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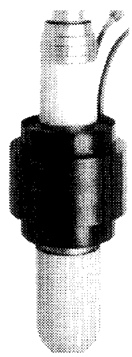
TP-116
Large Power Magnetrons

Application Note



Application Guide For BURLE Large Power Magnetrons

BURLE magnetrons are built to generate tens of kilowatts of cw power at 915 MHz (896 MHz in the U.K.) in industrial heating processes. With careful control during operation, the tubes will give highly reliable service for thousands of operating hours. As magnetron power loading increases, operating procedures and tube protection techniques become increasingly critical. Close attention to the installation, operation and protection procedures described in this technical note will assure longer tube life, less down time, and fewer tube handling accidents.

BURLE Electron Tubes

Contents: Page

Personnel Safety

Warning - Personal Safety Hazards

Electrical Shock - Operating voltages applied to these devices present an electrical shock hazard.

RF Radiation - In operation, these devices produce RF radiation which may be harmful to personnel.

High Voltage Protection

Large power magnetrons require mechanical protective devices such as interlocks, relays, and circuit breakers. Circuit breakers alone may not provide adequate protection when the power-supply filter stores high energy.

Additional protection may be achieved by the use of high-speed electronic circuits to bypass the fault current until mechanical circuit breakers are opened. These circuits may employ a controlled gas tube, such as a thyratron or ignitron, to handle the required energy.

Great care should be taken during the adjustment of circuits. The tube and its associated apparatus, especially those parts which are at high voltage from ground, should be housed in a protective enclosure. The protective housing should be designed with interlocks so that personnel cannot possibly come in contact with high voltage. The interlock devices should function to break the primary circuit of the high voltage supplies and to discharge high voltage capacitors when any gate or door on the protective enclosure is opened. The interlocks should prevent the activation of the primary circuit until enclosure doors are again closed.

RF Radiation

The equipment designer, the equipment assembler and the equipment operator must be careful to assure that the RF seals located between the tube's RF Output Terminal Contact Surface (see Dimensional Outline) and Waveguide Transition, between waveguide flanges, between the pole piece in the electromagnet assembly and the Waveguide Transition, and between the waveguide and the RF probes are adequate to limit the RF leakage radiation to safe values.

Magnetron Protection

BURLE large power magnetrons are designed and built to give long, trouble-free service when operated properly. Proper operation starts with the incorporation of protective devices in the operating system. These precautions must be observed:

1. Do NOT apply filament power unless recommended amounts of water and air for cooling the tube are flowing. Designers should incorporate "underflow' protection in the filament circuit.
2. Follow the recommendations under "Filament" in applying filament power.
3. Do NOT energize the electromagnet unless the recommended amount of cooling water is flowing. "Underflow" protection should be incorporated in the electromagnet power supply circuit.
4. Atime-delay relay should be incorporated in the high voltage circuit to prevent the application of high voltage until the filament has had time to stabilize at its normal operating temperature.
5. Do NOT apply high voltage unless electromagnet current is high enough to keep magnetron plate current cut-off. The high voltage supply should be interlocked with respect to electromagnet cut off current.
6. Do NOT apply high voltage unless recommended amounts of water and air for cooling the tube are flowing. Designers should incorporate "underflow" protection in the high voltage circuit.
7. Protective circuits must de-energize plate voltage under these circumstances:
   a. Electromagnet current drops below the value needed to sustain π mode oscillation (see "π Mode" below).
   b. Plate current exceeds normal range.
   c. Internal tube arcing.
   d. Reflected power exceeds 5.0 kW.
   e. Air and/or water cooling drop below specified minimums.
8. The impedance of the high voltage power supply must restrict peak short-circuit current to 24 amperes maximum.

Magnetron Design

BURLE magnetrons are designed and built with 10 internal anode vanes in a double-ring-strapped anode block configuration. The fundamental magnetron operating resonance occurs when the slots between anode vanes appear as shorted 1/4 wave strip-line resonators.[1] Oscillation at the fundamental resonance is known as π mode oscillation from the π phase RF voltage difference between adjacent resonators. Other RF

1. For fuller discussion of magnetron operating characteristics, see:

   A.C. Metaxas and R.J. Meredith, INDUSTRIAL MICROWAVE HEATING, Peter Peregrinus Ltd., London (1983).

   George B. Collins, editor, MICROWAVE MAGNETRONS, MIT Rad. Lab. Series, McGraw Hill, New York (1948).

modes can exist in the magnetron interaction space, but only the π -1 mode, the next higher in oscillation frequency, is of any practical concern in large power magnetron operation. Large power magnetrons are optimized for oscillation in the π mode; waveguides, loads, and all circuit components should be matched for operation at π mode frequency.

The double-ring-strapped anode block design minimizes anode block size with respect to π mode wavelength and keeps π -1 mode oscillations well-separated in frequency from π mode oscillations. Wide frequency separation between π and π -1 modes minimizes the possibility of a magnetron jumping from π mode to π -1 mode oscillation during operation, thereby risking irreversible tube damage.

Magnetron Operating Conditions

Cooling

The external temperature of various parts of the operating magnetron must not exceed the values specified in the tube data sheet. Apply a safety factor to these temperatures to allow for all probable system and component variations throughout the magnetron's operating life.

Liquid Cooling -- Start liquid coolant flow before applying any voltages to the magnetron and, when possible, continue the flow for several minutes after removal of the voltages. Interlock liquid flow with power supplies to prevent magnetron damage in case of inadequate liquid flow. When water is the coolant, use distilled or filtered deionized water to prevent system contamination or corrosion. See "Application Guide for BURLE Power Tubes," TP-105, for further information necessary to the satisfactory operation of liquid cooling systems.

Air Cooling - The magnetron's output dome ceramic and filament stem ceramic require forced-air cooling. A short, straight manifold built in the wave guide transition directs cooling air at the ceramic dome. The standard filament connector incorporates a manifold to direct air cooling at the filament stem ceramic. Start air flow before applying tube voltages, and, when possible, continue the cooling for several minutes after removal of the voltages, Interlock air flow with the power supplies to prevent tube damage in case of air-flow failure. For further information on air cooling, see "Application Guide for Forced-Air Cooling of BURLE Power Tubes, TP-118.

Filament

The filament in each BURLE large power magnetron is a spiral-wound, vertically-mounted tungsten wire designed to give ample electron emission for tube operation when heated to its normal operating temperature. If filament temperature drops too low during magnetron operation, insufficient electron current will be available in the tube to support normal π mode oscillation. In that case, the tube may drop out of oscillation or may "mode", that is, jump to π -1 mode oscillation. Just a few seconds of operation in the π -1 mode may be enough to cause permanent magnetron damage. See sections on " π Mode" and " π -1 Mode" for further discussion. If thefilament is operated too hot, excessive tungsten evaporation and filament sagging will greatly reduce tube life. Therefore, close control of filament temperature is critical to long magnetron life.

For BURLE large power magnetrons, the filament power supply must be adequate to deliver a constant 120 amperes at 13.0 volts. Although a completely variable supply with variable transformer or solid-state control gives the greatest operating flexibility, a programmed supply with two or more increasing voltage steps can "power up" the filament in preparation for tube operation. The first step of a two-step supply should result in stabilized filament current between 65 and 70 amperes. Hold the current at that level for at least two minutes before proceeding to the second, full current, step. Never exceed "maximum starting current" listed in the tube bulletin of the magnetron in use. To assure stable, uniform filament temperature, operate the filament at full current for at least 2 1/2 minutes before applying anode voltage.

When magnetron oscillation begins (see " π Mode"), filament temperature increases above that resulting from filament input power only. Back-bombardment of the filament by electrons out-of-phase with the tube's RF field causes the added temperature rise, but the amount of heating cannot be measured directly. The filament supply must be capable of reducing filament current to compensate for the heating caused by electron back-bombardment. The reduction in filament power should preferably begin when anode current begins and should vary proportionately to anode input power.

The supply must have the capability of adjusting filament power to within +50 watts/-0 watts of power needed to run the filament at its designed temperature. Because back-heating differs from tube-to-tube and varies for an individual tube with changes in anode current and in VSWR, an adjustable filament power control circuit is required, especially for the higher power magnetrons.

Because filament temperature cannot be measured directly, the only reliable indicator of filament temperature is "hot filament resistance". With filament operation stabilized at the current specified in the tube's bulletin and with no anode voltage applied, calculate hot filament resistance as follows: divide measured filament voltage by filament current. Now, with the magnetron oscillating at the desired output, adjust filament input power until hot filament resistance of the oscillating tube equals hot filament resistance measured initially for the tube not oscillating. When hot filament resistance of the oscillating tube equals initial hot filament resistance, the filament of the oscillating tube is operating correctly at its designed temperature.

Ideally, filament metering consists of a voltmeter connected directly across the filament connectors and a current transformer and ammeter in series with the filament. Both meters should be well shielded and RF by-passed. If safety considerations or high voltage isolation problems make such metering impractical, acceptable alternates are a voltmeter and ammeter permanently connected in the primary side of the filament isolation transformer and temporary meters in the secondary of the filament transformer. The temporary meters are used ONLY when the tube is initially set up and NO HIGH VOLTAGE is applied. The temporary meters are used to establish correlation between secondary current and voltage readings and primary current and voltage readings. Temporary secondary metering MUST BE REMOVED before high voltage is applied to the magnetron.

Magnetic Field

Operation of a BURLE large power magnetron requires a uniform magnetic field coincident with the vertical axis of the tube. High voltage should NEVER be applied to the tube until electromagnet current establishes a stable magnetic field high enough to keep anode current cut-off. Refer to the appropriate tube bulletin for a curve showing the magnetron's cutoff characteristics. For those bulletins with a graph showing typical RF mode characteristics, tube cut-off lies to the right of the π mode threshold.

While anode voltage is applied to a large power magnetron, electromagnet current should never fall below the threshold for π-1 mode operation of the magnetron. Provide electromagnet undercurrent protection to immediately remove anode voltage as protection against this cause of magnetron failure. See "Suppressing π -1 Mode" for further discussion.

Separately Excited Electromagnet -- With a separately excited electromagnet, reasonably good magnetron operating stability is achieved when both anode power supply and electromagnet power supply have about the same line regulation characteristics. In this circumstance, fluctuations in the electromagnet current will be of approximately the right magnitude and in the right direction to compensate for fluctuations in anode voltage.

For example, consider a case where initial 8684 magnetron operating conditions are: No-Load Anode Voltage, 13 kV; Full Power Anode Voltage, 11.8 kV; and Electromagnet Current (full power), 3.0 A. Under these conditions, the magnetron operating load line is identified as Load Line A in **Figure 1** and RF output at full power is 25 kW. Now, assume that line voltage decreases and, consequently, no-load anode voltage decreases 5% to 12.35 kV. The new load line resulting from the voltage drop is shown by Load Line B.

For an electromagnet power supply with similar line regulating characteristics, electromagnet current will drop 5% to 2.85 A. The new operating point given by the intersection of the short, dashed 2.85 A constant electromagnet curve with Load Line B shows that the RF power output will drop only 2.5 kW to about 22.5 kW. A well-regulated electromagnet power supply would have reduced RF power output to about 16 kW, shown by the intersection of the 3.0 A constant electromagnet current curve and Load Line B.

Series Excited Electromagnet -- The sensitivity of RF output to line voltage variations may be further minimized by connecting the electromagnet in series with the magnetron as shown in the 8684 Data Sheet. In this configuration, the magnetron's anode current provides much of the electromagnet excitation, the remaining excitation coming from an auxiliary supply shunted across the electromagnet. It is recommended that the series-connected circuit be restricted to applications of not more than 30 kW output because of the tendency of higher-powered, series-connected magnetrons to begin oscillations in the π -1 mode when "keyed on" after a momentary trip-out.

The regulating characteristics of the series circuit is illustrated by an example with these initial operating conditions: No-Load Anode Voltage, 13.0 kV; Anode Voltage (full Power), 11.8 kV; Electromagnet Current (full power), 3.0 A; Anode Current, 2.46 A; and Auxiliary Electromagnet Power Supply Current, 0.54 A. The load line for these operating conditions is shown as Load Line A in **Figure 2.** At the full power operating point, the RF power output is 25 kW.

Now, assume the no-load anode voltage drops from 13.0 kV to 12.35 kV and the active load line shifts to Load Line B as the result of **a** line voltage drop. The operating point on the new load line can be identified by the intersection of the electromagnet current curve with the new load line. In the series electromagnet circuit, however, the electromagnet current is not constant as before. If we assume that the output of the auxiliary supply is approximately constant at 0.54 A and remembering the electromagnet current is the sum of anode current and auxiliary supply, the electromagnet current curve versus anode current for this example is shown in **Figure** 2. The intersection of the load line with the electromagnet current curve gives an indicated RF power output of approximately 22.5 kW. Moreover, if the line regulation characteristic of the auxiliary electromagnet power supply approximates that of the high voltage power supply, output of the auxiliary electromagnet supply will drop a little below 0.54 A, thus giving an RF power output between 22.5 and 25 kW.

Anode Current Sampling Feedback -- At power levels above 30 kW, where output stability and control is most important, it is recommended that an anode current feedbackcircuit be utilized to control electromagnet current. The circuit should sample anode current, electronically adjusting the electromagnet supply to compensate for variations from the desired anode current. Circuit design can be made as complex as economically justifiable, with adjustable set points, variable up slope and down slope envelopes, proportional control, built-in time delays, and fail-safe provisions. Such a circuit will cut down anode current fluctuations to an irreducible minimum.

High Voltage Supply

Typically, a full-wave, three-phase power supply is used to provide the magnetron's anode voltage. The allowable ripple and frequency modulation of the output voltage determine the size of the smoothing choke, if any, required in series with the power supply. Design the internal impedance of the supply to limit short circuit current to a maximum of 24 amperes in case of an internal arc-over in the magnetron.

Over-current protection should be provided for magnetrons operating up to 30 kW output by using a reliable, high speed, over-current relay in series with the anode to remove voltage from the anode in case of a fault. Adjust the relay for operation as close to maximum plate current as possible without causing unnecessary "tripping" due to normal transients and line voltage variations.

For magnetrons operating above 30 kW useful output, the large amount of energy stored in the power supply filter may require faster protection than that afforded by an over-current relay with a40 to 50 millisecond operating time. Faster protection (5 to 10 microseconds) is achieved by using a high-speed electronic circuitto totally by-pass fault current until mechanical contactors open. Such a circuit may employ a controlled gas tube, such as a thyratron or ignitron, to handle the required energy.

RF Load

When a magnetron is operating into a varying load, changes in frequency, anode current, power output, and filament back-heating will all occur. Operation may be highly unstable if the tube is operating in the "sink" region, Refer to the area of high VSWR between 140 degrees and 160 degrees on the Rieke diagram printed in the tube bulletin of any BURLE magnetron. Although a detailed explanation of the diagram is beyond the scope of this applications note, the user should be aware of these relationships. [2]

An oscillating magnetron should be protected from the large amount of power that may be reflected back to the tube from a mis-match of the RF load. A junction circulator, a non-linear ferrite device installed between the wave guide transition and the RF load, passes forward power to the output load essentially unattenuated but deflects reflected power away from the magnetron to a load which absorbs and dissipates the reflected power.

Although the magnetrons in many systems operating at 30 kW and less without circulators have demonstrated good life while working into well-matched loads, the absence of a circulator is risky at 30 kW and seriously jeopardizes magnetron life above that level.

π Mode

When a BURLE magnetron is started and operated in the sequence listed in "Step by Step Operation", it will always begin oscillating in the π mode providing filament emission is sufficient to supply the required anode current. Emission electrons "in-step" with the magnetron's RF field give up their potential energy to the RF field. Emission electrons "out-of-step" with the RF field spiral back and strike the filament with enough energy to cause extra filament heating, called "back-heating". Abrupt changes in the magnetron's operating conditions, for example: a line voltage jump, a sudden increase in RF load, or a drop in electromagnet current, may cause the tube to drop out of oscillation or to "mode"; that is, to jump from π mode to π -1 mode oscillations. "Moding" is more destructive to the magnetron than is dropping out of oscillation. Protect the tube against both possibilities.

Low filament emission resulting from low filament temperature is the major cause of failure to start or maintain π mode operation. Low filament temperature causes and corrections include:

1. Insufficient power supplied to the filament. In the oscillating magnetron, filament power is supplied partly by the filament supply. Changes in oscillating conditions change the amount of back-heating. Back-heating changes must be compensated for by adjusting the filament supply setting to maintain the correct hot filament resistance.
2. Reflectivity changes of internal tube parts due to normal tube aging. As the reflectivity of tube parts decreases, filament temperature decreases. Adjust for these normal changes by periodically monitoring and adjusting hot filament resistance (see Filament).
3. Excessive rate of start-up. As electromagnet current is reduced and tube oscillation begins, electron back-bombardment changes the filament temperature pattern, hence, the emission capability of various filament segments. Compensate for filament temperature changes by increasing the start-up time, allowing heat conduction time to minimize temperature variations.

Unfortunately, filament power insufficient to support π mode oscillations may be adequate to sustain π -1 mode oscillations because of the extra back-heating in the π -1 mode. Thus, a magnetron may drop out of π mode into π -1 mode unless adequate circuit protection is incorporated.

π -1 Mode

The π -1 oscillation frequency of BURLE large power magnetrons is approximately 1540 MHz. Because tubes and systems are optimized for 915 MHz oscillation, little 1540 MHz energy is coupled from magnetron to load during π -1 mode operation. The consequences of operating a magnetron in the π -1 mode are rapid and destructive:

1. Filament temperature increases greatly in a few seconds because of very high back-heating. The overheated filament sags, filament turns sometimes short together electrically, and filament burnout frequently follows.
2. High RF voltagedevelops between the tube's filament terminals and electrical ground, causing equipment component failure, dielectric support breakdown and external arcing. Arcing across the tube's high voltage ceramic insulator is likely to fracture the ceramic.
3. High RF voltage causes internal tube arcing which, in turn, generates gas in the tube due to the energy dissipated. If overload devices operate fast enough to protect the magnetron from total destruction from filament back-heating and external arcing, the gas usually results in additional severe internal arcing and in spurious radiation when the tube is restarted in the π mode.

Operation in the π -1 mode is shown by the following conditions:

1. Increased filament resistance shown by lower filament current at constant voltage.
2. Presence of little or no 915 MHz energy.
3. Low efficiency and high anode dissipation.
4. Excessive 1540 MHz radiation from the filament connector area.

Withoutthe use of special test equipment, it is frequently difficult to determine if anode supply overloads are caused by π -1 mode operation or are the result of internal tube arcs which occasionally occur spontaneously. If excessive anode supply overloading occurs, consult "Troubleshooting Hints".

Tests at BURLE indicate that oscillation in the π -1 mode is relatively stable up to about 1.0 A of anode current. Above this level, anode current becomes unstable and operation is not always predictable. Frequently the tube will arc internally due to the high RF voltages generated.

2. For further information on Rieke diagrams, consult these references:

REFERENCE DATA FOR RADIO ENGINEERS. Fifth ed., Howard W. Sams & Co., Indianapolis, (1968)

George B. Collins, editor, MICROWAVE MAGNETRONS, McGraw Hill, New York, (1948)

Suppressing (π - 1) Mode

Each BURLE large power magnetron data sheet contains a figure showing the threshold of π mode operation and the threshold of π -1 mode operation for a typical magnetron. **Figure 3,** reproduced from the data sheet for type 8684, illustrates graphically how AJ-2194 electromagnet current and magnetron anode voltage relate to π mode and π -1 mode thresholds. Study of **Figure** 3 shows that avoiding particular combinations of anode voltage and electromagnet current will avoid the onset of π -1 mode oscillations. The "critical value" of electromagnet current is defined as that electromagnet current which allows the magnetron's operating point to intercept the π -1 mode threshold.

A relatively simple form of protection which avoids π -1 operation is a reliable under-current relay in series with the electromagnet that removes anode voltage if the electromagnet current drops close to the critical value for that anode voltage.

Assume the following: a transmitter uses a separately-excited electromagnet and a fixed anode voltage supply. The unloaded anode voltage is 14.0 kV and the anode supply's internal impedance is 800 ohms. Anode current of about 2.8 A is needed to obtain 25 kW of useful power output. When anode voltage is on but the tube is "biased off', the operating point is between A and B', depending on the electromagnet current. As electromagnet current is reduced, anode current begins to flow at point B' and the magnetron begins to oscillate in the π mode. When the electromagnet current is reduced further, the operating point moves down the operating line B' C'. At C', the anode current required for 25 kW is reached. Now assume that, having oscillated satisfactorily at 25 kW output for a short period, the magnetron drops out of oscillation. The anode current goes to zero, anode voltage rises to the no-load value, and operating point moves to D', a point close to the π -1 mode threshold. This example requires an under-current relay in the electromagnet circuit set to de-energize anode voltage at an electromagnet current very close to 3.0 A. The operating tolerance of the relay is quite narrow for the conditions chosen in the example: if the relay trips much above 3.0 A, the magnetron will not be able to generate 25 kW output power; if the relay operates much below 3.0 A, the tube will go into π -1 mode oscillation when it drops out of π mode oscillation.

A wider safety margin results from using a power supply with 400 ohms internal impedance. In this case, the no-load anode voltage must be reduced to end up at the same voltage under load. The operating point moves from A to B to C. If the magnetron drops out of oscillation at point C, the operating point moves to D. Under these conditions, π -1 mode operation can be prevented if the electromagnet current stays above 2.75 A. For best protection, set the under current relay just below the value needed to achieve the required power output. Thoroughly test the under-current relay at various settings to assure the relay will always remove anode voltage at the value of electromagnet current required to avoid π -1 oscillation.

Follow two rules to avoid π -1 mode operation:

1. Select an anode supply with impedance such that no-load anode voltage will always fall below the π -1 mode threshold anode voltage at the minimum operating electromagnet current.
2. Always operate with minimum electromagnet current greater than that needed to initiate π -1 mode operation at no-load anode voltage.

Be sure to consider all conceivable operating conditions in selecting an operating range, allowing also for ripple and line regulation.

As a further example, consider operating an 8684 at 22.5 kW RF power output with an anode supply having a no-load voltage of 13 kV and internal resistance of 1000 ohms using a separately-excited electromagnet. What are the remaining operating parameters, and do the proposed conditions lead to stable operations?

Analyze the proposed operating parameters as follows:

1. Draw a 1000-ohm load line on the Typical Performance Characteristics graph at a no-load voltage of 13.0 kV. See **Figure 4.**
2. Draw an estimated 22.5 kW constant RF power curve through the above load line.
3. Read the operating parameters corresponding to the intersection of the load line and constant RF power curve. From **Figure 4,** the operating parameters for the example are: Anode Voltage, 10.4 kV; Anode Current, 2.58 A; and Electromagnet Current, 2.63 A.
4. Mark the operating point on the Typical Threshold Characteristics graph corresponding to an anode voltage of 10.4 kV and an electromagnet current of 2.63 A. **See Figure 5.**
5. Draw an anode no-load voltage line of 13 kV horizontally in **Figure 5** until it intersects the π mode threshold curve at the π mode cut-off point.
6. Draw a straight line between the π mode cut-off point and the operating point in **Figure 5.**

Now, the load line has not intersected the π -1 mode threshold curve, so tube operation will be satisfactory as long as the tube continues to oscillate in the π mode. Consider, however, what will happen if the tube should drop out of oscillation for reasons already discussed above. In this case, the following sequence of events will occur:

1. The electromagnet current remains constant because the electromagnet is separately excited.
2. Anode current of the 8684 will drop toward zero.
3. Anode voltage of the8684 will rise toward no-load level as the anode power supplycurrent loading drops. On **Figure 6,** the load line for this series of events follows the constant electromagnet current line of 2.63A, intersecting the π -1 mode threshold line at an anode voltage of approximately 12.3 kV.
4. When the anode voltage reaches 12.3 kV, the magnetron will begin oscillating in the π -1 mode and one of two possible sequences will follow, depending on the ultimate π -1 mode operating level:
   a. The π -1 mode will generate excessive RF voltage and will arc almost immediately.
   b. The tube will operate in an apparently stable manner in π -1 mode. During this oscillation, the magnetron filament and anode will overheat, gas will be generated in the tube, and the tube will arc internally.

Therefore, the operating conditions proposed in this example are not acceptable for safe magnetron operation.

The possibility of dropping into π -1 mode operation could have been avoided-in the example by selecting an anode power supply with lower internal impedance. Using a power supply with an internal resistance of 850 ohms, the operating conditions are as shown in **Figure 7. Figure 8** reveals that the π -1 mode threshold will not be exceeded at 13.0 kV anode no-load voltage. Hence, the example demonstrates the importance of anode supply impedance in avoiding π -1 operation.

Step-By-Step Operation

Magnetron Installation

Unpacking --

1. Cut the top seal of the shipping container and open the top cover lids.
2. Remove the four (4) Hardi-Pak spacers on the top corners of the inner shipping container.
3. Cut the top seal of the inner shipping container and open the top cover lids.
4. Remove the manila envelope containing:
   a. Test Data Sheet
   b. RF Gasket Installation Instructions.
   c. Personal Safety Hazard Warning.
5. Remove the rectangular cardboard sleeve, and sit the sleeve on end on a flat work surface.
6. Raise the magnetron package out of the shipping container. Lower the package so that the bottom plywood shipping plate rests flush and securely on the upper end of the cardboard sleeve provided in Step 5. The magnetron will be positioned with the ceramic dome down.
7. Remove the safety wires from each of the four (4) wing nuts.
8. Remove the four (4) wing nuts and washers.
9. Remove the top plywood shipping plate.
10. Open the upper end of the plastic bag encasing the magnetron. Slip the sides of the bag down below the magnetron cooling pipes.

Preparation and Installation --

1. Assemble the AJ2135 Magnetic Pole Piece to the magnetron. See the section on “Magnetron Support Equipment” for more details on the AJ2135. Carefully lower the magnetic pole piece over the magnetron’s filament terminal while keeping the pole piece slots aligned with the magnetron’s coolant tubing. Fasten the AJ2135 Magnetic Pole Piece to the magnetron with six (6) 1/4-28 UNF x 1/2” socket head cap screws. Holding the magnetron-pole piece assembly by the pole piece, lift the assembly clear of the plastic bag.
2. The magnetron was shipped with AJ2138 RF Gasket attached. Check to ensure the gasket is still correctly positioned on the magnetron’s RF contact surface. If necessary, reposition the gasket on the magnetron’s RF contact surface as shown in RF Gasket Installation Instructions included with the tube. Use the clips provided to hold the gasket in position. Avoid touching the ceramic dome with RF gasket or with bare hands.

   BURNING, ARCING AND PROBABLE TUBE DAMAGE WILL RESULT IF THE GASKET DOES NOT MAKE GOOD RF CONNECTION BETWEEN THE MAGNETRON AND THE ELECTROMAGNET SEAT AROUND THE ENTIRE CIRCUMFERENCE OF THE GASKET.
3. Lift the magnetron-pole piece assembly by the pole piece for installation in the operating socket. Hold the magnetron-pole piece assembly and carefully rotate it to align the assembly with the operating socket. The tube’s anode coolant tubing must match the location of the coolant hoses in the magnetron housing and the holes in the pole piece must align with the three studs protruding from the electromagnet. With a last visual check to assure the RF gasket is still in its proper position, carefully insert the magnetron, dome end first, into the electromagnet operating socket. Seat the magnetron squarely in the socket with the three electromagnet studs protruding through the pole piece. Assemble lock washers and nuts on the three studs. If the magnetron is positioned with the ceramic dome UP, push the magnetron upward firmly in the socket with one hand while tightening nuts with the other. Hand tighten the nuts. Check spacing between the pole piece and the magnet at several points.

   Uniform spacing assures that the tube is seated squarely in the electromagnet. If the spacing between pole piece and electromagnet is not uniform, loosen the three nuts and re-adjust the magnetron’s position until the spacing is uniform. Re-tighten the nuts hand-tight.
4. NOTE: THESE TIGHTENING INSTRUCTIONS APPLY ONLY WHEN LOCK WASHERS ARE USED AS RECOMMENDED. IF LOCK WASHERS ARE NOT USED, THE 2/3 TURN PRESCRIBED WILL BE EXCESSIVE AND WILL BE LIKELY TO CAUSE PERMANENT TUBE DAMAGE.

   After hand tightening the three nuts and checking to be sure the magnetron is squarely seated, turn the nuts an additional 2/3 turn with a wrench as follows:

   Turn each nut 60 degrees, or “one flat around”, in turn. Repeat three more times, completing 2/3 turn (240 degrees or “four flats around”). This is equivalent to compressing the gasket by .38-.43 mm (.015-.017 inch). The torque on each nut will now be 2.26-3.39 newton-meters (20-30 inch-pounds).
5. Filament contact surfaces of the magnetron and the filament connectors must be clean and free from grease and oxide buildup. Position the AJ2136V2 Filament-Cathode Connector squarely against the shoulder of the magnetron terminal. Tighten the connector screw to give a good electrical contact between the connector and the magnetron contact surface. Repeat for the AJ2137V1 Filament Connector.
6. Make cooling connections as follows:
   a. Connect and clamp air hoses to the AJ2137V1 Filament Connector and to the air inlet on the AJ2192 Waveguide Transition.
   b. Connect and clamp water hoses to the anode coolant ducts shown in **Figure 9.** Be sure the direction of water flow is as specified in the tube bulletin for the magnetron type being installed. The spacing between the coolant pipes and all objects at high voltage must be greaterthan 19 mm (3/4 inch).

7. Turn on air and water flow for cooling. Adjust flow rates to the values specified in the tube bulletin of the magnetron being installed.

Magnetron Operation

To minimize the possibility of permanently damaging a magnetron during initial operation, the first-time operator must read and understand the principles of magnetron operation summarized in the section titled "Magnetron Operating Considerations." The instructions below assume that the warnings and recommendations under Personnel Safety and Magnetron Protection have been incorporated in the system design.

Power On --

1. Turn on the filament power in accordance with the recommended procedure for the type of supply being used. Never exceed maximum starting current of 250 A. Set filament voltage and current to the values listed under Test Conditions A on the Test Data sheet of the tube being operated. After filament stabilization of approximately5 minutes, calculate "hot filament resistance", dividing filament voltage by filament current. The value calculated should correspond closely with that listed on the tube's Test Data sheet **(Figure 10).** If the calculated value differs appreciably from the data sheet "hot filament resistance", refer to "Trouble Shooting Hints" below.
2. Set electromagnet current high enough to assure anode current cutoff. Adjust anode voltage to the desired no-load operating level. Reduce electromagnet current smoothly, over several seconds, to increase the magnetron's anode current from cutoff to the desired anode current operating point. Watch metering carefully to be sure that the magnetron does not accidently jump to π -1 mode operation. In the unlikely event of π -1 mode operation, shut off anode voltage immediately, before magnetron damage can occur.
3. Quickly (within a few seconds), reduce the filament current until "hot filament resistance" equals the value obtained in Step 1. At load conditions and VSWR conditions similar to those given on the Test Data sheet (**Figure 10**), back heating will be essentially the same as given in the data. In that case, the data sheet values will give good approximations of the required filament voltage and current settings. For best filament life, always optimize "hot filament resistance" on the basis of actual operating conditions.
4. If magnetron RF operation is discontinued for a period not exceeding one hour, filament power should remain ON during the period.
5. To restart the magnetron after anode voltage is removed, reset filament current to the starting value and reset electromagnet current to greater than anode current cutoff. Follow the "Power On" procedure above.

Trouble Shooting Hints

This short checklist of common problems encountered when using systems with BURLE large power magnetrons assumes the use of magnetron protection circuits as recommended in this Applications Note. The list is not intended as a complete summary of all possible magnetron or system problems. For further assistance with magnetron problems not addressed in this list or the body of this Applications Note, contact Power Tube Applications Engineering, Tube Products Division, BURLE INDUSTRIES, INC., 1000 New Holland Ave., Lancaster, PA 17601-5688, telephone (717) 295-6888.

Possible Cause	Correction
Hot Filament Resistance -- If the measured hot filament resistance differs by more than 2% from the value recorded on the Test Data sheet accompanying the magnetron, correct the cause.	
High Contact Resistance	1. Remove grease and oxide buildup from filament and connector contact surfaces. 2. Replace AJ2136V2 and AJ2137V1 if worn or distorted.
Meter Error	1. Recalibrate meters. 2. Correct line drop due to remote meter location.
Failure to Start π Mode Oscillation	
Low Filament Power	1. Set filament to hot filament resistance specified on Test Data sheet. 2. Increase filament input power in 25 watt steps above Step 1 value to 75 watt max. 3. Reduce filament to Step 1 value and hunt elsewhere.
Insufficient filament preheat	Increase preheat time at full current
Failure to Maintain π Mode Oscillation	
Excessive rate of anode current rise	Max. increase: 0.5 ampere/second
Low filament power	1. Set filament to hot filament resistance specified on Test Data sheet. 2. Increase filament input power in 25 watt steps above Step 1 value to 75 watt max. 3. Reduce filament to Step 1 value and hunt else-where.
Short Magnetron Life due to Filament Burn-Out	
Excessive filament temperature during operating life	Reduce filament input on future tubes to compensate for back-heating (control hot filament resistance).
RF Arcing to Anode Coolant Duct	
Close Spacing	19 mm (3/4 inch) minimum spacing from high voltage surfaces to anode ducts.
Reflected power from mis-matched load	1. Add circulator and dummy load. 2. Correct circulator malfunction. 3. Match load.

Waveguide Transition Tuner Setting

Originally, AJ2192 Waveguide Transitions were built with an adjustable tuner. In current AJ2192s, the tuner has been replaced with a fixed stub. The adjustable tuner was pre-set in the factory and needs no further adjustment. The lock nut on the tuner must be kept tight at all times to prevent overheating. If the tuner should inadvertently be turned, reset it to 32.776 mm (1.290 in.) from the end of the tuner to the end of the flange. See **Figure 11.**

Magnetron Support Equipment

For safe and satisfactory operation of BURLE large power magnetrons, BURLE INDUSTRIES, INC. recommends use of the following parts and assemblies:

BURLE Type Number	Description
AJ2135	Magnetic Pole Piece
AJ2136V2	Filament-Cathode Connector
AJ2137V1	Filament Connector
AJ2138	RF Gasket
AJ2192	Waveguide Transition
AJ2194	Electromagnet

One unit of each of the recommended parts and assemblies is required for the proper operation of a BURLE magnetron. All items except the RF gasket may be used in the subsequent installation of replacement tubes. Do NOT reuse RF gaskets. Keep several RF gaskets on hand for possible use in reinstalling tubes. The use and precautions related to the parts and assemblies described in this section are discussed under "Magnetron Installation".

Operating Socket

The AJ2192 Waveguide Transition and the AJ2194 Electromagnet are shipped in separate cartons for maximum protection against shipping damage. The components, when assembled as described below, form a complete operating socket for BURLE large power magnetrons.

Magnetic Pole Piece

The AJ2135 Magnetic Pole Piece holds the magnetron in its correct position within the electromagnet and shapes the magnetic field for proper focusing of the magnetron's electron beam.

Filament-Cathode Connector

The AJ2136V2 Filament-Cathode Connector makes electrical contact to the filament-cathode terminal of the magnetron. It features a molded attenuator which suppresses spurious radiation from the high voltage insulator area of the magnetron. Typical spurious radiation attenuation is 12 dB: typical AC or DC current is 115 amperes.

Filament Connector

The AJ2137V1 Filament Connector makes electrical contact to the filament terminal of the magnetron. It contains a duct to permit forced air cooling of the filament terminal, the filament insulator, and the filament-cathode connector. Typical AC or DC current is 115 amperes.

RF Gasket

The AJ2138 RF Gasket is a mesh-type gasket to produce an RF connection between the magnetron and the waveguide transition.

Waveguide Transition

The AJ2192 Waveguide Transition couples the RF energy from the magnetron to a standard WR975 Waveguide. Its flange mates with a standard EIA Waveguide Flange CPR975F.

Electromagnet

The AJ2194 Electromagnet is liquid-cooled and will control the anode current for all specified values of anode-cathode voltage. It focuses the magnetron's electron beam as required for efficient performance.

Maximum Ratings, Absolute Maximum Values

DC Electromagnet Voltage	50	v
Peak Voltage (Transient)	**500**	**v**
DC Electromagnet Power	**250**	watts

General Data

Electrical:

Coil Current at 39 volts	**3.0**	**A**

Mechanical:

Overall Height, Max.	158.8 mm (6.25 in.)
Greatest Diameter, Max.	325.1 mm (12.80 in.)
Weight, Uncrated	58.6 kg (128 lb.)
Weight, Crated	83.0 kg (83 lb.)

Thermal:

Liquid cooling of the electromagnet coil is essential.

See "Cooling" section for further discussion.

Metal Surface Temperature	100 max.	°C
Storage Temperature	-65 min.	°C

Flush all coolant from coolant courses for shipping or storage at temperatures below freezing.

Typical Water Flow for Coil Dissipation of 140 Watts	.95 l/min (0.25 gpm)	
Maximum Pressure Drop at .95 l/min (0.25 gpm)	0.7 bar (10 psi)	
Maximum Outlet Water Temperature	**70**	**°C**
Maximum Inlet Water Pressure, Gauge	6.9 bars (100 psi)	

Operating Socket Assembly Instructions

The Waveguide Transition and Electromagnet are shipped separately to prevent damage to the waveguide transition. Accessories necessary to complete the assembly of the waveguide transition and electromagnet are enclosed in two packets and shipped inside the corrugated box with the waveguide transition.

Theelectromagnet is secured to a wooden skid by a metal band. It is enclosed with a wooden cover secured to the skid by two metal bands. While severing the metal bands during the uncrating operation, use care to prevent personal injury from the "whipping" ends of the bands when the bands are cut.

Item	Description	Quantity
1	Electromagnet	1
2	Waveguide Transition	1
3	Pole Piece	1
4	8-32 NC x 1/2" Flat Head Screws	6
5	1/4"-20 NC x 3/4" Socket Head Screws	6
6	3/16" Hex Key	1
7	1/4" Flat Washers	8
8	1/4"-20 NC x 6 3/4" Hex Head Bolts	4
9	1/4" Lo&washers	4
10	3/8"-16 Hex Nuts	3
11	3/8" Lockwashers	3
12	Polyethylene Air Sleeve	1

Items 1 and 2 must be ordered separately. Items 3-12 are supplied with Item 2.

Step 1: Lay the elctromagnet (1) on its side and attach the Pole Piece (3) to it using the six 8-32 NC x 1/2" Flat Head Screws (4) as shown in **Figure 15** and Detail A of **Figure 17.**

Step 2: Place the Waveguide Transition (2) on supports with the air inlet down as shown in **Figure 16.** Be sure the Polyethylene Air Sleeve (12) is in position as shown in Details A and B of **Figure 17.**

Step 3: Position the Electromagnet and Pole Piece assembly from Step 1 on the Waveguide Transition (2) in accordance with **Figure 17,** assuring that the counterbored 1/4 inch holes of the Pole Piece (3) are aligned with the 1/4" -20 tapped holes in the Waveguide Transition (2). Check for the correct orientation of the electromagnet coolant ducts.

Step 4: Insert the six l/4"-20 NC x 3/4" Socket Head Screws (5) in the counterbored 1/4" clearance holes in the Pole Piece (3) and, using the 3/16" Hex Key (6), start the screws into the threaded holes in the Waveguide Transition (2) as shown in Detail B of **Figure 17.** Do NOT tighten screws.

Step 5: Position two 1/4" Flat Washers (7) between the Waveguide Transition (2) and the Electromagnet (1) at each of the four 1/4" -20 NC x 6 3/4" Hex Head Bolt (8) positions. Refer to **Figure 17.**

Step 6: Place a 1/4" Lockwasher (9) beneath the head of the four 1/4" -20 NC x 6 3/4" Hex Head Bolts, threading the bolts through the Electromagnet (1) and Washer pairs (7) into the mounting brackets. Do NOT tighten.

Step 7: Tighten the six 1/4" -20 NC x 3/4" Socket Head Bolts (5). Note: The contact between the Pole Piece (3) and the welded flange of the waveguide Transition (2) must be a good RF seal to prevent burning and RF leakage.

Step 8: Tighten the four (4) 1/4" -20 NC x 6 3/4" Hex Head Bolts (8).

Step 9: Install the three 3/8" Hex Nuts (10) and Lockwashers (11), round side down, on the three threaded rods of the Electromagnet (1).

Step 10: Mount the completed operating socket with the axis of the Electromagnet vertical. Support the assembly by the mounting brackets shown in **Figure 17.**

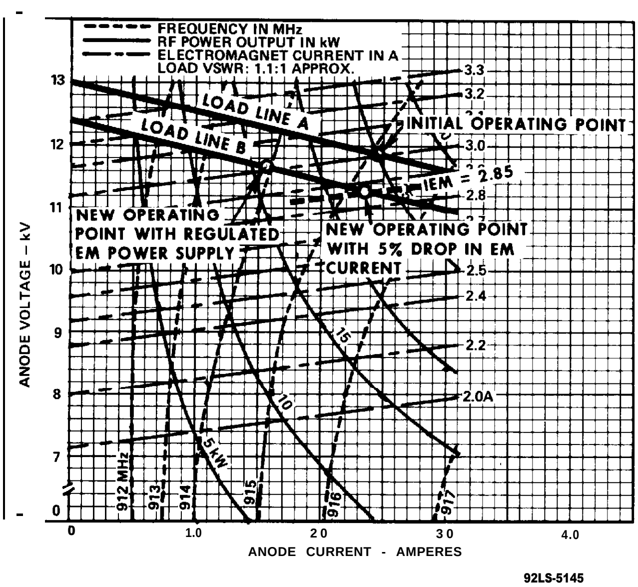


Figure 1 - Performance Characteristics with Separately-Excited Electromagnet

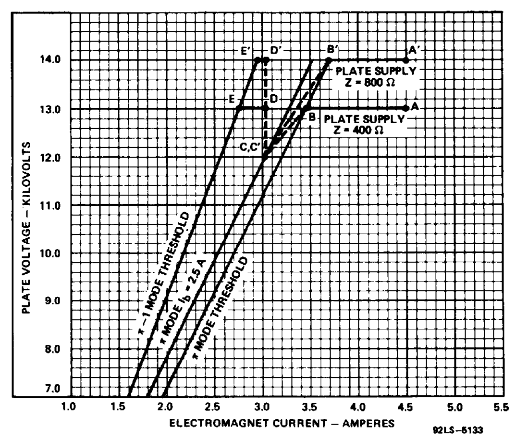


Figure 3 - RF Mode Characteristics

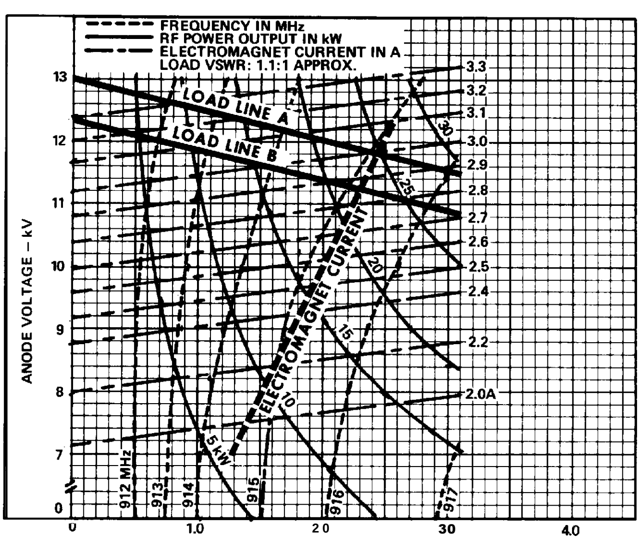
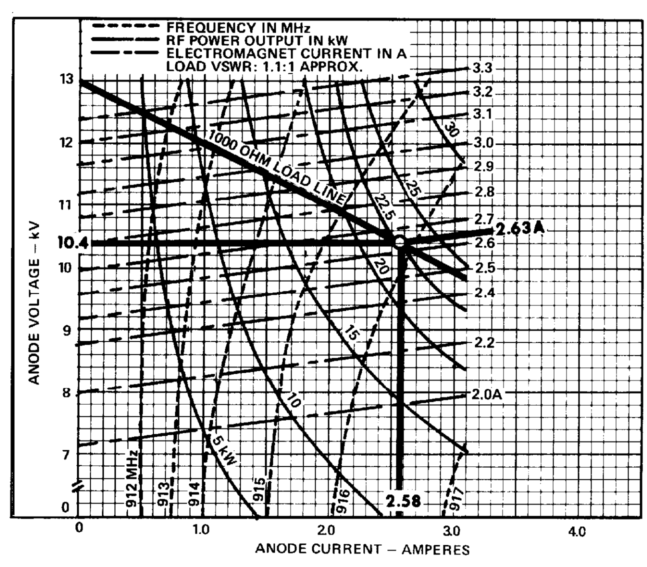


Figure 2- Performance Characteristics with Series-Excited Electromagnet



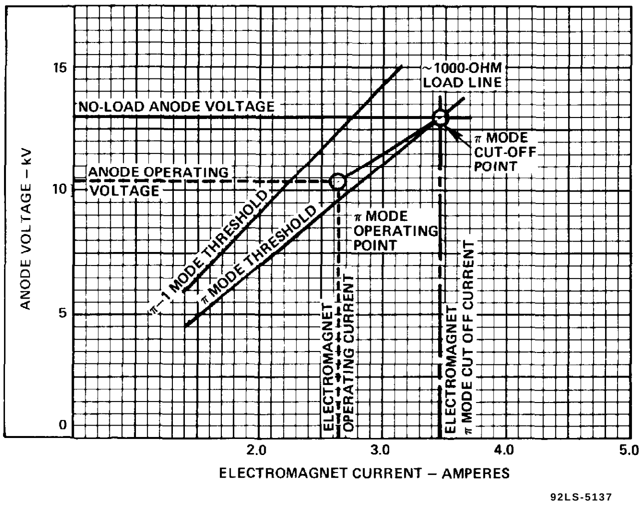


Figure 5 - 8684 π Mode Threshhold Characteristics, 1000-ohm Load Line

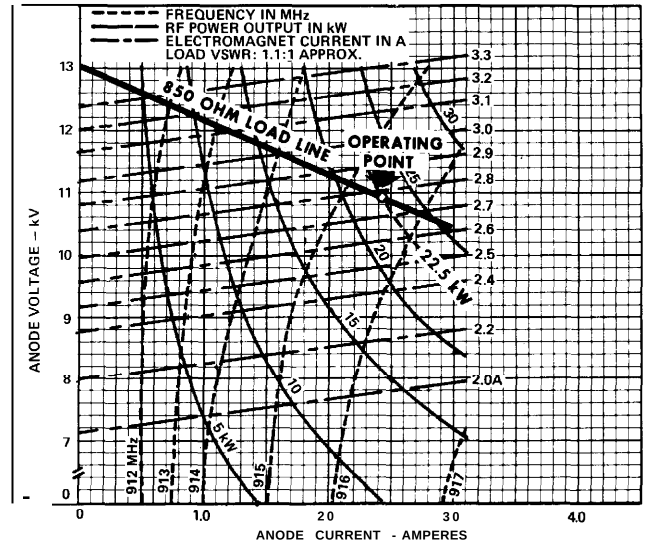


Figure 7 - Performance Characteristics, 850-ohm Load Line

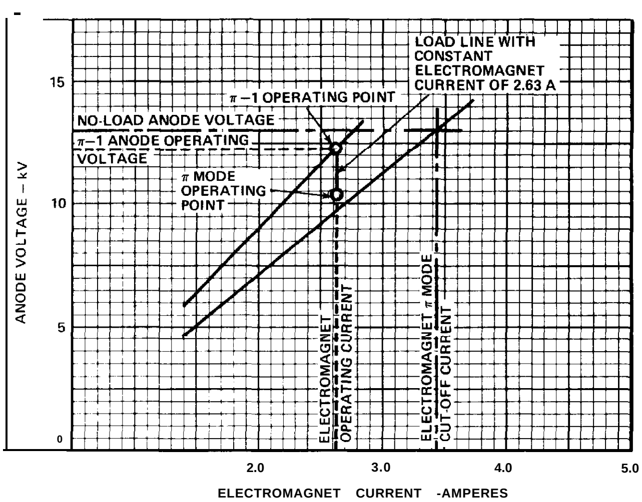


Figure 6 - Drop Out of π Mode Operation, 1000-ohm Load Line

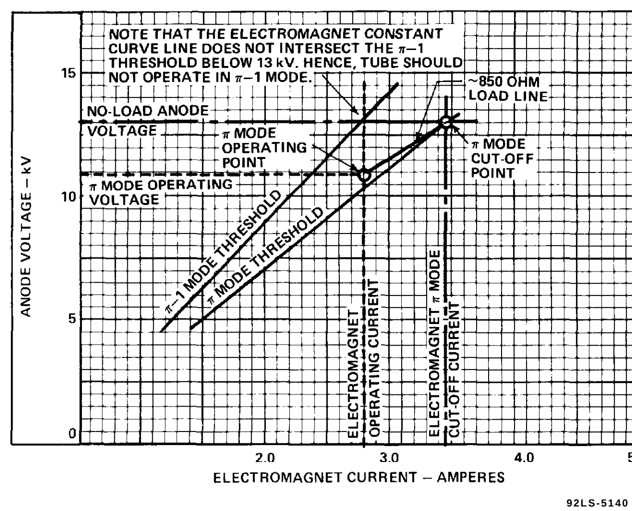


Figure 8 - π -Mode Threshold Characteristics, 850-ohm Load Line

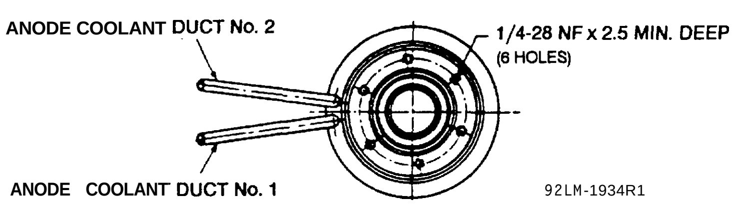


Figure 9 - Filament End of Magnetron

BURLE INDUSTRIES INC.
TUBE PRODUCTS DIV.

LARGE POWER MAGNETRON TEST DATA

TUBE TYPE NUMBER: ____________ SERIAL NUMBER: ____________

TESTED BY: ____________ DATE: ____________

QUALITY ASSURANCE: ____________ DATE: ____________

PARAMETERS	NOTE	UNITS	TEST CONDITIONS		
TEST CONDITIONS	5		A	B	C
FILAMENT VOLTAGE		V			
FILAMENT CURRENT		A			
HOT FILAMENT RESISTANCE	1.	ohms			
EFFECTIVE FILAMENT POWER		W			
FILAMENT SUPPLY POWER	2	w			
EFFECTIVE BACK-HEAT POWER	3.	W	N.A.		
ELECTROMAGNET CURRENT		A	N.A.		
ANODE VOLTAGE		kV	0		
ANODE CURRENT		A	0		
LOAD VSWR			N.A.		
R.F. POWER OUTPUT		kW	0		
TUBE EFFICIENCY		%	N.A.		
FREQUENCY		MHz	N.A.		
NO-LOAD FILAMENT VOLTAGE	4.	v	N.A.	N.A.	
NO-LOAD FILAMENT CURRENT	4.	A	N.A.	N.A.	

PUSHING FACTOR ________ MHz/A PULLING FACTOR ________ MHz

COOLANT PRESSURE DROP AT ______ GALLONS PER. MINUTE: ______ psi.

NOTES:
1. THE ABSOLUTE MAXIMUM HOT FIIAMENT RESISTANCE AT WHICH MIS TUBE MAY BE OPERATED IS ThE VALUE SPECIFIED PLUS 0.004 ohms.
2 FIIAMENT SUPPLY POWER = (FILAMENT VOLTAGE) X (FILAMENT CURRENT)
3. EFFECTIVE BACK-HEATING POWER = (EFFECTIVE FILAMENT POWER) - (FILAMENT SUPPLY POWER)
4. CUT Off ANODE CURRENT BY INCREASING ELECTROMAGNET CURRENT WHILE THE TUBE IS OPERATING AT RF. POWER OUTPUT LISTED.
READ NO-LOAD FILAMENT VOLTAGE AND CURRENT WITHOUT ADJUSTING FILAMENT POWER SUPPLY
5. TEST CONDITIONS A IS WITH P out=0; TEST CONDITION B IS AT APPROXIMATELY 80% RATED POWER TEST CONDITION C IS AT APPROXIMATELY 100% RATED POWER

OBSERVE AIR AND LIQUID COOLING REQUIREMENTS AND ALL PRECAUTIONS AS DESCRIBED IN OPERATION AND USE OF BURLE INDUSTRIES, INC. LARGE POWER MAGNETRONS AN-4985 AND IN INDIVIDUAL TUBE TYPE BULLETIN

MAGADATA

Figure 10

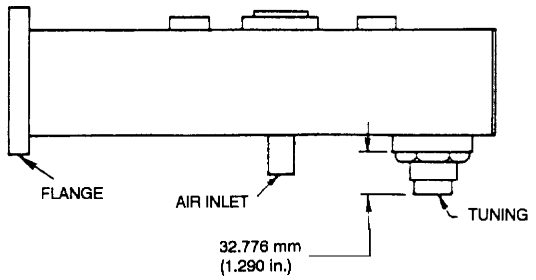


Figure 11 - AJ2192 Waveguide Transition

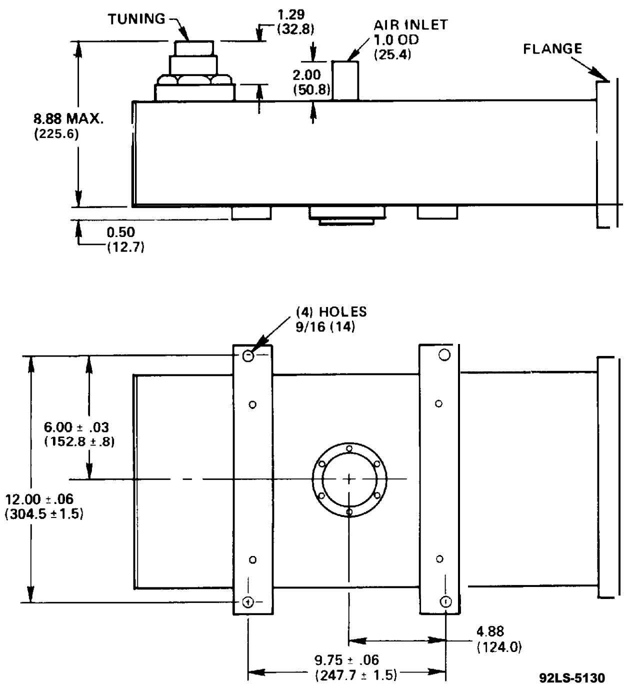


Figure 12 - AJ2192 Dimensional Outline

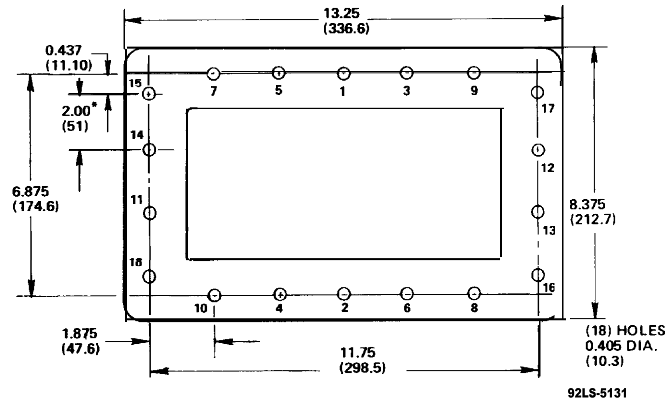


Figure 13 - AJ2192 Flange to Mate CPR975F

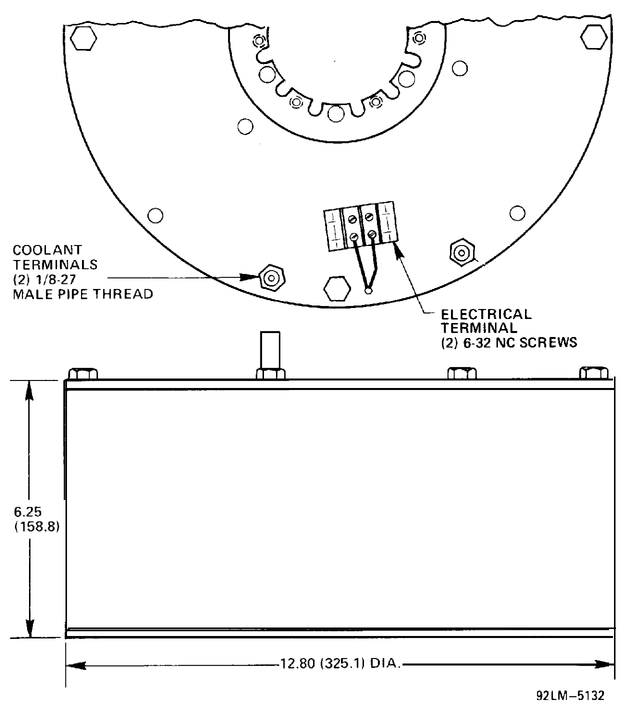


Figure 14 - AJ2194 Dimensional Outline

RETURN TO MENU

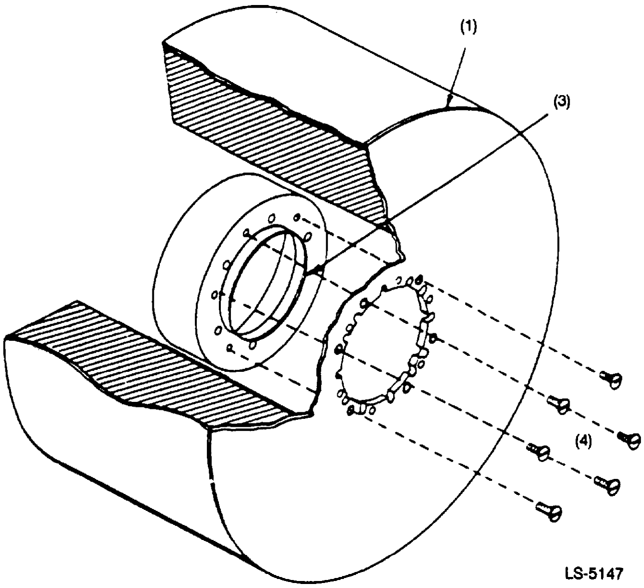
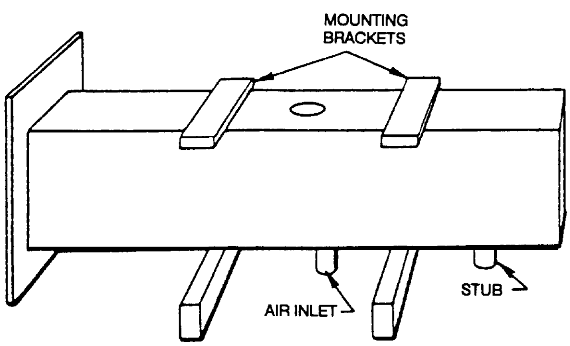


Figure 15 - Assembly of Electromagnet and Pole Piece



LS-5148

Figure 16 - Waveguide Transition Positioned on Supports

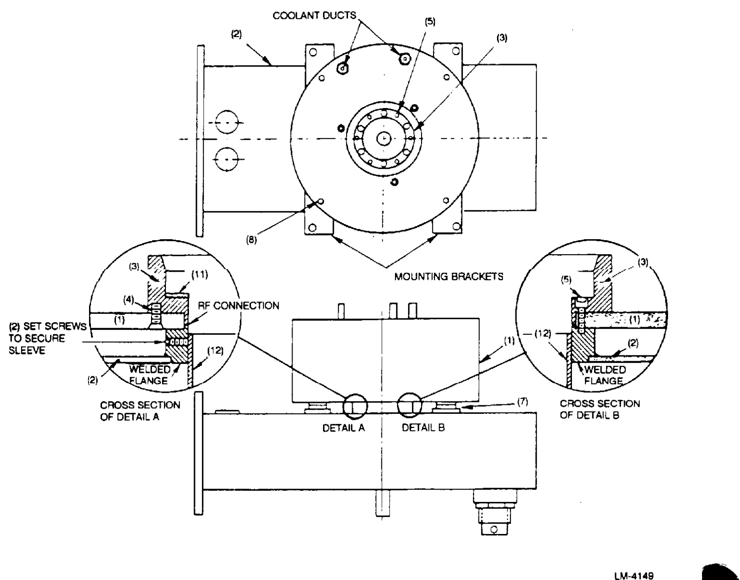


Figure 17 - Assembly of Electromagnet and Waveguide Transition