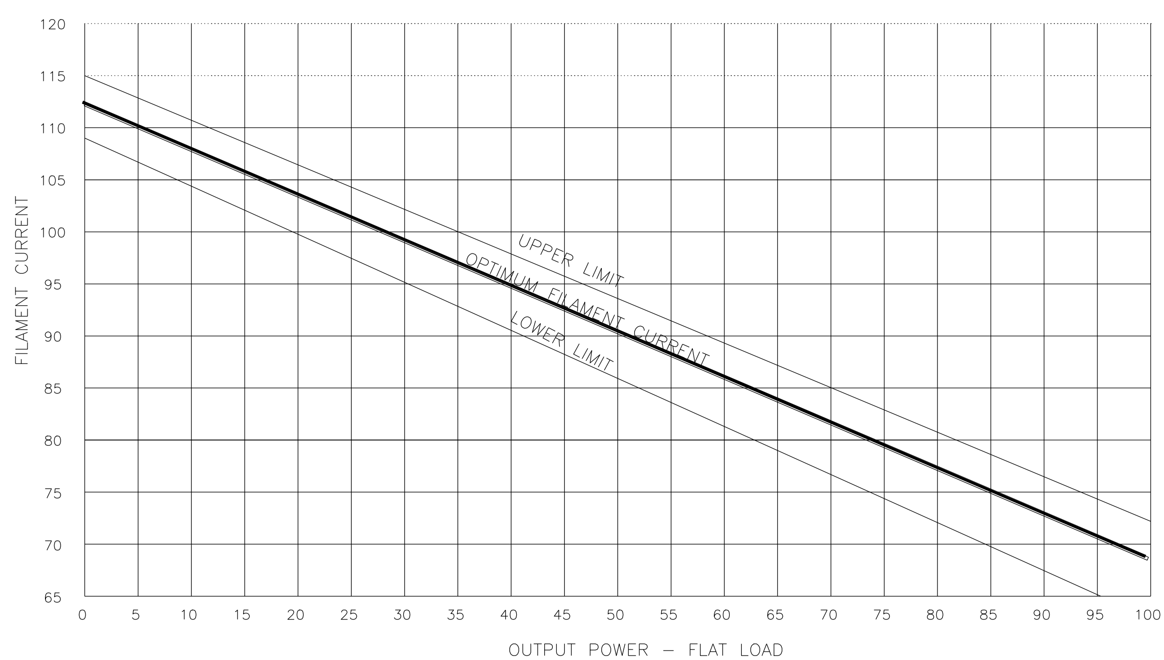
Operation in the π-1 mode, even at very low plate current values and for just a few seconds, can damage the filament and shorten its life. If the filament is operated too hot in the π-mode due to excessive power from normal back heating in addition to the filament supply, the result is again shortened life. Thus, the control is critical, and the only parameter that gives an indication of temperature is resistance.

The filament is subjected to electron back bombardment during operation, which will increase the filament temperature and reduce tube life if left uncorrected. Therefore, the filament power should be reduced under operating conditions to a value that will give the same “hot filament resistance” as when no RF power is being generated.

7.5.2) POWER ON

Step 1: Start up the generator. Check the filament current to insure that the filament power supply is operating correctly. Never exceed the maximum starting current of 250 A. With no anode voltage applied, the filament current should be close to the value specified in the Magnetron Specification Sheet in Section 7.3 (approximately 115A). After filament stabilization (approximately five minutes), measure the filament voltage. The filament voltage should closely correspond to that listed on the Magnetron Test Data Sheet.

Step 2: Apply sufficient power to the focusing electromagnet to assure anode current cut off. Make sure that the generator is connected to a proper load. Turn the high voltage ON. Check that the anode voltage is at the desired operating level. Reduce the electromagnet power to get the required magnetron anode current. Make sure that the filament current decreases as the anode current (or output power) increases. See Filament Turndown Schedule below.



FILAMENT TURNDOWN SCHEDULE

Step 3: Check the generator for various power levels to insure that the filament current follows the turndown schedule as indicated in the above Filament Turndown Schedule or in the Magnetron Specification Data (see Section 7.3). If the magnetron RF operation is to be discontinued for a period not exceeding one (1) hour, it is highly recommended that the filament power remain on during this time.

Step 4: To restart the magnetron after the anode voltage has been removed, make sure that the filament current is reset to the starting value, and the electromagnet current is at a value that will keep the anode current cut OFF when the anode voltage is reapplied. Reapply the anode voltage and reduce the electromagnet current to obtain the desired anode current and MW power output.

7.5.3) EXCESSIVE FAULTING

Excessive faulting of the anode supply is often the first indication that the filament is operating too cool. If faults occur while the anode current is being increased, the starting filament current should be increased, preferably in one-ampere steps (overall increase should not exceed 5 A) until faulting ceases. If an increase of 5 A does not help, the filament current should promptly be reduced to the original value and other reasons for the faulting should be sought.

If faults occur during the course of operating at the desired power level, it is possible that the filament power has been reduced too much to compensate for back heating. The filament power should be increased, preferably in 25-watt steps (overall increase should not exceed 75 W) until faulting ceases. If an increase of 75 W does not help, the filament power should promptly be reduced to the original value and other reasons for the faulting should be sought.

If the increase in filament supply power results in eliminating the excessive faulting and if the new value of filament voltage exceeds the absolute maximum values shown the Magnetron Test Data provided by the tube manufacturer the new value should be logged as revised operating parameters. If this change occurs during the tube warranty period, Thermex should be informed immediately.

7.5.4) ELECTROMAGNET CONSIDERATIONS

To prevent damage to a magnetron, the anode voltage must not be applied without first increasing the electromagnet coil current to a level that will keep the magnetron anode current cut off. Once the anode voltage is applied, the electromagnet coil current may be reduced to the required level controlled by the electromagnet supply. The magnetron anode current and the MW power output will increase as the coil current is gradually reduced. The anode current should not be increased at a rate exceeding 0.5 amperes per second, unless necessary for the process. Exceeding 0.5 A/sec may result in a significant reduction in magnetron life.

7.5.5) MW LOAD CONSIDERATIONS

Unstable operation may result if the MW load is such that the tube is operating in the "sink" region. The operator should understand that variations in frequency, anode current, power output, and filament back heating would occur. To reduce the effects of these variations, it is desirable to use a circulator in the magnetron output circuit as designed and built by Thermex. If a circulator is not used, a load VSWR protection circuit should be used to remove anode voltage if the VSWR exceeds the maximum values shown in the magnetron technical specification data sheet available from the magnetron manufacturer upon request.

7.5.6) MAGNETRON MW MODES

The magnetron is designed to operate in the π-mode at 915 MHz. The mode number for the next adjacent mode is one less than that for the π-mode; therefore, in these instructions the next adjacent mode is arbitrarily called the "π-1 mode". The frequency of the π-1 mode is approximately 1540 MHz. Operation in this mode results in low efficiency; high plate dissipation, high MW radiation, and very high filament back heating. The high filament back heating will cause tube failure in a short period of time. When the magnetron is turned on in the proper sequence, the first pre-requisite to π-1 mode operation is to have π-mode operation fail to start or cease to exist.

7.6) POSSBLE FAILURES OF THE MAGNETRON

The causes of magnetron tube failures are divided into three groups: termination of life, faulty use, and defects in workmanship. Tubes rejected at the initial state of application are generally because of other causes than termination of life. There is an intimate relationship between the magnetron tube and the operating conditions.

Faulty use consists of problems in maintenance and operation of the microwave oven. Deviations in the production conditions and environment could negatively influence the life of the magnetrons. In this respect, it is very important for both operators and maintenance personnel to study the actual reasons for the failures and to take corrective actions.

Sometimes, it is impossible to specify the independent cause between faulty use and material failure. However, the study of operating conditions and of the details of failure helps to make it clear. Therefore, when such a phenomenon is seen, the user should report the short life of tubes to the manufacturer. Appropriate methods for dud packaging and shipment should be arranged so that the duds can arrive in an unchanged condition.

For reference in rejection checks, causes of major failures and precautions to be taken are explained as follows:

7.6.1) DAMAGED ELEMENTS

Damaged elements may be related to one of two causes, rough handling during shipping or installation or abuse in operation. Examples of the latter include: a dented anode jacket, punctured vacuum seals, misaligned filament due to handling by the cathode / filament (stem), operation with incorrect voltages / currents or insufficient cooling (air and water).

7.6.1.1) BROKEN FILAMENT OR HEATER

In general, the filament or heater has almost no chance to break before termination of life. Instead, vibration or shock is often attributed to broken rejections. Due to the particular fact that, for directly heated cathodes, thoriated-tungsten wire is used, the surface of which has been specially treated (known as carburization) in order to ensure good electron emission. The filament or heater has poor mechanical strength against shock. The tube manufacturer, therefore, pays careful attention to the packaging and the shipment. The user also has to handle magnetrons with identical care (including reusing the original packing materials for reshipment of the tubes). Handling should be free from a sharp shock as a result from falling, impact, etc. When installing a tube in the microwave generator, special care should be taken.

The filament contactors are subject to a large amount of current required to heat the cathode. Poor connections through the filament contactors can also cause problems. This phenomenon is often mistaken for a broken filament or heater. Poor mechanical contact in the wiring tends to raise the temperature and to accelerate oxidation of the contacts. In case the filament or heater does not light during the operation, it is necessary to check the connection.

7.6.1.2) DAMAGE TO CERAMICS

Ceramic material is used for both parts of the cathode and the MW antenna of the tube. The temperature of the cathode stem becomes extremely high due to the thermal radiation of the heater. For this reason, certain types of magnetrons specify the maximum temperature of the stem and the lead wires in the specifications, and special care for cooling of those parts must be taken. An unusual increase in the temperature may cause damage to ceramic parts.
The MW antenna (dome) slight heating due to MW energy radiated by the antenna is acceptable as long as the tube is operated under normal conditions. Under the influence of the increased reflection from the load (increased VSWR = voltage standing wave ratio.), however, the ceramic of the MW antenna may overheat and crack.

When the anode temperature exceeds the maximum rating, the ceramic part will break down because of overheating. The anode cooling, therefore, must be carefully maintained.

In handling magnetrons, care must be taken to avoid damage to the ceramic parts.

7.6.1.3) DEFORMATION AND ASSYMMETRY OF THE FILAMENT

The thoriated-tungsten filament is generally coiled in shape. Therefore, it is easily deformed and/or can become asymmetric, when it receives a series of heat cycles exceeding the maximum ratings. The higher the temperature in operation, the more failures might take place. This potentially leads to a drop in power, an increase in filament current, moding, etc. In order to avoid these rejections, care as outlined in Section 7.6.5 should be taken. Additionally, the magnetron should be cooled properly, as specified.

7.6.2) BURN OUT OF ELECTRODES

When the cooling system of the microwave is able to maintain tube temperature below the maximum ratings, it will not cause burn out of the electrodes. In order to avoid damage to tubes due to trouble in the cooling system, it is always necessary to check the protective circuit (temperature and flow switches). Special care should be taken to insure proper cooling of the filament and antenna of the magnetron. This is accomplished by forced air via the magnetron blower.

7.6.3) POOR VACUUM

Various rejections like poor emission, poor insulation at high voltage, etc., as a result of the degraded vacuum of tubes, are mostly caused by two reasons: discharged gas from the inner electrodes and/or the insulation materials; and air leakage (intrusion of the atmosphere). When sealing rejections, like cracks in the ceramics are observed, the leakage progressively leads to glow or internal arcing. Proper cooling minimizes the potential failures due to decreased vacuum in the magnetron. The same care as outlined in Sections 7.6.2 and 7.6.3 must be taken.

7.6.4) POOR EMISSION

Rejection due to insufficient electron emission from the cathode will show a sharp drop in the output power and moding during operation. Poor emission is due to residual gas in the tube, improper cathode temperature, etc.

An increase in the residual gas contaminates the cathode and quickly deteriorates emission quality. Too high cathode temperature also contributes to poor emission by reason of excessive evaporation. Too low cathode temperature, on the other hand, not only produces insufficient electron emissions but also represents temporary degradation of the thoriated-tungsten filament.

The filament or heater voltage must be maintained within the specifications. As emission rejection actually includes such deceptive reasons as poor contacts of contactor and increased resistance of the filament circuit, care as outlined in Section 7.6.1 must be taken.

The electric power supply voltage must be carefully monitored. Variation of the supply voltage leads to excessive anode current (greater than the maximum ratings), which shows the same phenomenon as emission failure. A special voltage regulator network must be installed to minimize any potential changes in the supply voltage greater than 2.5%.

7.6.5) DROP IN OUTPUT POWER

The cause of this rejection is not always related to the drop in the emission, because secondary electrons ejected from the cathode by back bombardment also contribute to the emission during operation.

The major reason for the drop in the output power is in the decrease of efficiency due to the increased surface loss in the cavities as a result of the deposits from the cathode or other parts. Also, the deformation and asymmetry of the thoriated-tungsten filament, the structure of which is easily deformed, results in a disturbance of the interaction space. The higher the temperature, the more evaporation, deformation, and asymmetry of the cathode are observed, and care as outlined in Sections 7.6.3 and 7.6.5 must be taken.

7.6.6) MODING

Moding occurs when the MW electric field inside of the tube can no longer maintain the oscillation in π-mode because of the disturbance by the reflected waves from the load, resulting in an unusual oscillation.

Insufficient electron emission from the cathode also discontinues the π-mode oscillation, which gives rise to moding.

In order to avoid moding, care as outlined in Section 7.6.5 is needed. The operator of the microwave is advised to check the operation of the circulator and request Thermex Thermatron's advisement regarding the load impedance, reflection from load, load variations, etc.

7.6.7) RUNAWAY

Generally, when a magnetron is operated with a larger reflection in the off sink phase the tube can no longer control the electrons in the interaction space because of the increased temperature in the electrodes. This causes the anode current that does not contribute to the oscillation to be increased. The phenomenon is referred to as “runaway”. Large magnetrons are protected from reflected power by a circulator and water load.

In order to avoid “runaway”, care as outlined in Section 7.6.3 and 7.6.6 must be taken so as to suppress the increase in cathode temperature. Also, care in Section 7.6.7 should also be taken as the change in the load impedance of the microwave oven has a pronounced effect on this phenomenon.

7.6.8) ARCING INSIDE THE MAGNETRON

Arcing, the phenomenon that represents high voltage breakdown between electrodes inside of the magnetron, has complicated causes. Generally, sparking that is not repeated is not cause for concern, except that the potential failures caused by poor emission, excessive application of voltage and poor vacuum must be watched for carefully.

Application of high voltage at low electron emission due to too low filament voltage or insufficient preheating of the cathode occasionally gives rise to sparking and may destroy the surface of the cathode. The sparking also might take place because of the unusual high voltage generated as a result of transient phenomenon or parasitic oscillation and by the momentary deterioration in the vacuum due to the excessive loss in electrodes.

7.6.9) MAGNETIZATION OF THE ELECTROMAGNET

Due to the fact that the electromagnets of the magnetron have to be precisely controlled, they do not perform properly once the magnet current supply fails to provide the right magnetizing current. Adjoining or attaching to the ferromagnetic materials to or nearby magnetrons might change the magnetic field. The electromagnet should be separated from the ferromagnetic materials and kept to a distance as indicated by the manufacturer.

Surge Voltage

Although this is not considered a cause for rejection, this phenomenon is associated with magnetron operation.

When the high voltage and the filament voltage are excited in the magnetron simultaneously, or when the high voltage is applied before the cathode achieves its thermal equilibrium enough to emit electrons, surge voltage is occasionally observed in the power supply circuit. Moding also sometimes contribute to surge voltage.

Although, the magnetron will not generally be damaged by surge voltage, the breakdown voltage of the power supply should be such to withstand the surge voltage, and proper operation of the high voltage filter/protective circuits should be checked.

7.7) GENERATOR CIRCUIT BREAKER CHART

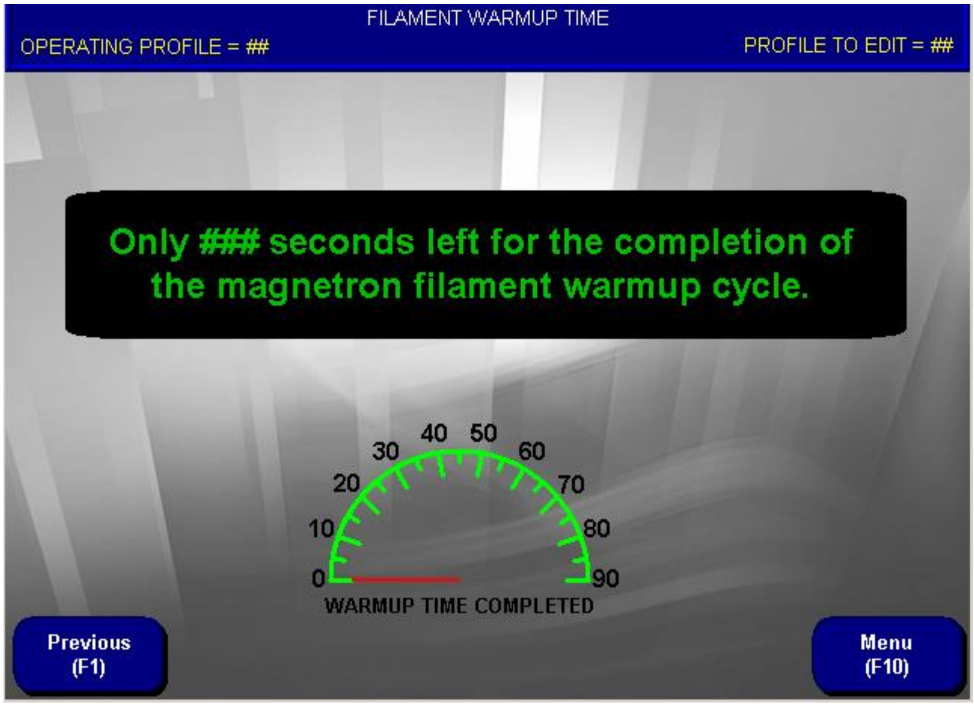
CODE	VOLTAGE	AMPS	DESCRIPTION
Q1	**480 AC**	**250**	**MAIN DISCONNECT**
Q2	**480 AC**	**225**	**ANODE BREAKER**
Q3	**480 AC**	**25**	**CONTROL BREAKER**
Q4	**480 AC**	**6**	**COOLING WATER PUMP**
Q5	**480 AC**	**8**	**CONTROL TRANSFORMER (T1)**
Q6	**480 AC**	**6**	**FILAMENT CONTROLLER**
Q7	**240 AC**	**10**	**MAGNET CONTROLLER**
Q8	**240 AC**	**10**	**COOLING BLOWERS**
Q9	**120 AC**	**10**	**SERVICE RECEPTACLE**
Q10	**120 AC**	**10**	**120V AC CONTROL CIRCUITS**
Q11	**24 DC**	**10**	**24V DC CONTROL CIRCUITS**

7.8) GENERATOR RELAY USAGE CHART

CODE	VOLTAGE	DESCRIPTION
K1	**24 DC**	**MASTER CONTROL**
K4	**120 AC**	**OVERLOAD**
K5	**120 AC**	**HIGH VOLTAGE ON**
K6	**120 AC**	**APPLICATOR READY**
K8	**24 DC**	**CONTROLLED SHUTDOWN**
K9	**24 DC**	**SYSTEM RESET**
K10	**24 DC**	**FILAMENT PERMISSIVE**
K11	**24 DC**	**ARC DETECTOR TEST**
K12	**24 DC**	**HIGH VOLTAGE PERMISSIVE**
K15	**24 DC**	**MODE STIRRER**
KM1	**24 DC**	**WATER PUMP**
KM2	**24 DC**	**MAGNET & BLOWERS**
KM3	**24 DC**	**FILAMENT CONTACTOR**
KM4	**120 AC**	**STEP-START CONTACTOR**
KM5	**120 AC**	**HIGH VOLTAGE CONTACTOR**
SR3	**24 DC**	**SAFETY RELAY**

7.8) GENERATOR PANELVIEW SCREENS

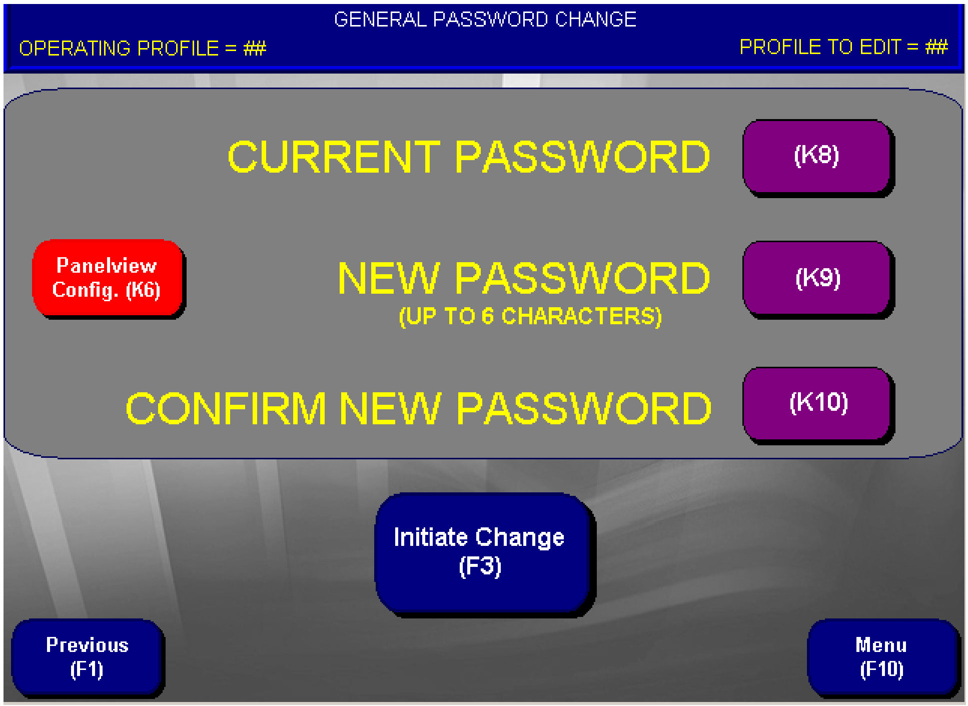
The first screen viewed upon power up.



This screen will be displayed when the "Start Generator" button is pressed. It displays the remaining time for the warm up cycle. The operator may press the "Menu" button to exit this screen at any time, although the PLC will automatically display your previous screen after the countdown ends.

General Password entry screen.

The Set Up Password screen is shown above.
Only Thermex trained technicians will need access past this screen.

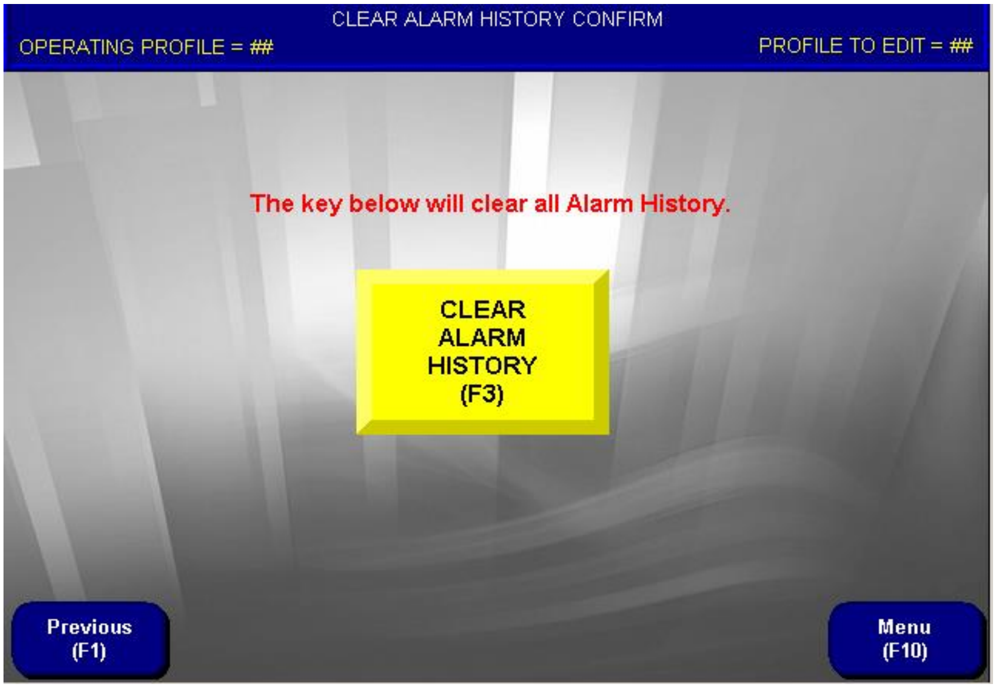


General Password Change screen.

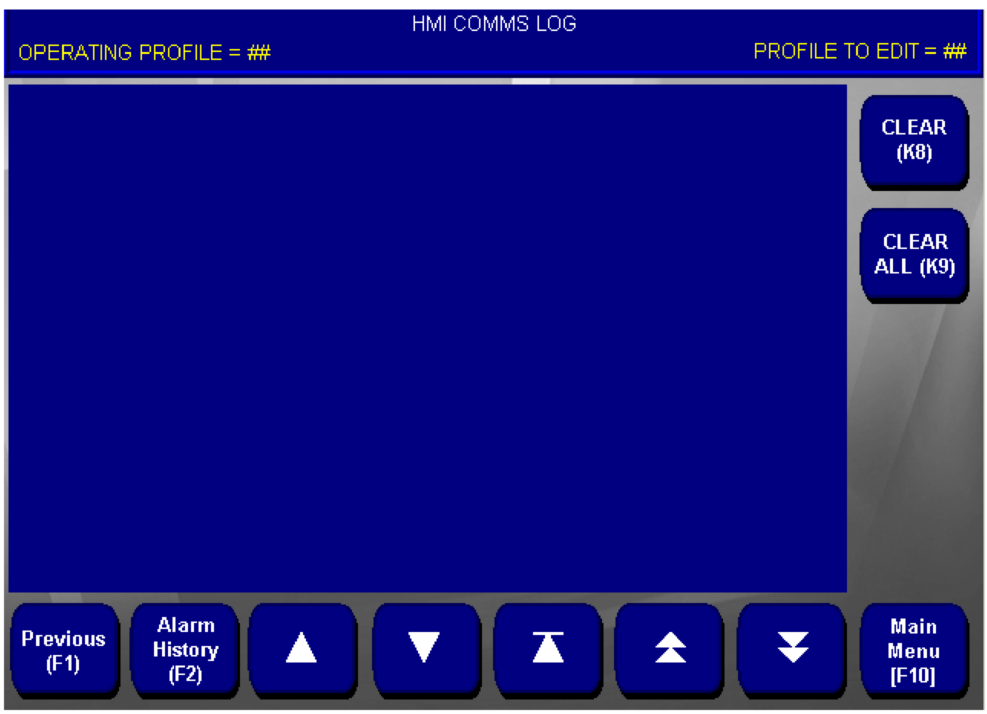
The Log Off screen can be accessed by pressing F7 on the Main Menus screen.
The generator will also automatically log the user off user after 15 minutes of inactivity.

All currently active alarms are displayed on the Current Alarms screen.
Pressing "Reset Alarm Triggers" will reset these alarms.
The messages will reappear if the generator is still in an alarm state.

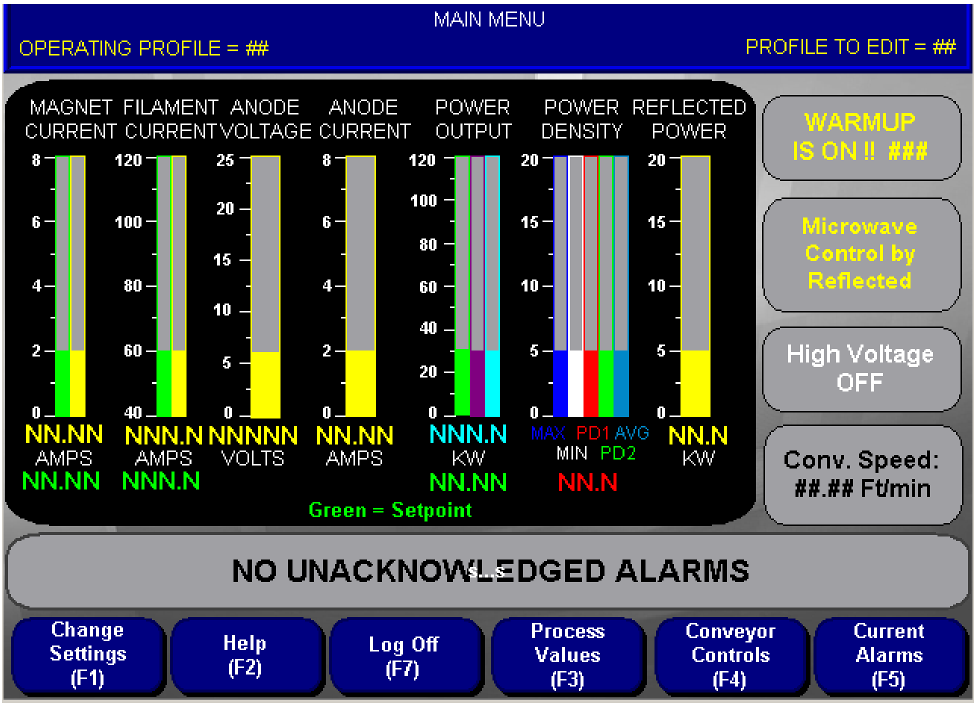
The Alarm History screen will show alarm triggers
even after they are reset on the previous screen.



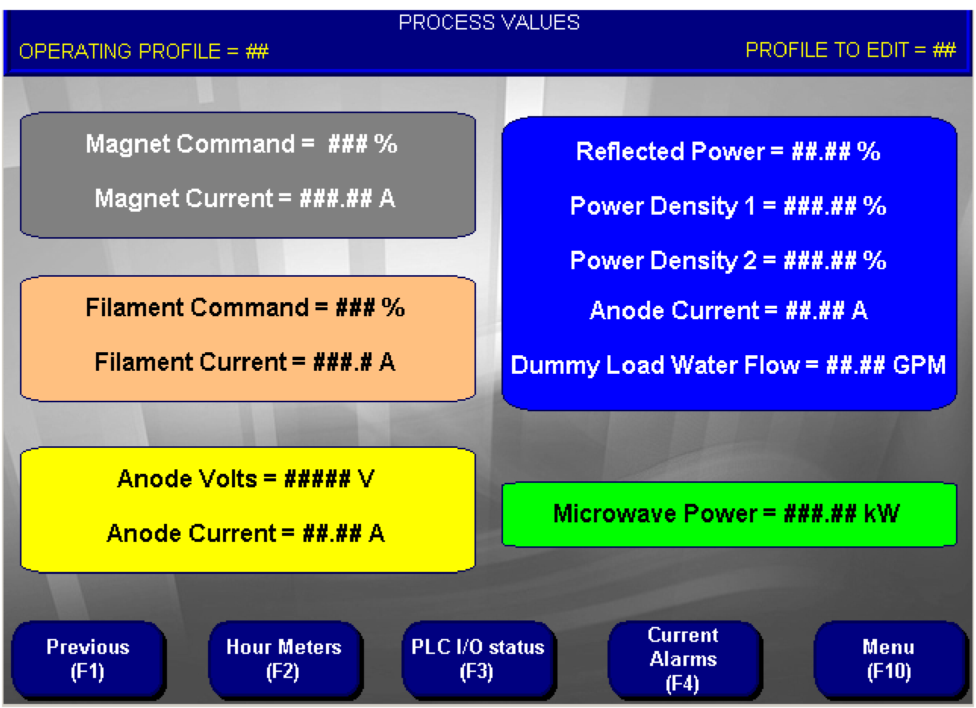
The Clean Alarm History Confirm screen is used to clear ALL alarm history from the previous screen. Be cautious when using this feature, as it will not reset the alarm triggers but will clear ALL alarm history.



The HMI Comms Log screen is used primarily by Thermex technicians to diagnose generator faults.

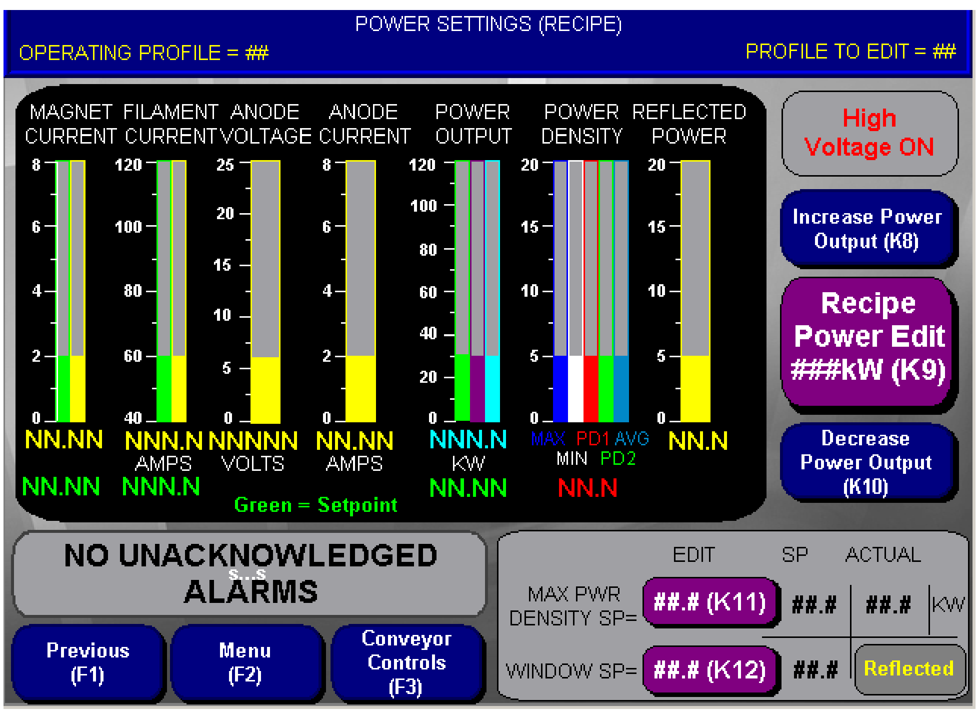


This Main Menu screen will be displayed any time the respective button is pressed from any of the other screens.

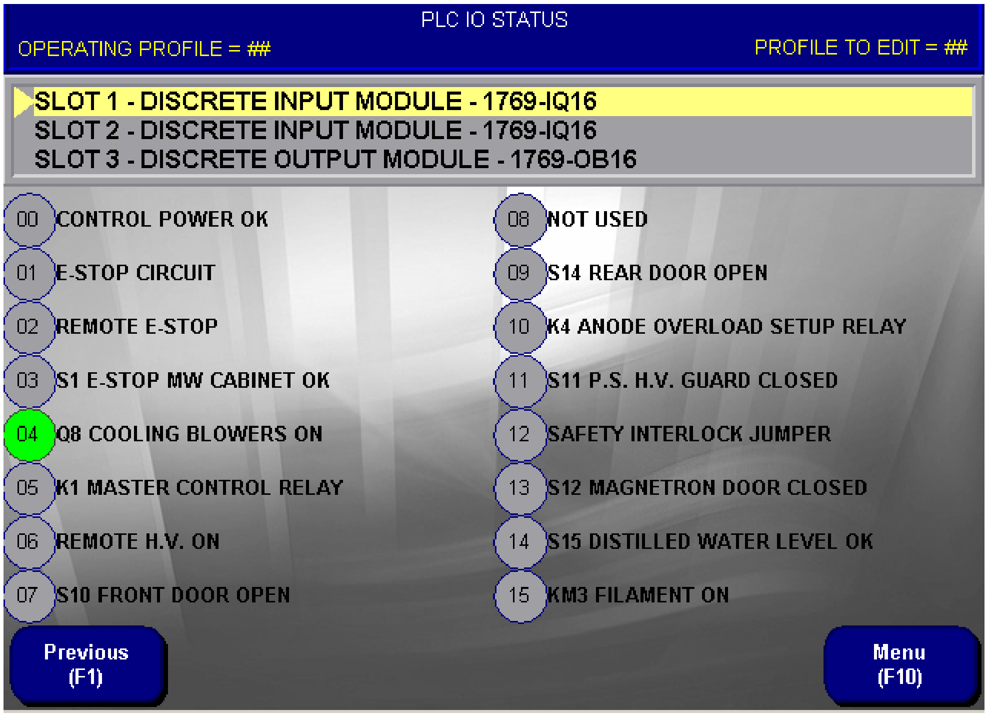


All measured analog values are displayed on the Process Values screen.

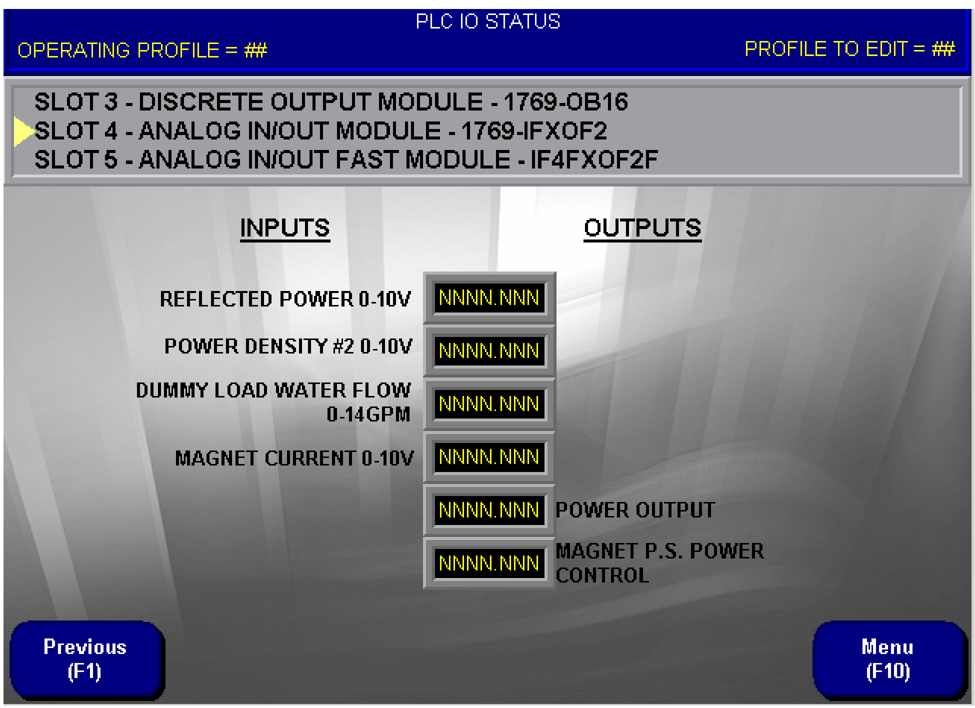
Once the general password is entered, access will be granted to the Settings Menu screen where the user can monitor and change various operating values within the generator.



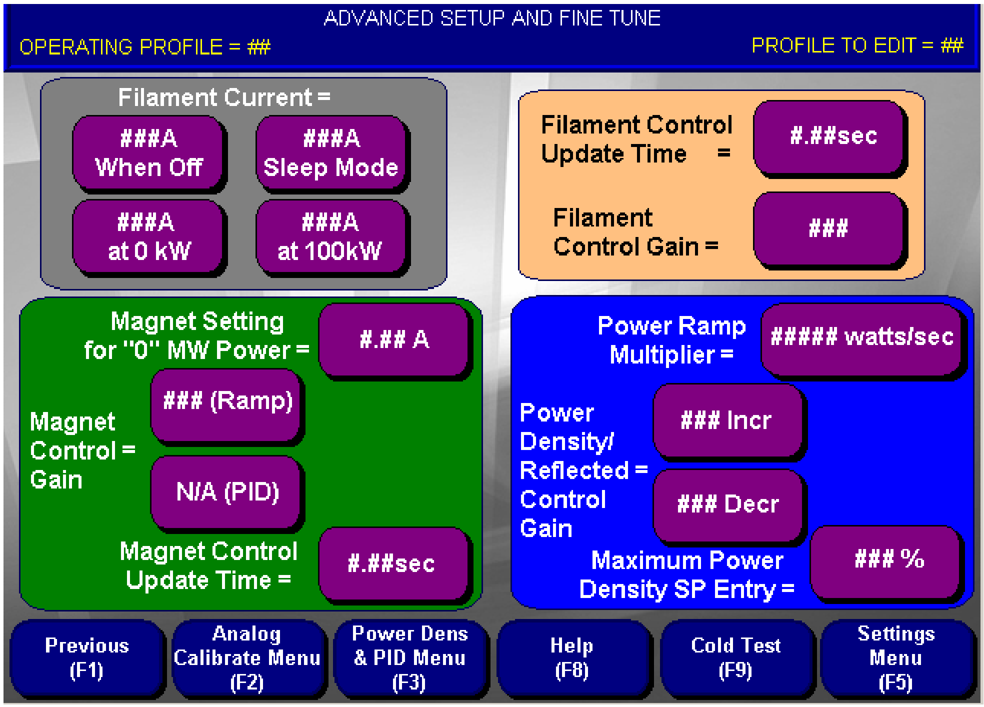
On the Power Settings Recipe screen, the user may increase or decrease the generator's power output and also modify the max reflected power and window set points.



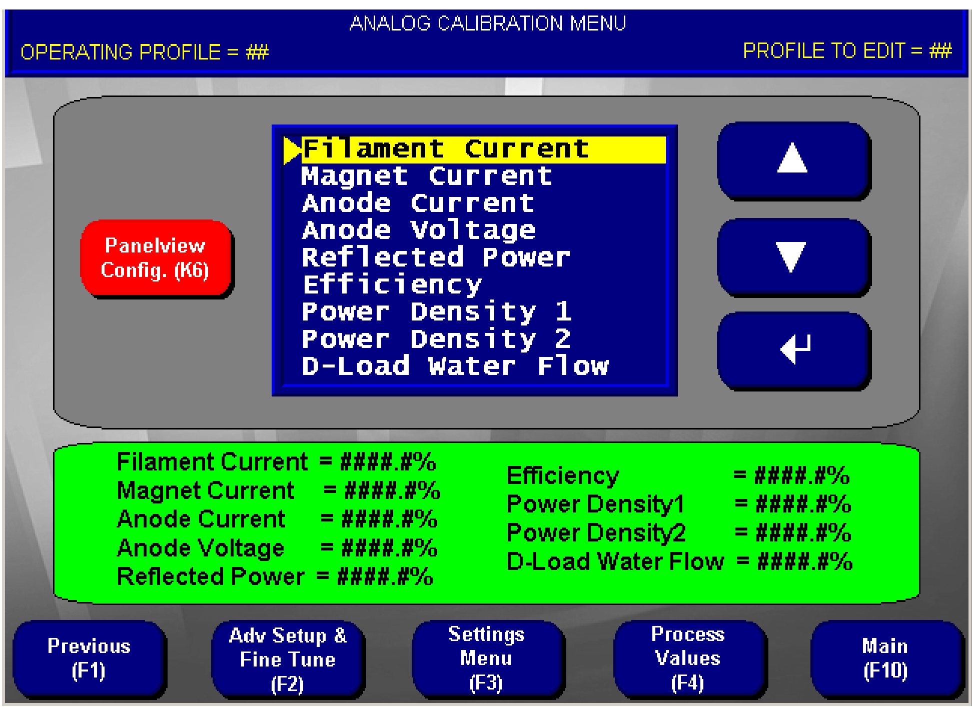
The PLC IO Status screen is useful for trouble shooting and viewing all digital I/O points. A green circle represents if the input or output is true. Use the up, down, and enter keys to change the card displayed.



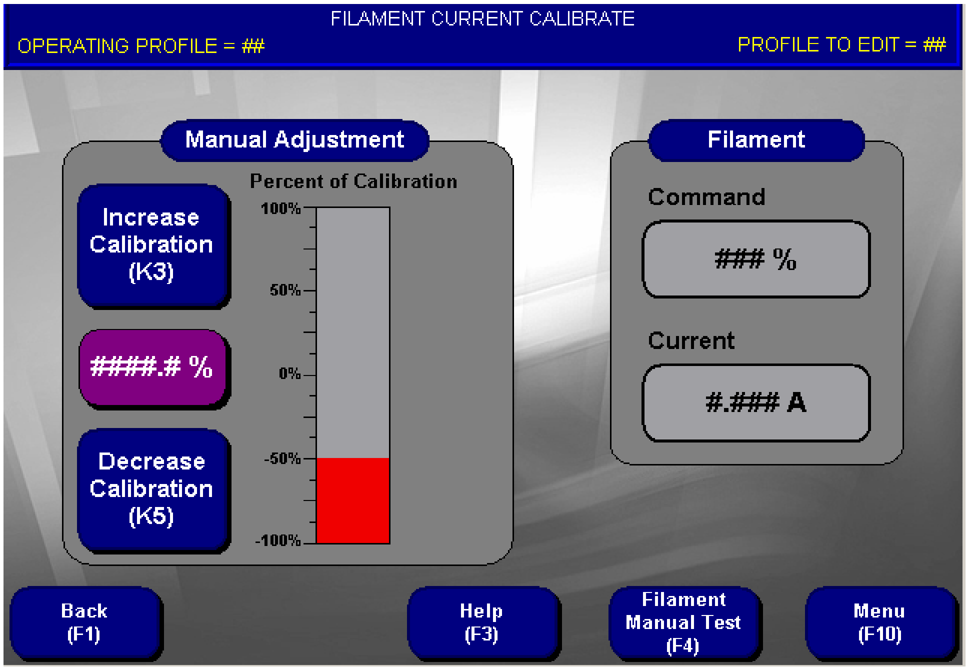
***This is the same screen as above**, but one of the analog cards has been selected. Use the up, down, and enter keys to change the card displayed.*



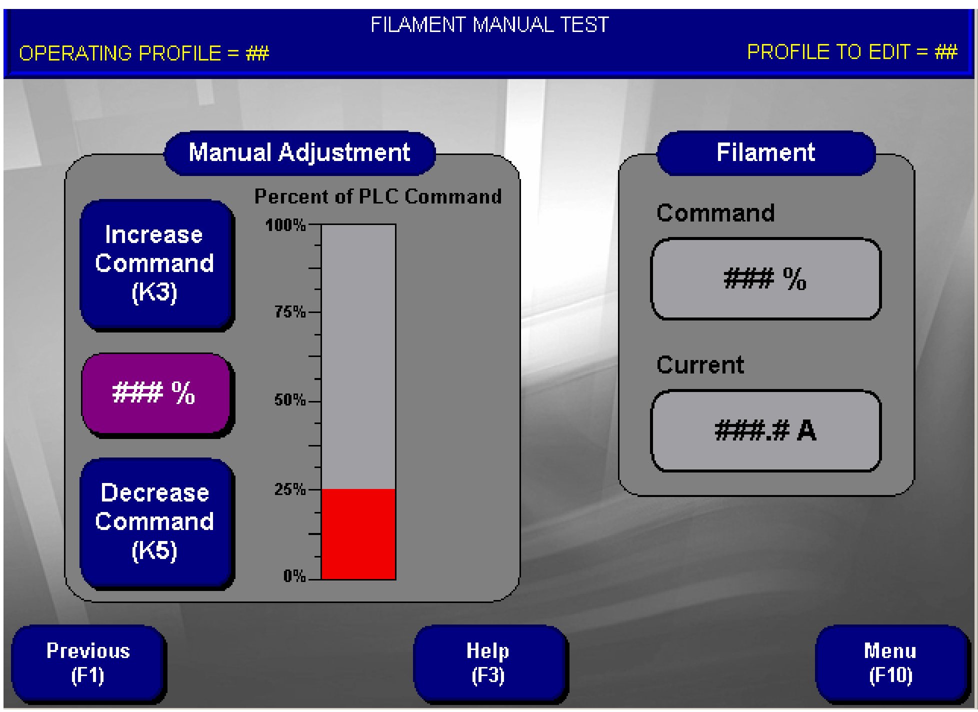
Reached after the advanced password is entered, the Advanced Setup and Fine Tune screen is used by Thermex technicians to set generator control limits.



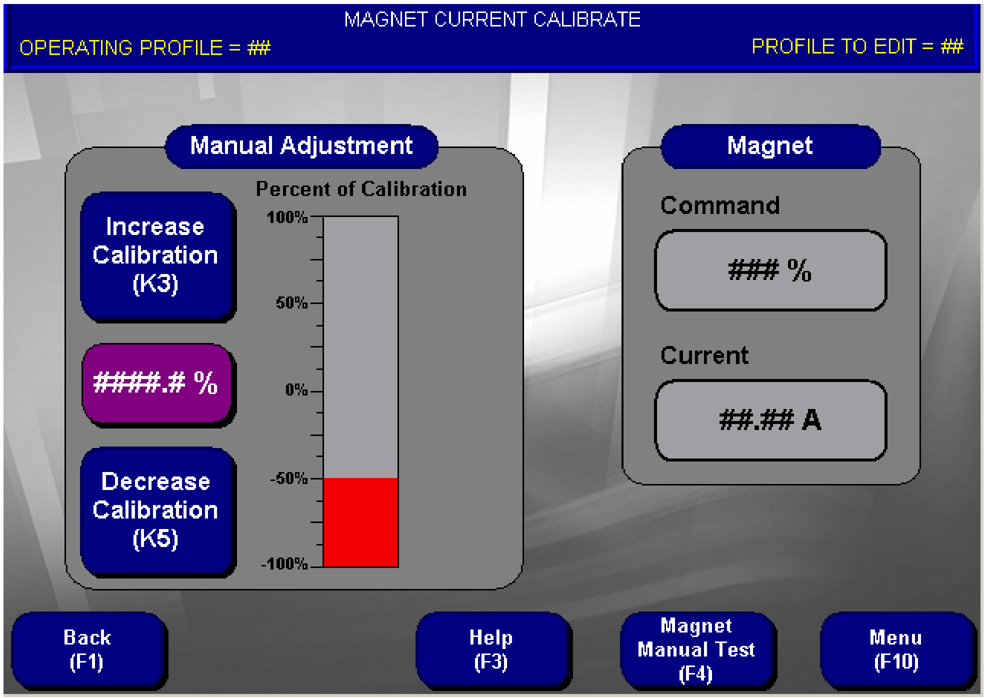
The Analog Calibration Menu screen is displayed after the advanced password is entered and is used to dial in correction factors upon initial setup.



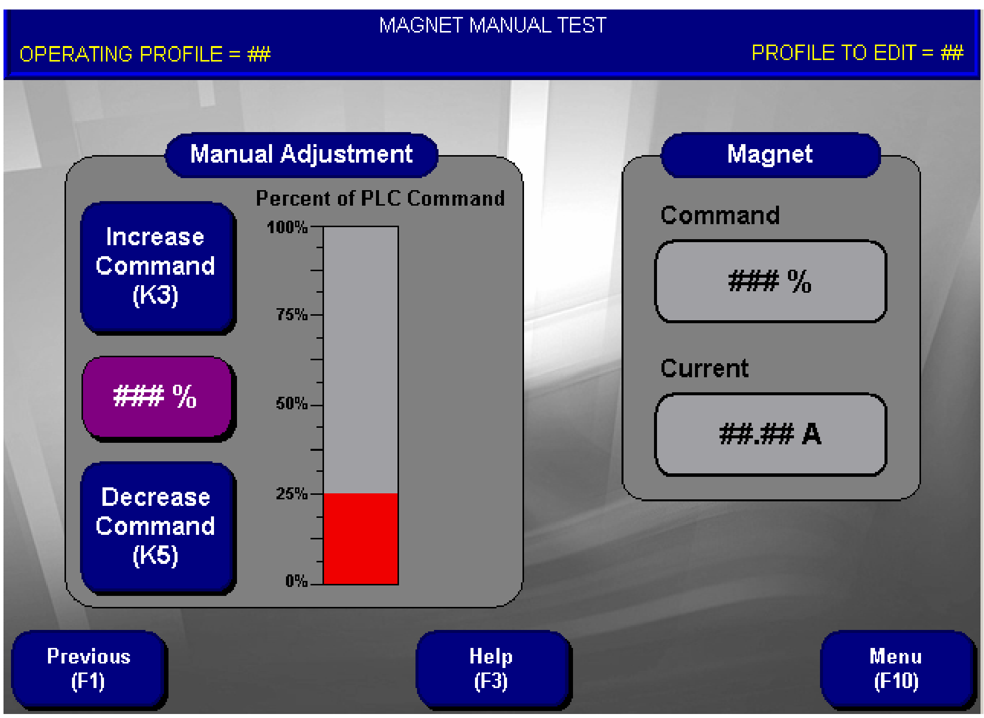
The Filament Current Calibrate screen is used to calibrate the filament current display of the generator.



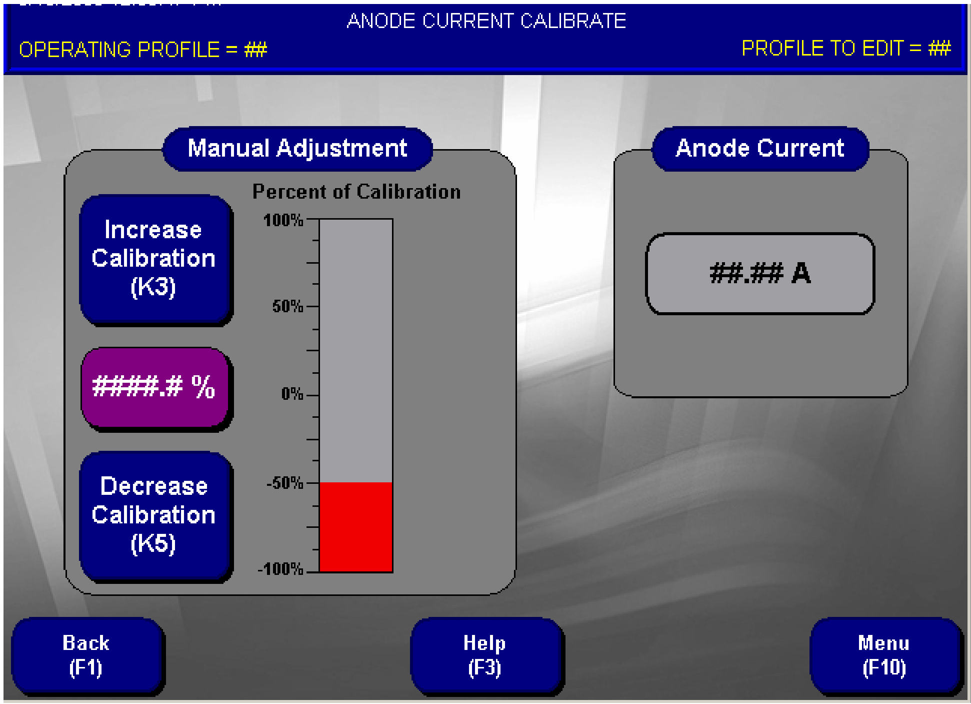
From the Filament Manual Test screen, the operator can drive the filament current anywhere between 0-100% of its full value for further testing and calibration purposes.



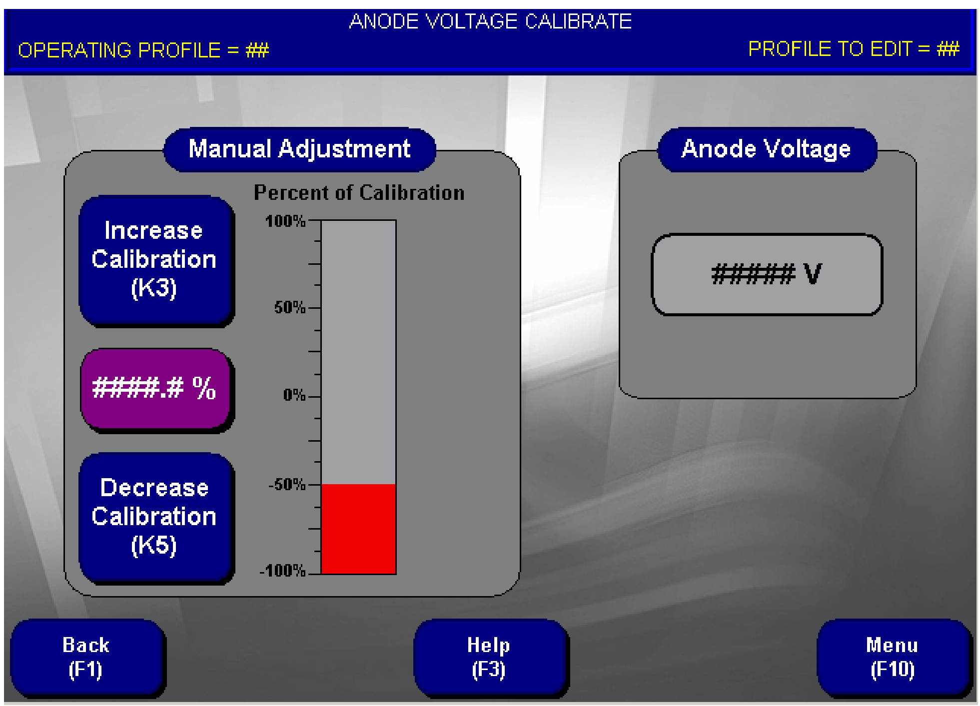
The Magnet Current Calibrate screen is used to calibrate the magnet current display of the generator.



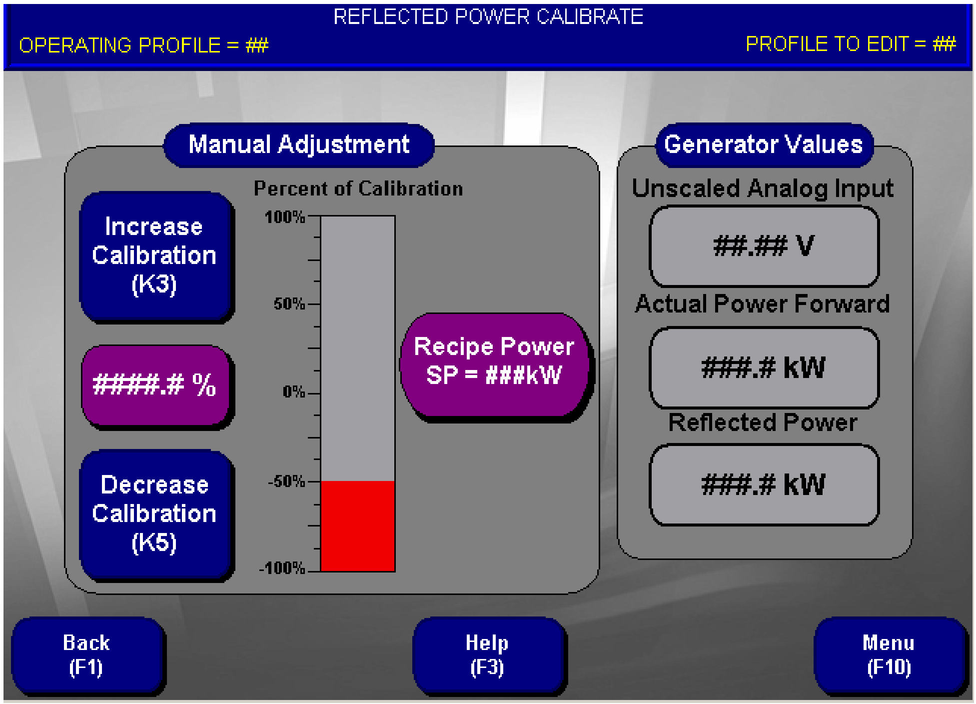
From the Magnet Manual Test screen, the user can drive the magnet current anywhere between 0-100% of its full value for further testing and calibration purposes.



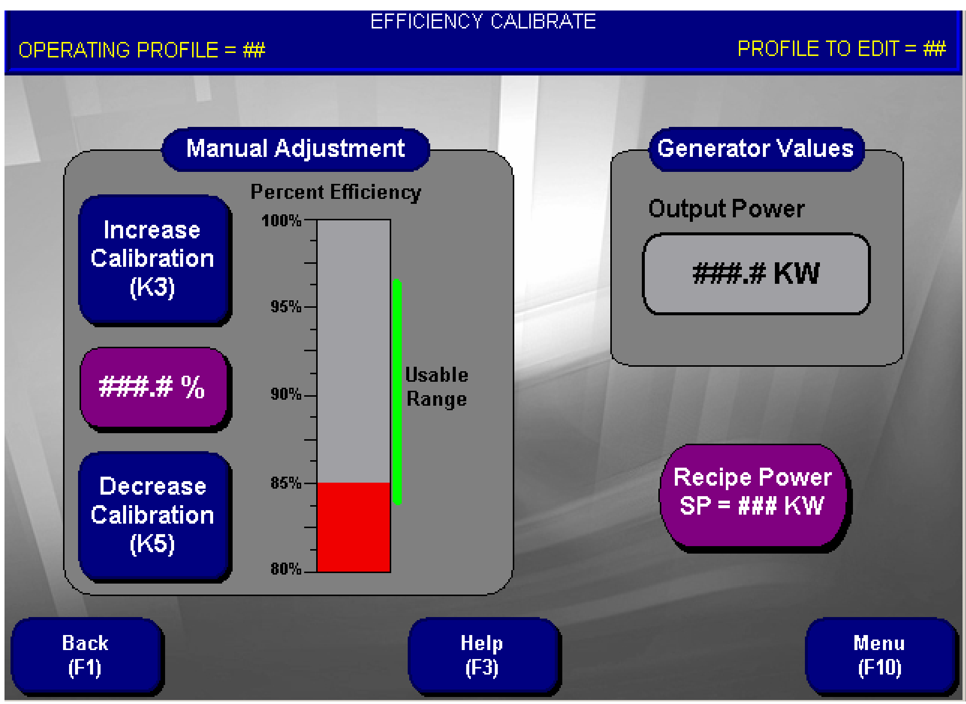
The Anode Current Calibrate screen is used to calibrate the anode current display of the generator.



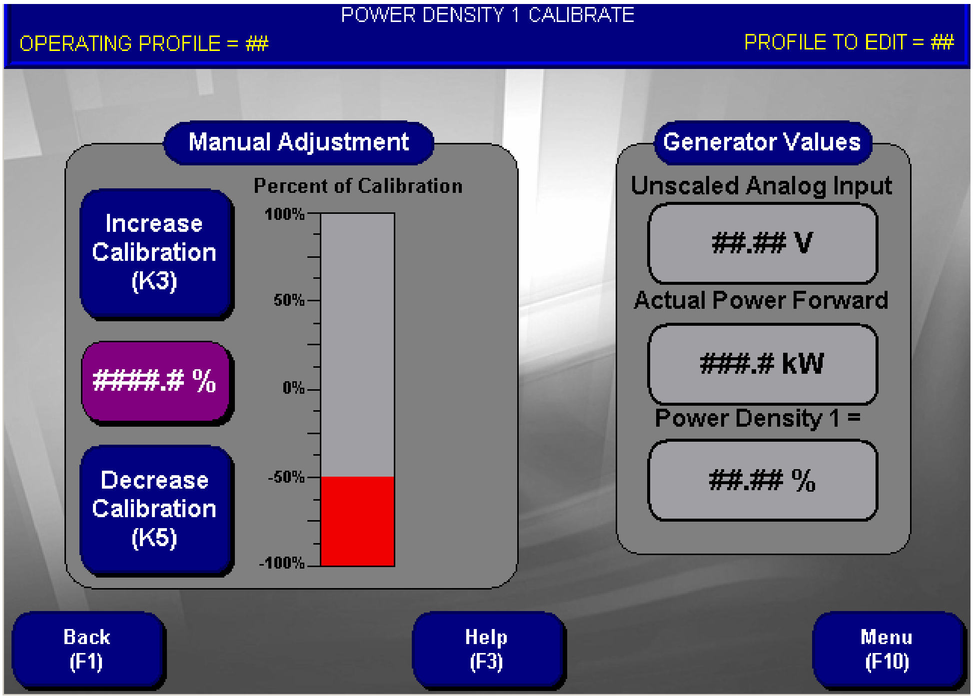
The Anode Voltage Calibrate is used to calibrate the anode voltage display of the generator.



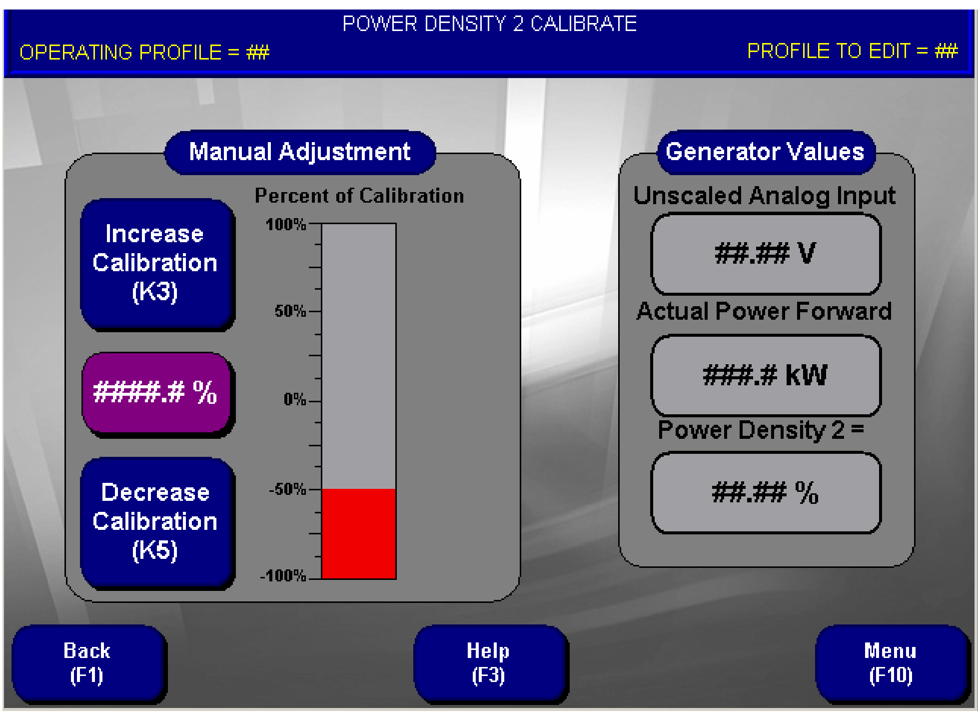
The Reflected Power Calibrate screen is used to calibrate the reflected power display of the generator.



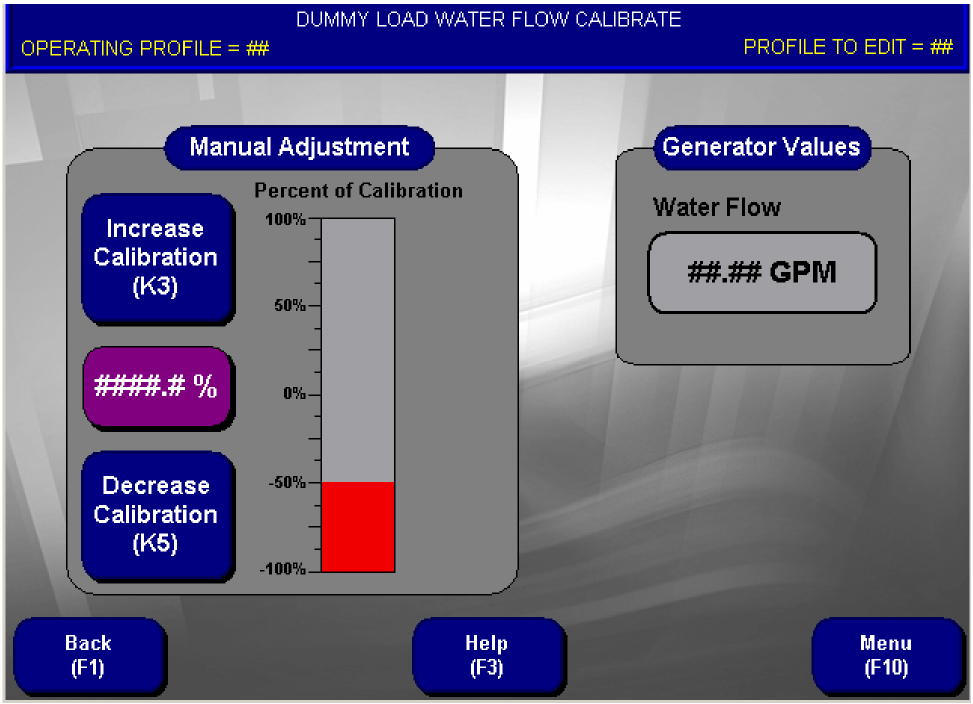
The Efficiency Calibrate screen is used to calibrate the power output display of the generator.



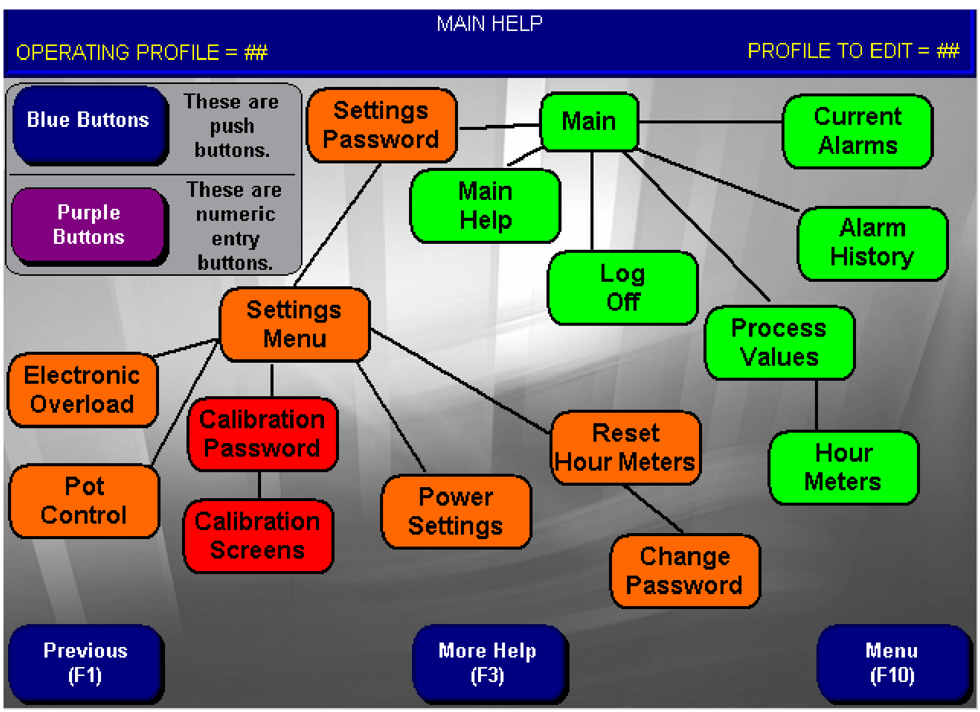
The Power Density 1 Calibrate screen is used to calibrate the Power Density 1 display of the generator.



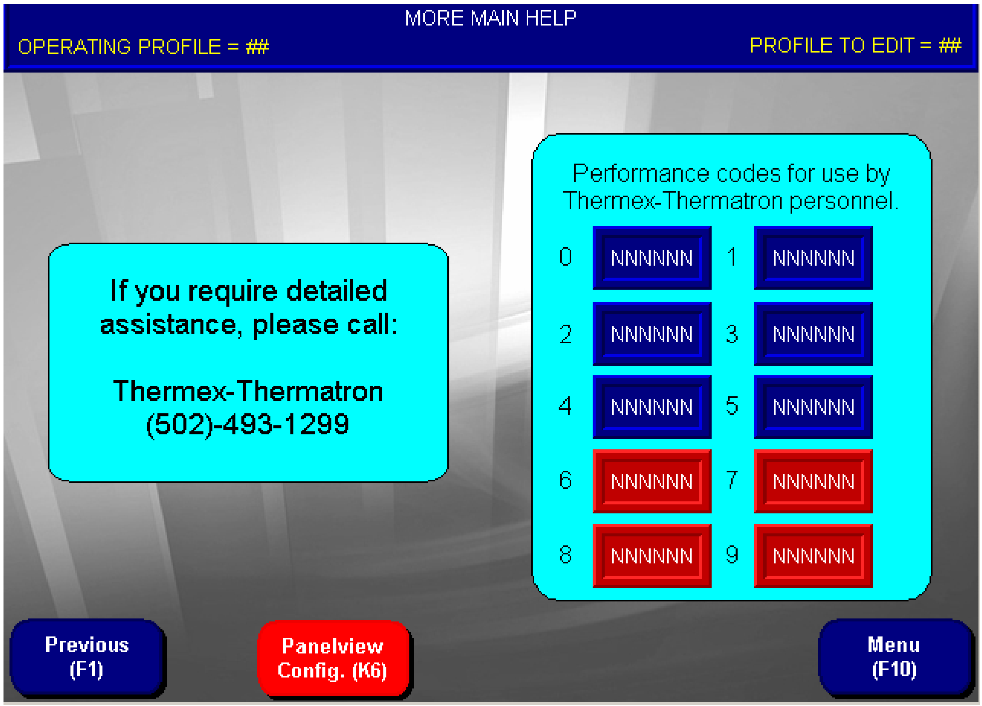
The Power Density 2 Calibrate screen is used to calibrate the Power Density 2 display of the generator.



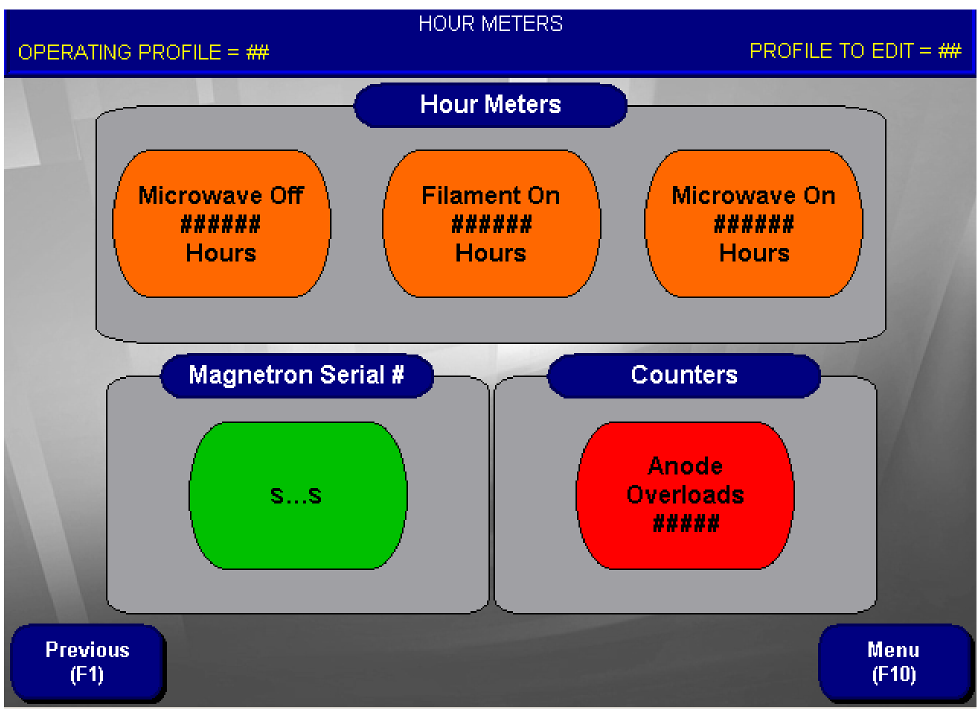
The Dummy Load Water Flow Calibrate screen is used to calibrate the dummy load water flow display of the generator.



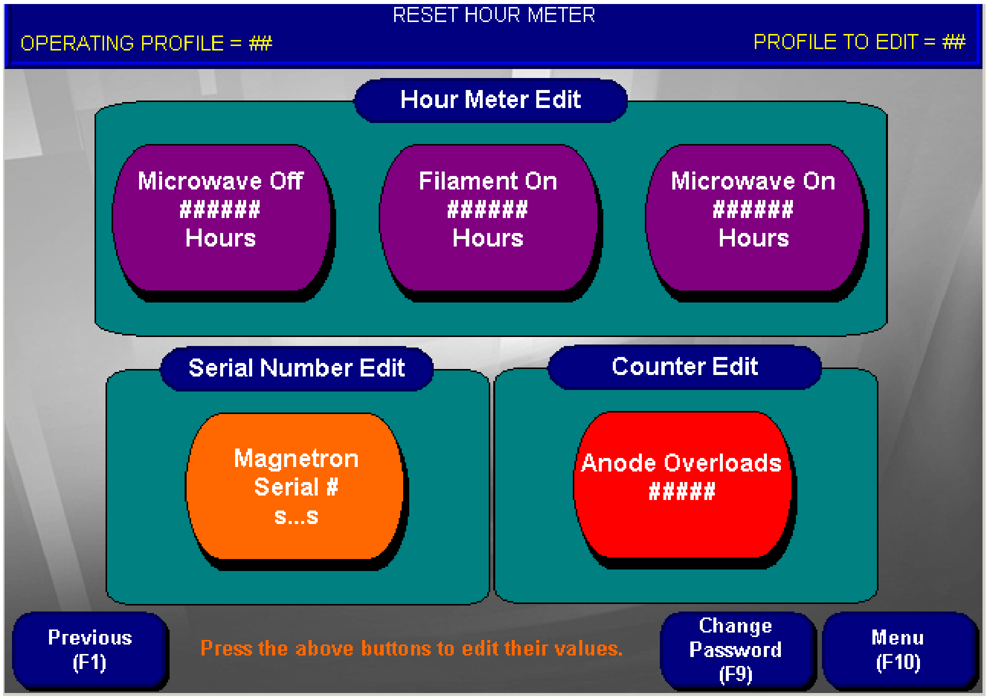
The Main Help screen displays a map diagram showing the various pathways to other screens.



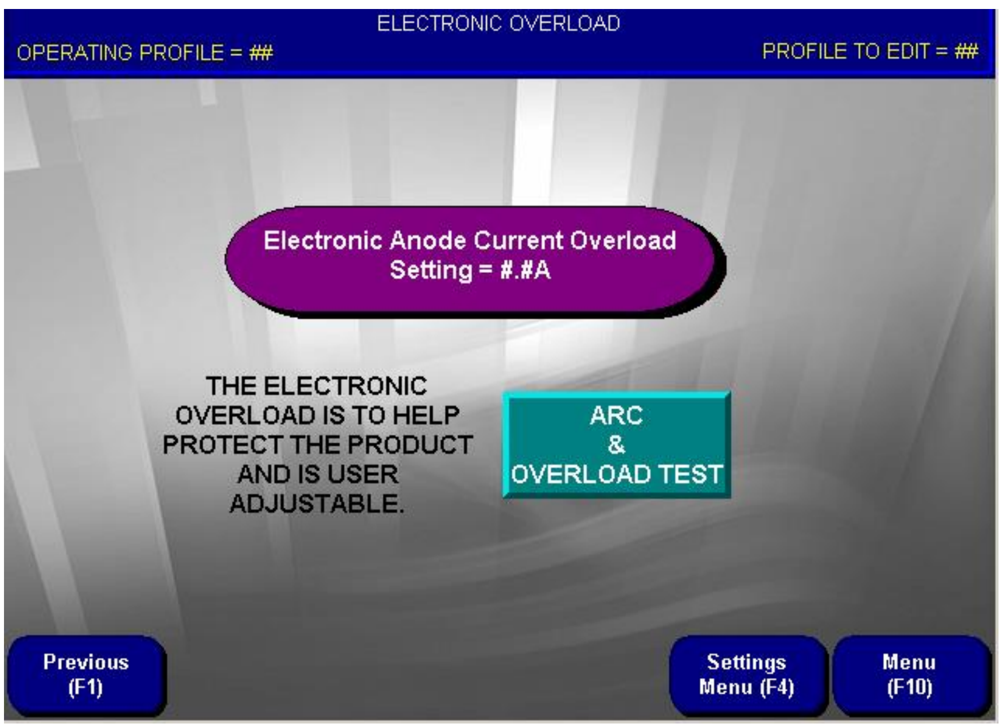
The More Main Help screen (or Help Screen 2) will give various performance codes which can be used by Thermex personnel in the event of a lost password.



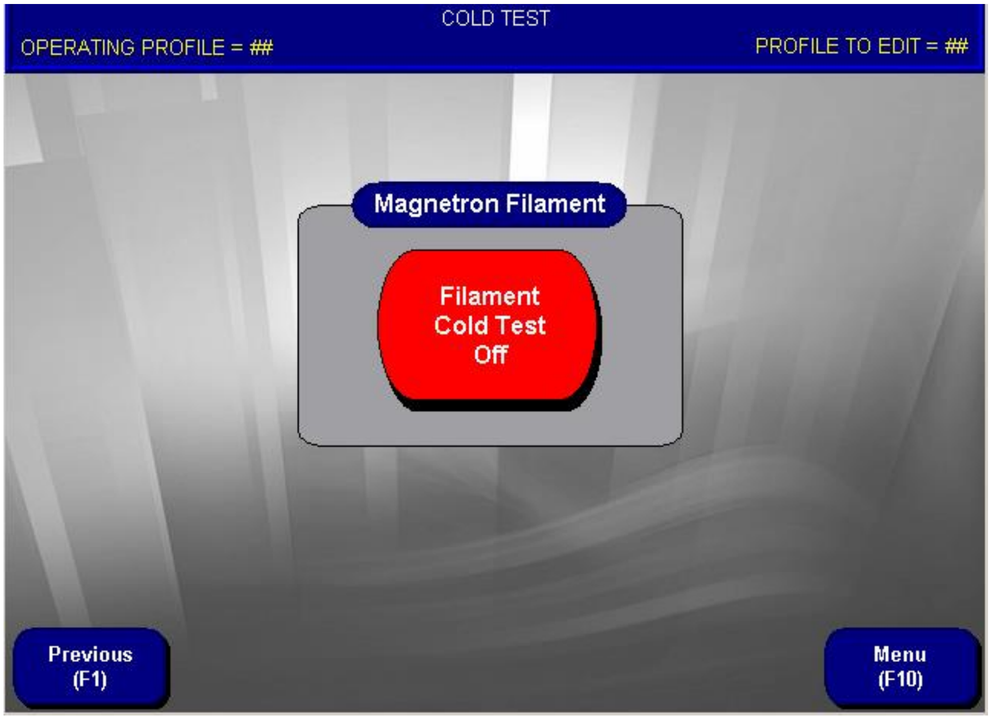
The Hour Meters screen displays running hour meters for various aspects of the generator, the number of anode overloads and the serial number of the current Magnetron.



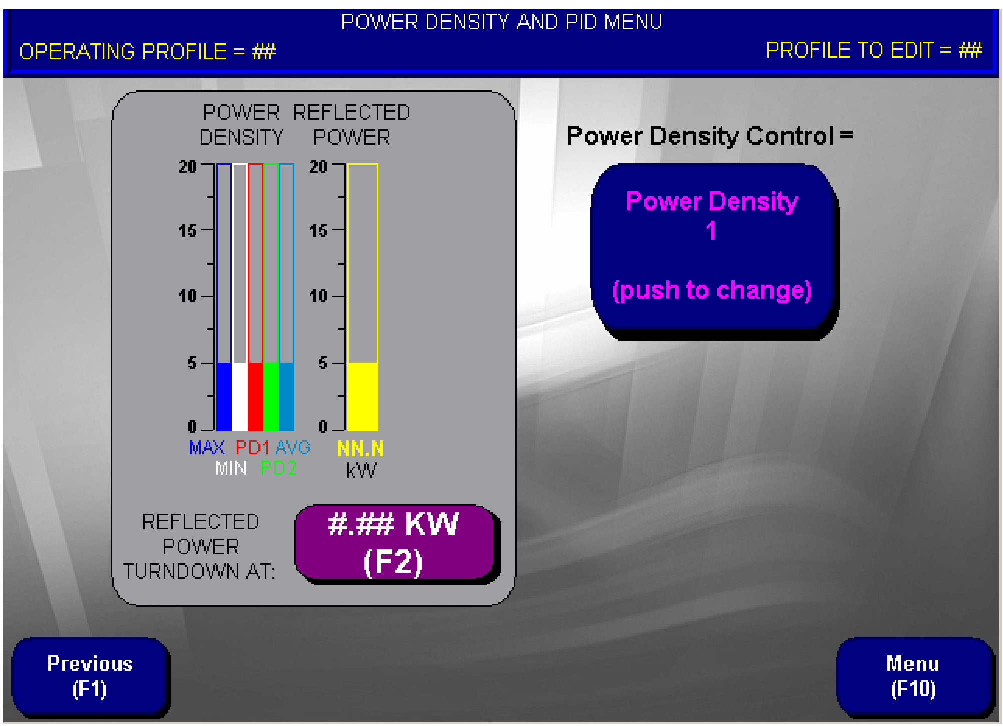
The Hour Meter Edit screen is a user editable screen as described above.



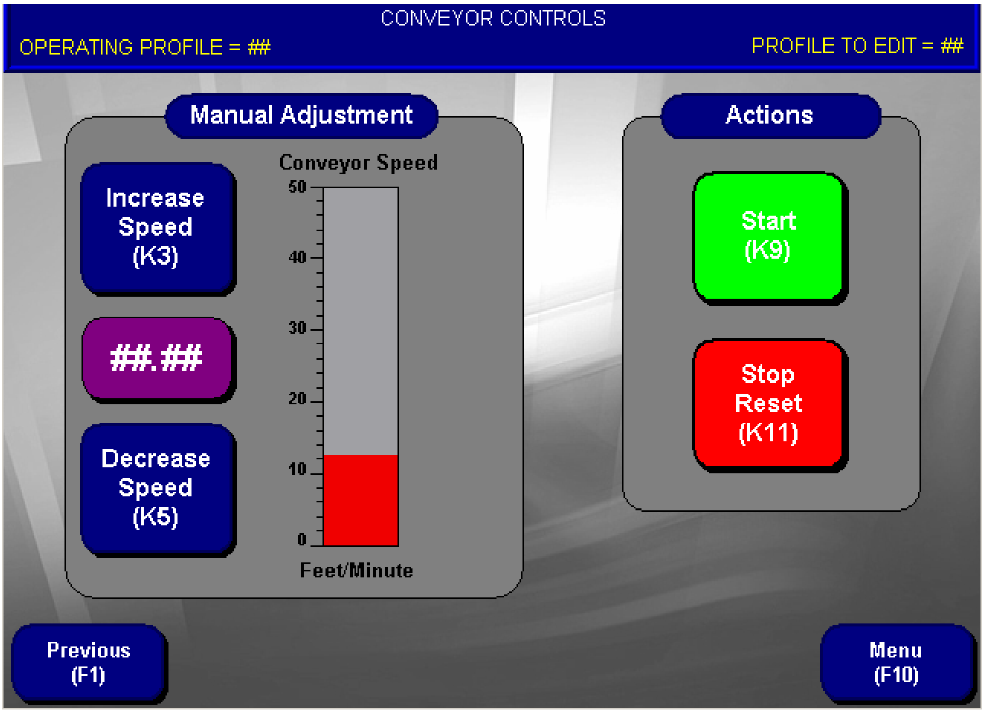
The Electronic Overload screen is used to test the arc and anode overload circuits.
The Electronic Overload can be also set to a desirable range using this screen.
The generator will still have its own preset overloads in case of a fault.



From the Cold Test screen, the Magnetron Filament button will allow high voltage to be brought on without the magnetron creating any power by keeping the filament switched off.



From the Power Density and PID Menu screen, the user can adjust how the generator will react to reflected power.



The Conveyor Controls screen is an optional feature.
If the system is connected to a conveyor, this screen will control the speed.

The Shutdown screen will show the remaining time for the shutdown process. It appears after the shutdown button is pressed when the generator has previously been running. The generator will count down for 5 minutes to complete the cool down cycles.

8.0) GENERAL DESCRIPTION OF THE CONVEYORIZED MW APPLICATOR AND CONVEYOR SYSTEM

The MW generator is connected to the Applicator Module (oven) with standard WR-975 Waveguide with EIA flanges.

The main conveyor carries the product through the MW applicator modules at the required drying speed.

Replaceable plastic belt slides are supplied for all belts, both internal and external of the applicator, to minimize belt contamination from metal surfaces.

The applicator is supplied with a special Attenuation Tunnel (Vestibule) with MW chokes on the input and exit end of the Main Conveyor.

One access door with window is installed in the front of the applicator.

8.1) CONVEYORIZED MW APPLICATOR

8.1.1) CONVEYOR SYSTEM SPECIFICATION

The conveyor is approximately 13’3” long x 4’ wide and carries the product through the module at the required drying speed. Removable and replaceable polypropylene (or Teflon) belt slides are utilized to prevent contamination of the belt. The belt does not move over metal surfaces.

8.1.2) LOAD SIZE

The conveyor system is designed to accommodate a 72” long microwave applicator compatible load and up to 2-3/8” inches high. The total height of the load and carriers, if any, combined is to be less than 2-3/8” inches.

The applicator is designed with a main conveyor belt speed of one (1) foot per minute to ten (10) feet per minute. The conveyor drive is controlled by an **Allen-Bradley PowerFlex** variable frequency drive unit. The conveyor drive VFD and the disconnect are located on the applicator. The conveyor VFD is networked with the main control panel.

The applicator is supplied with tunnels called *vestibules* located on the input and the exit of the applicator. The vestibules contain microwave chokes designed to suppress leakage of microwave energy through the openings for the conveyor.

The MW generator supplies the microwave energy to the applicator module by the means of a waveguide system. The location of the generator in relation to the applicator module shall determine the layout and length of the waveguide system. Additional waveguides may be purchased from Thermex Thermatron.

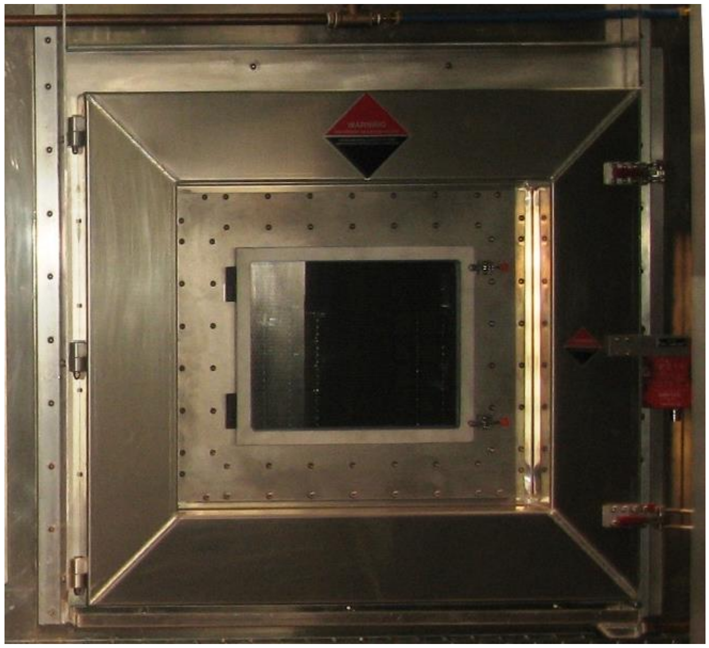
8.2) UTILITIES FOR THE APPLICATOR AND CONVEYOR SYSTEM

Power Input: 480 VAC, 3-phase, 60 Hz, and approximately 30 KVA

9.0) MULTIMODE MW APPLICATOR MODULE SPECIFICATION

9.1) APPLICATOR

The applicator is a Multimode MW Applicator Module approximately 6’ long and 5’6” wide and is provided one access door on the front of the applicator module.



The access door with observation wind is shown above.

Four (4) exhaust ports with honeycomb microwave chokes are provided in the ceiling of the applicator – one (1) exhaust port in each corner. Moisture or fumes may be exhausted through these vents. Make up air is drawn through the vestibules.

9.2) APPLICATOR LIGHTS

A light is provided in the applicator to improve the ability to visually monitor the drying process. The light is of a high intensity L.E.D. type.

10.0) CALIBRATION AND TROUBLESHOOTING

10.1) CALIBRATION SEQUENCE

Caution: This Calibration Sequence should only be performed by trained service technicians.

10.1.1) FILAMENT CURRENT

Be sure the anode breaker is turned OFF and that the high voltage safety interlocks are working properly. Opening the safety doors should trip the safety relay. The applicator safety relay will open contacts between 280 and 281. High voltage must be disabled before entering the magnetron compartment.

The filament current must be lowered automatically as microwave power output is increased due to the additional electron back bombardment of the filament as the microwave power output is increased. L3 Magnetrons operate from 110 Amps no-load to 69 amps at 100kW.

a. Perform a visual inspection of the filament circuit. Look for signs of over-heating, oxidation and poor connections on the filament leads from the transformer to the magnetron.
b. Verify that the displayed filament current on the PanelView matches a true RMS clamp-on current meter. When there is no anode current present, the filament current should be 110 amps true RMS current.
c. Adjust the PanelView calibration, as necessary.
d. The filament preset and actual bar graphs on the PanelView main screen should match. On the process values screen, the filament command should be less than 85 % so that the PLC has some reserve adjustment to accommodate for fluctuations for line voltage. The filament transformer may need to be re-tapped if the filament current is too low.

10.1.2) MAGNET CURRENT

The magnet current is decreased automatically from a starting value of 6.5-6.8 amps DC depending on the anode voltage level. A higher anode voltage will require a higher magnet current to block MW output power. The lower the magnet current the more microwave power output is. 100kW output will correspond to approximately 4.5 – 5.0 amps of magnet current depending on the anode voltage and the type of magnetron used. The internal resistance of the magnet increases as the magnet heats up requiring more voltage to maintain a constant magnet current.

- Make sure that when the microwave power is OFF, the magnet current is at the set point called for by the PLC of 6.5 amps or greater.
- Go to the process values screen and verify that the PLC magnet command is at a value of 60 - 80 %.
- The displayed magnet current on the PanelView should be the same as the DC voltage across R5.1 and R5.2 shunt resistors. This is measured at test point TP2. Calibrate the PanelView display as necessary.
- The displayed PanelView value should match the analog meter. Verify that meters are reading correctly.

10.1.3) ANODE CURRENT AND PROTECTIVE ANODE OVERLOAD DEVICE

Anode current increases as more microwave power is drawn from the power supply.

Step 1: Connect the anode current calibrator between cabinet ground and the positive side of the high voltage rectifier - Blue wire #150 or Test Point TP1. This will allow a substituted DC current to be passed through the anode current overload and metering circuit.

Step 2: Verify that the anode current displayed on the PanelView and the analog meter matches the reading on the current calibrator. Anode current will vary between 0 and 5.8 amps depending on microwave power output.

Step 3: If the current displayed on the PanelView is 5.0 amps, the voltage across the anode current shunt resistors should be 5.0 volts.

Check the operation of the anode overload relay.

- The overload trip should be set between 7.0 and 7.2 amps using the current calibrator. This relay is designed to detect short circuits.
- There is an electronic overload setting in the PLC. This setting should never be adjusted higher than 6.5 Amps.

10.1.4) ANODE VOLTAGE

Anode voltage for the 100kW magnetron is designed for 19,000 – 19,500 volts DC under full-load conditions. This voltage may be as high as 21,000 volts when not loaded.

Warning! Never hold the high voltage probe in hand or touch while voltage is present. Always lock out high voltage and verify that all components are discharged before installing the high voltage probe.

The anode voltage can be checked with a fluke high voltage probe. The voltage displayed by the PanelView should be calibrated to match the fluke measurements. Enter a set point of 0 Kilowatts for this calibration so that the voltage is not changing as the output power ramps up.

10.1.5) POWER OUTPUT AND CALORIMETER TEST

The generator can now be operated with a dummy load to perform calorimeter tests so that the transmitter efficiency can be set. Most magnetrons are between 88 – 90 percent efficient. The PLC uses the equation (Anode Voltage * Anode current) * Percent efficiency to calculate actual microwave power output.

- When 100 % power output is requested, the displayed power should now equal 100kW. Output power is equal to the calorimeter and reflected power added together.
- Adjust the efficiency as required to match the L3 Magnetron Specifications. Thermex recommends not adjusting the efficiency.
- If this test is skipped, set to 90 percent as per L3 Magnetron Specifications.
- The Calorimeter equation = (Outlet temperature F. – Inlet Temperature F.) * Water flow rate GPM * 0.1467.
- The output power should match the calorimeter plus reflected power unless the Microwave transmitter was not properly calibrated following the steps listed in this document.

10.1.6) RELFECTED MICROWAVE POWER

Reflected power is measured by the directional coupler and crystal diode.

If the sensor is installed in a section of waveguide located between the circulator and the dummy load in the microwave transmitter cabinet, a reflected power test plate must be installed between a wave guide section just outside of the generator to check calibration. The reflected power test plate will block the microwave energy. With the wave guide blocked, all generated microwave energy will be reflected back to the transmitter.

Step 1: If a directional coupler is installed between the circulator and the output of the generator, a test plate does not need to be installed. Reverse the Crystal diode with the 50ohm load on the directional coupler and it will now read forward power instead of reflected power.

Step 2: First, make sure the reflected power display is at zero. Adjust the zero pot on the analog meter if necessary.

Step 3: Operate the microwave generator at 10 KW output. The reflected power meter should also show 10 KW. If the test plate is used, all produced power will be reflected back from the test plate. If the directional coupler diode and resistor is reversed, it is now measuring the forward output power. For the electro-mechanical meter, adjust the reflected power calibration pot if necessary.

Step 4: Check the calibration on the PanelView. Increase or decrease the PanelView calibration as needed.

Step 5: Now check calibration at 10 KW. Re-calibrate for 10 KW. Next, try 15 KW, then 20 KW output. The generator should fault and automatically turn off the microwave power when the reflected power meter displays 20 KW reflected power.

Step 6: Reflected power into the Dummy load is also calculated by the (Outlet temp F.- Inlet temp F.) * GPM *0.1467 = Kilowatts. This is displayed by the Yellow bar graph and should be within 2 kilowatts of the Red bar graph indicating reflected power based on the directional coupler that is currently being calibrated.

Step 7: The microwave transmitter must not be operated if this interlock does not work.

10.1.7) ARC DETECTOR

Arcing in the waveguide can cause severe damage to the Microwave Transmitter.

- When the Microwave power is on, press the "Arc Detector Test" button. The Microwave Transmitter should fault out and automatically turn the Microwave power off.
- If this test fails, replace the photo-arc detector sensor.

10.1.8) NOTES ON THE MAGNETRON

10.1.8.1) Replacement

When replacing the magnetron, the mesh gasket should be replaced and the three mounting nuts should be hand tightened, then the nuts should be tightened 3/4th's of a turn with a wrench. They need to be tight but do not over-tighten. Periodically check tightness of the three nuts when performing preventative maintenance. The torque on each nut should now be 20 – 30 inch pounds. When the tube is operated with the dome down, the right anode coolant duct is "in" and the left anode coolant duct is "out".

The filament current should be on for 30 minutes to "season" a newly installed magnetron before microwave power is turned on. This will burn off any gas that may have formed within the vacuum of the magnetron due to shipping and shelf life.

See also Section 11.0 for more magnetron details.

10.1.8.2) Cooling System

The distilled water should be replaced every 12 months or every time the magnetron is replaced. **Use distilled water only. Do not use tap or spring water.**

Minimum Distilled Water Flow Rates:

Magnetron water flow =	4.0	GPM
Circulator water flow =	2.0	GPM
Magnet water flow =	0.75	GPM

Minimum Cabinet and Dummy Load (Plant Water) Water Flow Rate: 6 GPM

Magnetron water flow = 6.0 GPM

10.1.8.3) Troubleshooting Notes

The magnet current and filament current is automatically controlled by the PLC. The analog signals going into the PLC MUST BE PROPERLY CALIBRATED by the procedure listed above for proper operation. Calibration tools required are: DC current calibrator, Fluke True RMS multi-meter, High Voltage Probe, and a True RMS Clamp-on Current Meter.

The Magnet and Filament current must always match its set point called for by the PLC. The green bar on the PanelView is the set point given by the PLC. The yellow bar is the actual value and must match the green bar. If there is a deviation, there is either a problem with calibration or hardware.

No modifications to PLC Program is required, all calibration and troubleshooting can be accomplished with the provided PanelView screens and the above listed test equipment.

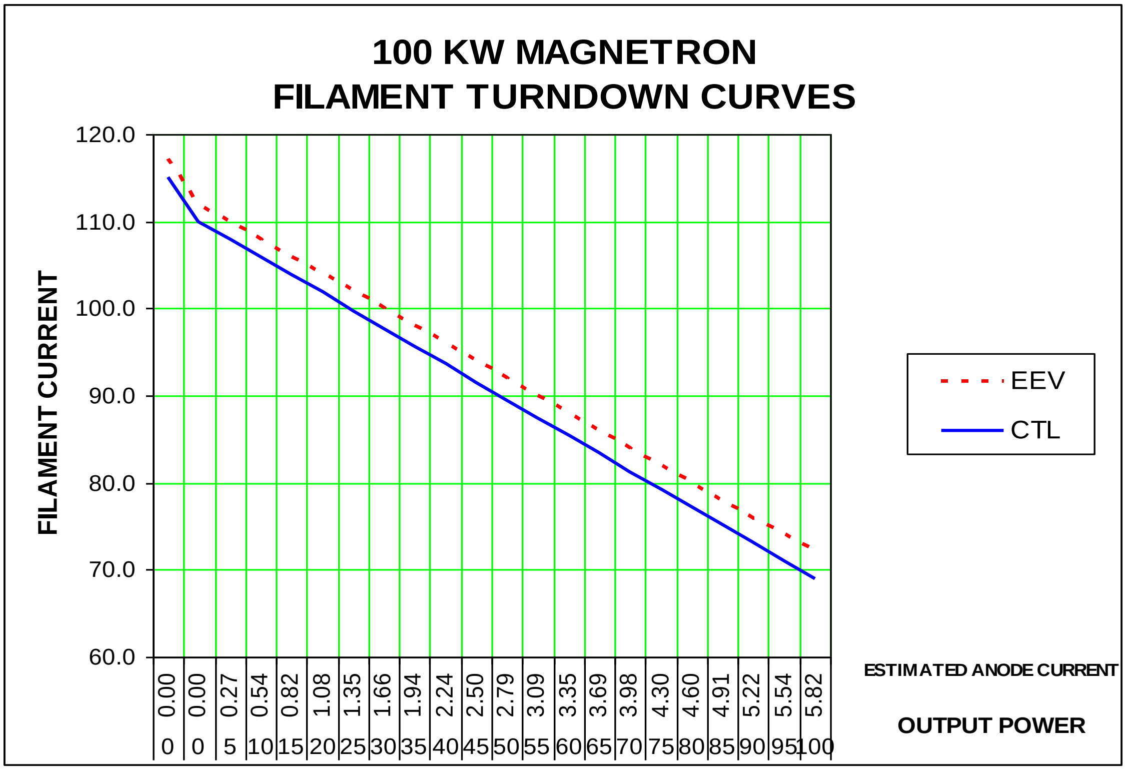
Modifications to the PLC program voids all warranties.

10.2) NEW MAGNETRON START UP AND FILAMENT TURNDOWN ADJUSTMENT PROCEDURE

After the installation of a new magnetron, the filament current and Anode voltage calibration must be verified to be correct. Anode Voltage is should be 19.5 – 21.5 KV unloaded and 17.5KV or greater at 100kW (see Section 9.1 for instructions). The new magnetron filament should be allowed to run for at least 30 minutes prior to applying high voltage. This will allow the filament to burn off possible gas build up within the vacuum tube that can occur during shelf life, rough handling, and from repeated arcing that can occur if the magnetron operating parameters are not correct.

Note: The magnet setting for “0” MW power is found on the “Advanced Settings and Fine Tune” PanelView screen. A change in anode voltage due to plant line voltage fluctuations or re-tapping the anode transformer will require adjustment to the magnet setting for “0” MW power. When high voltage is applied to the magnetron, the output power should be less than 2kW. If the MW power output is higher, then the magnet setting at zero kilowatts must be increased to effectively block MW power generation from the magnetron. If the magnet current is set too high, there could be a delay before microwave power ramps up.

Be sure to check the filament turndown settings found on the Advanced Settings and Fine Tune PanelView screen. The settings should match the default settings for the brand of magnetron being installed. For example: L3 default setting = 115, 110 and 69 amps.

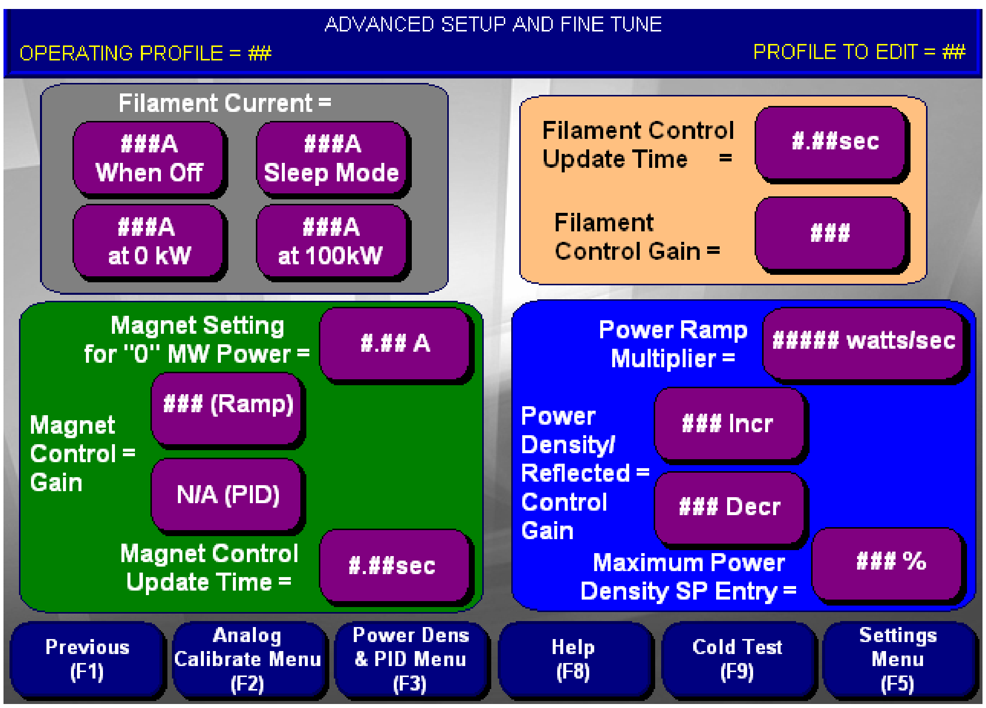


After the filament warm up period, high voltage can be applied with a power setting of zero kilowatts. An internal arc may occur inside the magnetron the first time high voltage is applied thus tripping the anode overload or the anode circuit breaker. Occasional magnetron arcing can be considered a normal occurrence. If the magnetron arcs off, restart the high voltage after five (5) minutes and leave the power setting at zero kilowatts for five (5) minutes before increasing power output. This is an important additional step that will help de-gas the magnetron. Newly installed magnetrons should have the MW power brought up slowly to properly “season” the magnetron. After high voltage is applied, increase the generator output power in increments of ten kilowatts. Stay at each power level increment for a minimum of five (5) minutes.

Filament Turndown Adjustment Procedure

Normal manufacturing variations between magnetrons may require that the filament turndown curve be adjusted and tailored to match the characteristics of each individual magnetron for optimum stability. The optimum magnetron filament turndown curve can vary significantly as they are custom made devices.

If the magnetron still trips the anode overload or the anode circuit breaker occasionally after performing the "seasoning procedure listed above", it may be necessary to adjust the filament turndown schedule. The filament turndown is automatically controlled by the PLC based on the three (3) filament turndown parameters entered in the Advanced Set Up and Fine Tune PanelView screen shown below:



MW Generator Advanced Setup and Fine Tune PanelView Screen.

Based on manufacturer's specifications, **L3 Magnetrons** are designed to operate at 115 amps with high voltage off, 110 amps at 0 kW and 69 amps at 100kW MW output. EEV magnetrons are designed to operate at 117 amps with high voltage off, 112 amps at 0 kW and 72 amps at 100kW MW output. Perform the following adjustments for optimum magnetron performance:

- If the magnetron trips immediately when high voltage is applied, try first increasing then decreasing the filament current preset with high voltage off. Range allowed by the PLC is 105-119.

- If the magnetron trips with output power settings below 50kW, try first decreasing then increasing the filament current preset for zero kilowatts in five (5) amp increments. Range allowed by the PLC is 95-117.

- If the magnetron trips with output power settings above 50kW, try first decreasing then increasing the filament current preset for 100kW in five (5) amp increments. Range allowed by the PLC is 65-80.

Try changing the above settings in five (5) amp increments. Adjust until the magnetron operation is stable with minimal arcing. Do not exceed more than a 15 Amps excursion from magnetron manufacturers recommended filament turndown settings to avoid possible damage to the magnetron.

10.3) SETTING UP POWER DENSITY SENSORS FOR LEAKY WAVEGUIDE APPLICATORS

10.3.1) POWER DENSITY SYSTEM OVERVIEW

This system monitors the microwave power density inside the applicator. The power density sensor is designed to control the microwave power delivered to the applicator based on the loading inside the applicator. In an empty applicator there is nothing to absorb the microwave energy. This condition will allow high circulating currents to be present inside the applicator and increase the possibility of arcing. If a product is placed inside the applicator and is receptive to microwave, the load absorbs the microwave energy and the circulating currents will decrease.

10.3.2) POWER DENSITY SIGNAL STRENGTH CALIBRATION PROCECURE

Thermex Thermatron has developed a procedure for calibrating the power density control system. The power density system will limit the power applied to an empty applicator to approximately 10 kW.

- Adjust the power density control to 24kW with a 3kW window so that the PLC does not drive the output power down while attempting to calibrate the system.

- If the PanelView does not accept 24kW, you may need to change the ”MAXIMUM POWER DENSITY SP ENTRY” to 24kW on the Advanced Settings and Fine Tune screen.
- Enter a microwave power set point of 10kW.
- Turn the microwave on to apply 10kW of microwave energy to the applicator that is being calibrated.
- Under Analog Calibration Menu, select the Power Density Calibrate Screen.
- The unscaled analog input is displayed in volts. Maximum analog card input is 10 volts DC. The unscaled analog input voltage should be 2.0 – 2.5 volts and is displayed on the PanelView screen. No voltmeter is required but may be handy when adjusting the input pot on the signal conditioner. Set the MW output to supply 10kW into the empty applicator then adjust the input pot on the signal conditioner as needed to obtain an un-scaled voltage of 2.5 volts.
- With the proper amount of signal into the PLC system, the power density signal can now be scaled by the PLC. Calibrate the power density signal to 7.5 % using the power density calibrate screen.
- Turn the microwave OFF and set the power density control setting to 11kW and a window of 3kW.
- If the ”MAXIMUM POWER DENSITY SP ENTRY” was altered in the Advanced Settings and Fine Tune screen for this calibration procedure, this must be reversed back to its original setting.
- Turn the microwave ON. The power density system is now calibrated and should be limiting the empty applicator power to about 10kW.

10.4) ANODE OVER CURRENT ALARM TROUBLE SHOOTING SUPPLEMENT

Anode over current can occur for a number of reasons. There are three different groups of potential problems that this alarm can be broken down into - high voltage power supply problem, calibration of magnetron control parameters, or a faulty magnetron.

If after several attempts at restarting the generator, the user will need to isolate portions of the generator to determine where the fault occurs.

Select the “COLD TEST” feature from the Advanced Settings and Fine Tune screen. When the filament is off, the magnetron will appear as an open circuit unless gas has formed inside the

Restart the generator. If the generator runs without anode overload, then the high voltage power supply should be adequate. See Section 9.6 for additional magnetron troubleshooting.

If the generator continues to trip out on anode over current or trips the anode breaker, the high voltage supply wire will have to be disconnected from the filament lead.

DANGER! The generator main disconnect should be locked out before entering the magnetron compartment.

Disconnect the high voltage lead from the filament transformer. Make sure that the lead is at least three (3) inches from ground potential. Restart the generator.

If the anode breaker still trips, see Section 9.6 regarding power supply troubleshooting.

If the anode does not trip, see Section 9.5 regarding magnetron troubleshooting.

10.5) MAGNETRON TROUBLESHOOTING

If the magnetron becomes unstable and arcs frequently during operation, gas can build up inside the magnetron. The magnetron may need to be left idle with the filament current only for approximately thirty minutes before attempting to restart high voltage. After the thirty minute “seasoning time”, the magnetron should be run with 0 microwave power output for an additional thirty. See Section 9.2 for additional magnetron procedure assistance.

If anode overload still occurs, replace the magnetron.

If anode overload occurs with a new magnetron, see calibration of magnetron control parameters.

10.6) POWER SUPPLY TROUBLESHOOTING

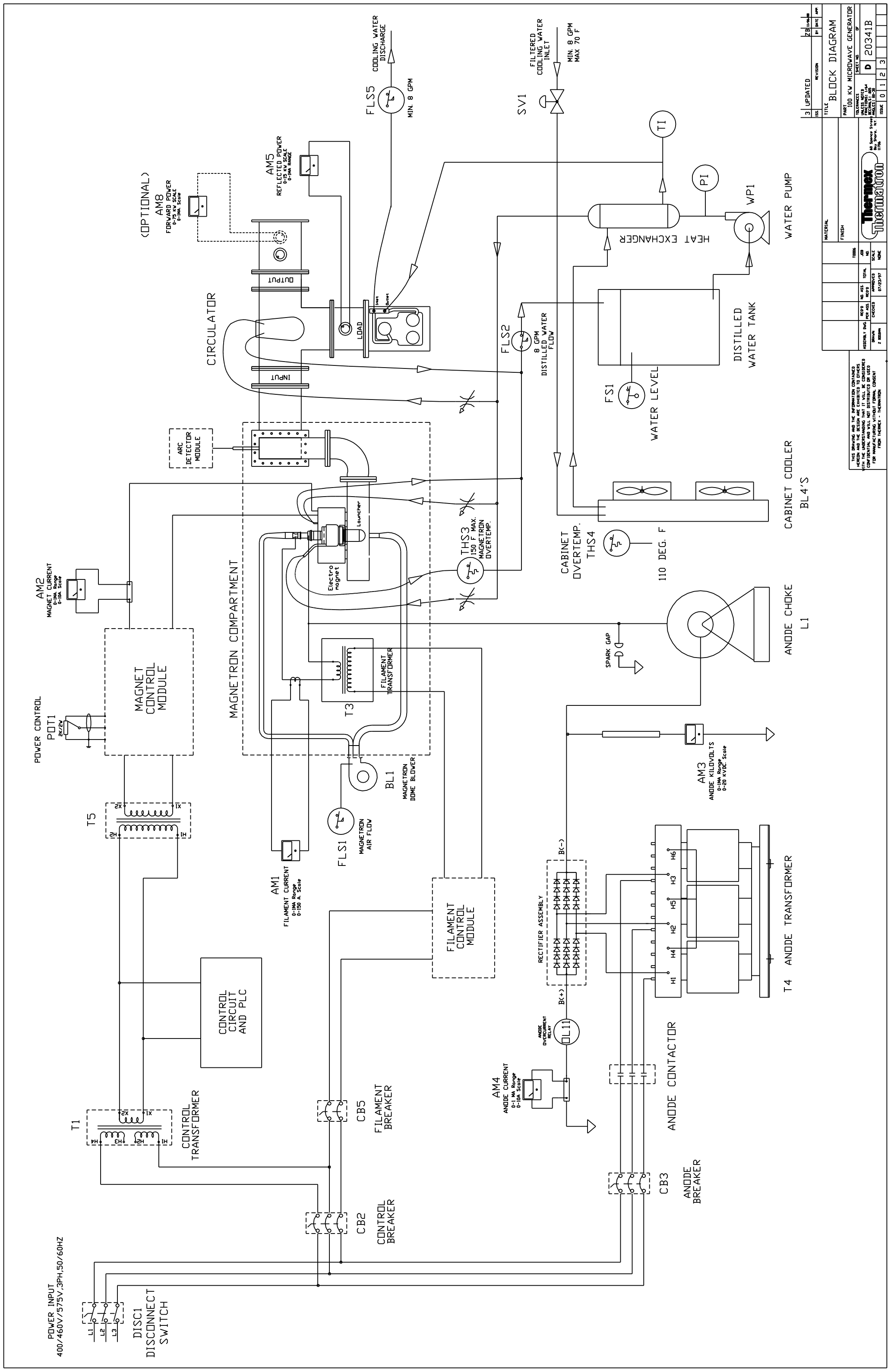
Danger! The generator main disconnect should be locked out before entering the magnetron compartment.

The high voltage power supply should be isolated from the magnetron compartment. Disconnect the high voltage lead from the filament transformer. Make sure that the lead is at least three (3) inches from ground potential. Restart the generator.

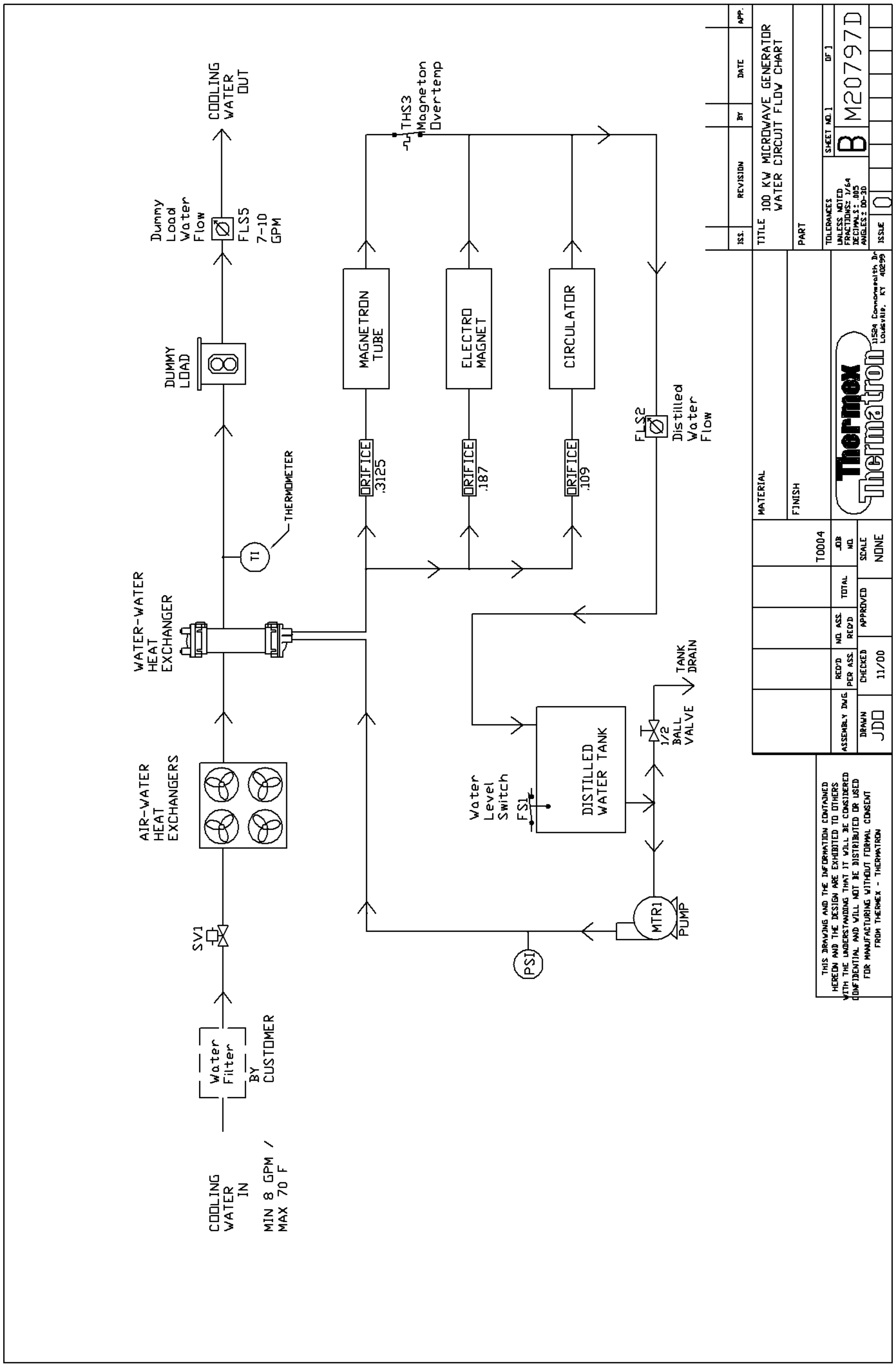
If an anode overload still occurs, investigate the anode choke, rectifiers, and B- wiring.

If anode breaker trips without the anode overload alarm, check the anode transformer, rectifiers, and snubber circuit

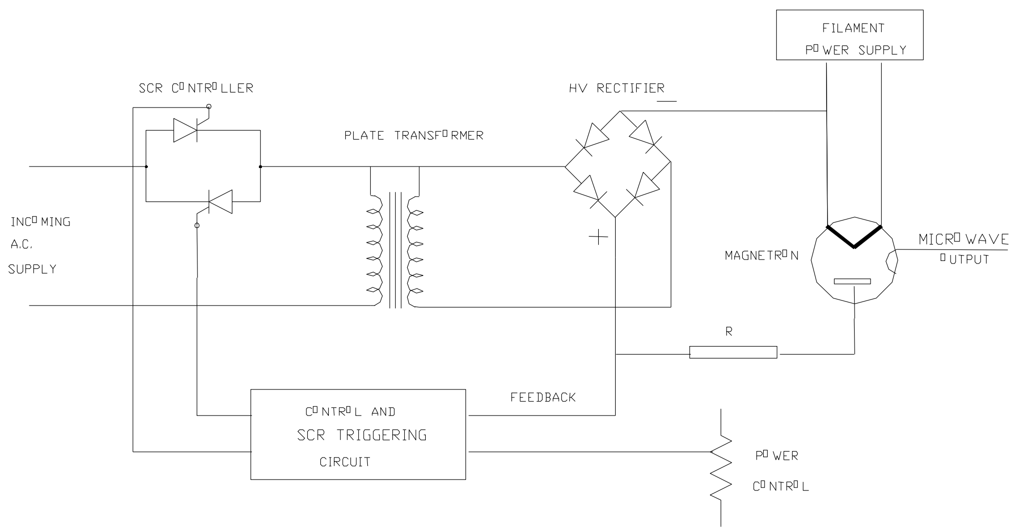
ATTACHMENT A: General Layout Diagram



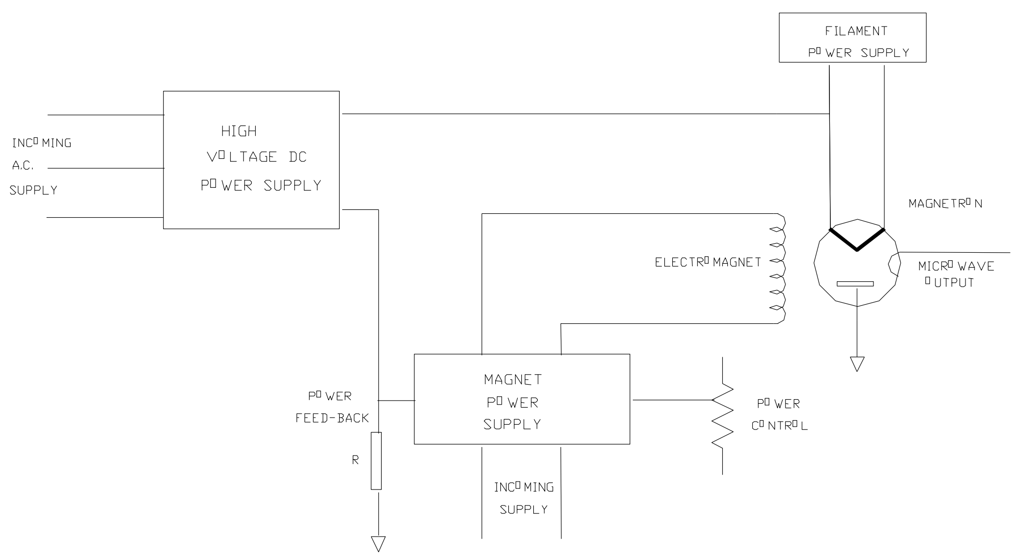
ATTACHMENT B: Water Circuit Flow Drawing P23409



ATTACHMENT C: Magnetron Circuit Diagrams



CIRCUIT DIAGRAM FOR A PERMANENT MAGNET TYPE MAGNETRON



CIRCUIT DIAGRAM FOR AN ELECTROMAGNET TYPE MAGNETRON

ATTACHMENT D: Replacement Parts

THERMEX THERMATRON, LP

10501 Bunsen Way, Suite 102
LOUISVILLE, KY 40299

Replacement Parts List No: E45623

Date 4 / 1 3 / 1 7

Assembly Name: 100KW MW GENERATOR AND LAB APPLICATOR

Job No: T1612 BUNKER HILL CHEESE

Ref No/Prod I	Product Description	Stock No:	Qty:	Unit Price	UM
6434	TUBE LAUNCHER AIR MANIFOLD	**T11-1090**	1	$20.13	EA
5504 AM1	METER, 0-1 MADC RANGE, 0-120 KW SCALE, 3-1/2" FACE PER DWG M30966	**T29-1036**	1	$180.00	EA
5170 ARC	ARC DETECTOR MODULE 24V	**T13-1001**	1	$231.56	EA
18175 BL1	BLOWER, HIGH PRESSURE, CENTRIFUGAL, 230 VOLT, 1 PHASE, 265CFM, 3450 RPM, 3.1 AMPS, 50/60HZ	**T26-1062**	1	$1,468.00	EA
23862 BL2	BLOWER, 230 VAC, 1 PHASE, 133 CFM WITH BALL BEARINGS (replaces 2C915)		1	$200.00	EA
677 BL3,5,6	FAN, SQUARE, AXIAL,6", 240V, 50/60Hz, 239CFM	**T26-1004**	1	$122.57	EA
395 BL4.1-4.4	HEAT EXCHANGER, COPPER TUBE, ALUMINUM FIN, FAN PLATE, .875 OD UNION	**T26-1002**	1	$3,250.80	EA
2055 BL4.1-4.4	FAN, 230VAC, 50/60HZ ,FOR HEAT EXCHANGER, PART# 100236-12	**T26-1027**	1	$130.13	EA
5167 CAP1.1-1.5	CAPACITOR, 1000 PF, 500V FEED THROUGH (150106-1)	**T15-8**	1	$9.92	EA
17964 CT1	UNIVERSAL VOLTAGE AND POSITIVE CURRENT TRANSDUCER	**T12-1244**	1	$210.72	EA
3048 D2	DIODE HOLDER, TYPE "N-MALE" TO "BNC-FEMALE", FREQUENCY RANGE 200 TO 4000MHZ	**T48-1003**	1	$219.20	EA
1008 D2	DIODE, MICROWAVE RECTIFICATION, CARTRIDGE TYPE, REVERSIBLE POLARITY, WITHOUT HOLDER	**T48-1005**	1	$75.00	EA
4471 H2-4	PILOT LIGHT, WHITE, 24VDC LED, 1NO & 1NC	**T39-1001**	1	$54.20	EA
4472 H5,7,8	PILOT LIGHT, RED, 24VDC LED 1 N.O. & 1 N.C.	**T39-1144**	1	$49.86	EA
4473 H9	PILOT LIGHT, GREEN 24VDC LED, 1 N.O.& 1 N.C. CONTACT, CHROME BEZEL	**T39-1145**	1	$54.20	EA
2216 HM	HOUR METER, NON-RESET, 10-80 VDC	**T22-1008**	1	$67.94	EA
5550 K4,6	RELAY, CONTROL. 2 N.O. & 2 N.C. 120V COIL 39mA	**T45-1047**	1	$21.92	EA

THERMEX THERMATRON, LP

10501 Bunsen Way, Suite 102
LOUISVILLE, KY 40299

Replacement Parts List No: E45623

Date 4/13/17

Assembly Name: 100KW MW GENERATOR AND LAB APPLICATOR

Job No: T1612 BUNKER HILL CHEESE

Ref No/Prod I	Product Description	Stock No:	Qty:	Unit Price	UM
806 K8-12,K15	RELAY, CONTROL, WITH 2 N.O. & 2 N.C. CONTACTS, 24 DC COIL	**T45-1037**	1	$29.78	EA
4305 KM1	OVERLOAD UNIT FOR CONTACTOR, 1 N.O. 1 N.C. 4 TO 6 AMPS	**T46-1058**	1	$37.16	EA
4296 KM1-3	CONTACTOR, 3 POLE, 12 AMP, W/ 24VDC COIL	**T46-1066**	1	$79.66	EA
4292 KM4	CONTACTOR, 3 POLE, INDUCTIVE 65 A /RESISTIVE 80A 110 V.,50/60 HZ (AUX. CONTACTS 1NO-1NC)	**T46-1054**	1	$237.60	EA
4294 KM5	CONTACTOR, 3 POLE, 270 AMP, 50/60 HZ, 110 VAC COIL	**T46-1055**	1	$574.88	EA
7508 KM5	NOISE SUPPRESSOR, FOR LC1F CONTACTOR, SNAP IN WITH LEADS	**T46-1093**	1	$14.18	EA
3054 L2	ELECTRO-MAGNET FOR 100KW OR 75KW MAGNETRON	**T56-52A**	1	$3,171.00	EA
6759 LS11,12	SAFETY LIMIT SWITCH, 1 N.O., 3 N.C., DOUBLE BREAKING (082123) (NEEDS ID # 7071 ADAPTOR WHEN ORDERING THIS PART!)	**T51-1167**	1	$179.41	EA
2135 LS11,12	ACTUATOR, FLEXIBLE, RIGHT	**T63-1007**	1	$65.77	EA
675 MTR1	PUMP, BRONZE TURBINE, 1-1/2 HP, 208-230/460, 3 PHASE, 130 PSI MAX	**T35-1068**	1	$1,926.40	EA
20234 PLC	PLC, COMPACT LOGIX, PROCESSOR, ENET, 16 D24 IN, 16 D24 OUT, 4/2 ANALOG I/O, & HS COUNTERS, 512 MB MEMORY	**T40-1346**	1	$3,734.00	EA
6019 PLC	PLC COMPACT LOGIX, INPUT MODULE, 24VDC 16 POINT	**T40-1087**	1	$215.94	EA
17622 PLC	PLC COMPACT LOGIX, FAST ANALOG INPUT/OUTPUT MODULE, 4IN, 2OUT	**T40-1242**	1	$917.48	EA
3143 PLUG	PLUG, BULKHEAD HOUSING, 24 PIN, END CLIP	**T21-1080**	1	$38.32	EA
3144 PLUG	PLUG, INSERT, 24 PIN, FEMALE, SCREW TERMINALS	**T21-1079**	1	$36.30	EA
3147 PLUG	PLUG, BULKHEAD HOUSING, 10 PIN, END CLIP, 2 LEVER, FOR USE W/SIDE PIN HOUSINGS	**T21-1180**	1	$33.64	EA
3149 PLUG	PLUG, INSERT, 10 PIN, MALE, SCREW TERMINALS	**T21-1181**	1	$25.64	EA
21673 PS1	POWER SUPPLY, 120V/230VAC TO 24VDC 10 AMP, DIN RAIL MT.	**T40-1385**	1	$330.00	EA

THERMEX THERMATRON, LP

10501 Bunsen Way, Suite 102
LOUISVILLE, KY 40299

Replacement Parts List No: E45623

Date 4 / 1 3 / 1 7

Assembly Name: 100KW MW GENERATOR AND LAB APPLICATOR

Job No: T1612 BUNKER HILL CHEESE

Ref No/Prod I	*Product Description*	*Stock No:*	*Qty:*	*Unit Price*	*UM*
20389 PS2	POWER SUPPLY, 24VDC, 3.3AMP, 120/240VAC INPUT	**T40-1388**	1	$129.00	EA
17971 Q1	DISCONNECT, 250A, 100KV INTERUPT, NEMA 12 ENCLOSURE INCLUDED	**T52-1332**	1	$2,062.50	EA
17477 Q10,11	CIRCUIT BREAKER, 1 POLE, 10 AMP, D CURVE old style , please use id# 21704	**T52-1311**	1	$18.00	EA
4319 Q2	CIRCUIT BREAKER, 3 POLE, 225 AMP, 480 VAC	**T52-1059**	1	$1,448.54	EA
4320 Q3	CIRCUIT BREAKER, 3 POLE, 25 AMP	**T52-1066**	1	$299.58	EA
17026 Q4	CIRCUIT BREAKER, 3 POLE, 6 AMP, D-CURVE	**T52-1287**	1	$49.00	EA
17635 Q4,8	CIRCUIT BREAKER, AUX CONTACT, 1NO,1NC	**T52-1328**	1	$49.00	EA
16409 Q5	CIRCUIT BREAKER, 2 POLE, 8 AMP, DCURVE	**T52-1295**	1	$36.00	EA
17476 Q6	CIRCUIT BREAKER, 2 POLE, 6 AMP, D-CURVE	**T52-1312**	1	$36.00	EA
17802 Q7,8	CIRCUIT BREAKER, 2 POLE 10 AMP, D-CURVE	**T52-1317**	1	$36.00	EA
1275 R1'S	RESISTOR, 5 OHM, 225 WATT	**T47-79A**	1	$30.50	EA
19393 R2	COILED COIL ASSEMBLY, 82 FT. WIRE, 10 1/2 TURNS, FOR 100 KW. MW	**T47-1203**	1	$390.00	EA
9300 R6	RESISTOR, 1 OHM, 250 WATT NON INDUCTIVE STYLE	**T47-1135**	1	$108.86	EA
17893 REC 1	RECTIFIER ASSEMBLY- POLYPHASE, 21 KVDC, FOR UPTO 100kW GENERATORS (DO NOT USE OR SELL) SEE ID# 24389	**T48-1150**	1	$2,505.83	EA
18938 RPCN	CONDITIIONER NETWORK, REFLECTED POWER, 0-10V	**T12-1240**	1	$104.00	EA
19494 S1	CONTACT BLOCK, 1 N.C.	**T46-1143**	1	$5.64	EA
9320 S10,14	LIMIT SWITCH, SPDT, MINATURE, METAL BRACKET, 8-32 THREADED ACTUATOR PLUNGER TYPE	**510200**	1	$76.22	EA
1274 S15	LEVEL SWITCH, FLOAT TYPE, STAINLESS STEEL, 3/8 THREAD	**T51-97A**	1	$95.86	EA

THERMEX THERMATRON, LP

10501 Bunsen Way, Suite 102
LOUISVILLE, KY 40299

Replacement Parts List No: E45623

Date 4 / 1 3 / 1 7

Assembly Name: 100KW MW GENERATOR AND LAB APPLICATOR

Job No: T1612 **BUNKER HILL CHEESE**

Ref No/Prod I		Product Description	Stock No:	Qty:	Unit Price	UM
S16	2036	TEMPERATURE SWITCH, MODEL C-1S, 25-225 F., 5" PROBE, 1/2" NPT BUSHING, 50-500F ADJUSTABLE CALIBRATE AT 130 F	T51-1025	1	$496.38	EA
S17	687	TEMPERATURE SWITCH, ADJUST TEMPERATURE, SNAP DISC CONTROL, SPST, OPEN ON RISE 135-175 DEG F,	T51-1068	1	$96.20	EA
S18	361	FLOW SWITCH, MULTI-PURPOSE, SPDT, CONTROL RANGE, 0.05" TO 12" WC, 0.05" TO 12" WC	T51-82A	1	$76.18	EA
S2,4,5	4726	PUSH BUTTON, FLUSH HEAD, BLACK, 1 N.O. CONTACT	T51-1045	1	$16.10	EA
S9	4390	KEYSWITCH, 2 POS. MAINTAINED 1 N.O. 2 POS KEY REMOVAL	T51-1041	1	$56.02	EA
SR1,SR2	16217	SAFETY RELAY, 24VDC COIL, 6 N/O, 2 N/C	T45-1098	1	$242.30	EA
T1	20437	TRANSFORMER, 3 KVA, 60 Hz, 240x480 Primary, 120/240 Secondary, Open-Style	T56-1275	1	$1,200.00	EA
T2	16951	TRANSFORMER, 1KVA, 277V PRIMARY, 115V SECONDARY	T56-1240	1	$455.92	EA
T3	2050	TRANSFORMER, FILAMENT, 13 V @ 115A, 1.6KVA, SINGLE PHASE, 50/60HZ. PER THERMEX SPECIFICATION NOTF13X115 (REPLACED BY TF13X115U)	T56-1010	1	$1,374.45	EA
T4	20239	TRANSFORMER, ANODE, POLYPHASE, 120KVA, PRI: 3 PHASE, 440/480/520 VAC, 60HZ SEC: 21KVDC 11-12% IMPEDANCE	T56-1280	1	$17,922.00	EA
T5	5240	CURRENT TRANSFORMER, (DONUT) SUPPORT	T11-1075	1	$130.00	EA
T5	1295	CURRENT TRANSFORMER, (DONUT), 150 AMP. RANGE, 5 AMP SECONDARY, 2 VA.	T56-86F	1	$61.46	EA
TERM	1475	DIN RAIL, HI-RISE SYM. DIM (ALUMINUM), 39.37" L	T21-1173	1	$22.80	EA
TERM	17222	TERMINAL BLOCK, 600VAC, DUAL LEVEL BEIGE, NEW	T21-1012	1	$3.04	EA
TERM	17224	JUMPER, 300VAC, 2 POSITION, BEIGE, SCREW IN	T21-1078	1	$0.80	EA
V1	1500	MAGNETRON SOCKET FABRICATED PER THERMEX SPECIFICATION, LOWER POLEPIECE	T57-33	1	$208.60	EA
V1	1875	GASKET, FOR 75/100 KW MAGNETRON TUBE, MESH MATERIAL	T57-22	1	$56.00	EA
V1	2038	MAGNETRON, 100 KW 915 MHZ., CAL (Replaces T57-61)	T57-1000	1	$10,725.00	EA

THERMEX THERMATRON, LP

10501 Bunsen Way, Suite 102
LOUISVILLE, KY 40299

Replacement Parts List No: E45623

Date 4 / 1 3 / 1 7

Assembly Name: 100KW MW GENERATOR AND LAB APPLICATOR

Job No: T1612 BUNKER HILL CHEESE

Ref No/Prod ID	*Product Description*	*Stock No:*	*Qty:*	*Unit Price*	*UM*
929 WIRE	CABLE, HIGH VOLTAGE, 60 KVDC, 12 GA, SILICONE INSULATION, 0.38 DIA. per foot	**T21-1068**	1	$22.03	FT

TOTAL REPLACEMENT PARTS = $59,194.22

NOTE: PRICES ARE SUBJECT TO CHANGE WITHOUT NOTICE!

ATTACHMENT E: Spare Parts

THERMEX THERMATRON, LP
10501 Bunsen Way, Suite 102
Louisville, KY 40299

Spare Parts List No: E45623

Assembly Name: 100KW MW GENERATOR AND LAB APPLICATOR

Job No: T1612 BUNKER HILL CHEESE

Ref No/Prod I	*Product Description*	*Stock No:*	*Qty:*	*Unit Price*	*UM*
5170 ARC	ARC DETECTOR MODULE 24V	**T13-1001**	1	$231.56	EA
5167 CAP1.1-1.5	CAPACITOR, 1000 PF, 500V FEED THROUGH (150106-1)	**T15-8**	1	$9.92	EA
17964 CT1	UNIVERSAL VOLTAGE AND POSITIVE CURRENT TRANSDUCER	**T12-1244**	1	$210.72	EA
3048 D2	DIODE HOLDER, TYPE "N-MALE" TO "BNC-FEMALE", FREQUENCY RANGE 200 TO 4000MHZ	**T48-1003**	1	$219.20	EA
10144 IOL11	OVERLOAD RELAY ASSEMBLY, SOLID STATE	**T12-1080**	1	$535.10	EA
3054 L2	ELECTRO-MAGNET FOR 100KW OR 75KW MAGNETRON	**T56-52A**	1	$3,211.75	EA
675 MTR1	PUMP, BRONZE TURBINE, 1-1/2 HP, 208-230/460, 3 PHASE, 130 PSI MAX	**T35-1068**	1	$1,926.40	EA
21673 PS1	POWER SUPPLY, 120V/230VAC TO 24VDC 10 AMP, DIN RAIL MT.	**T40-1385**	1	$330.00	EA
19393 R2	COILED COIL ASSEMBLY, 82 FT. WIRE, 10 1/2 TURNS, FOR 100 KW. MW	**T47-1203**	1	$390.00	EA
17893 REC 1	RECTIFIER ASSEMBLY- POLYPHASE, 21 KVDC, FOR UPTO 100kW GENERATORS (DO NOT USE OR SELL) SEE ID# 24389	**T48-1150**	1	$2,505.83	EA
18938 RPCN	CONDITIIONER NETWORK, REFLECTED POWER, 0-10V	**T12-1240**	1	$104.00	EA
1295 T5	CURRENT TRANSFORMER, (DONUT), 150 AMP. RANGE, 5 AMP SECONDARY, 2 VA.	**T56-86F**	1	$61.46	EA
1875 V1	GASKET, FOR 75/100 KW MAGNETRON TUBE, MESH MATERIAL	**T57-22**	1	$56.00	EA
2038 V1	MAGNETRON, 100 KW 915 MHZ., CAL (Replaces T57-61)	**T57-1000**	1	$10,725.00	EA

TOTAL SPARE PARTS = $20,516.94

NOTE: PRICES ARE SUBJECT TO CHANGE WITHOUT NOTICE!

NOTES