

Tube Maintenance Guide

 **Richardson
Electronics**

The Richardson Story

The year 1947 was filled with milestones. Jackie Robinson became the first African-American to play for a major-league baseball team. President Harry S. Truman implemented the Truman Doctrine to squelch the spread of Communism and ENIAC, one of the world's first digital computers, was turned on.

That same year Arthur Richardson, Sr. began his own story. After World War II, Arthur worked for the Majestic Radio & Television Corporation selling war assets. Upon leaving the company, Arthur collected his salary in radio tubes. Soon afterwards, he and his wife, Florence, were selling tubes out of a barn on their farm in the rural town of Wayne, Illinois.

During the day Arthur would make sales calls and at night he and his wife would pack and ship tubes. The couple worked hard, but they enjoyed working together. Their diligence paid off and their business grew. An office was established in Chicago and soon afterwards the Richardsons moved their operations to a warehouse in the Chicago suburb of Franklin Park.

In 1961, the Richardsons welcomed their youngest son, Ed, into the business. From picking & packing in the warehouse to assisting in the front office, Ed worked side by side with his parents while learning the family business.

Ed was appointed president of the Company in 1974 and began to expand the Company's horizons. The Company acquired tube manufacturing companies such as National Electronics and Cetron and added product lines from RCA, GE, Westinghouse and Philips to its ever-expanding line of products.

In 1979, Arthur Richardson, Sr. died. After his father's death, Ed continued to build upon his parents' legacy. Continuing with its plans for expansion, the Company established an RF and microwave semiconductor product offering in response

to the rise of solid-state technology. Business continued to boom and by the early 1980s, Richardson Electronics was distributing radio frequency (RF) and wireless communications, industrial power conversion, security and display systems products.

Under Ed's direction, the Company flourished and opened several offices in the USA, as well as distribution and design centers in Latin America, Europe and Asia. Today the Company has over 70 locations worldwide and a customer base of more than 135,000. The Company went public in 1983 and moved to its current location in LaFox, Illinois in 1986. Like Wayne, the birthplace of the Company, LaFox is a small, farm community about 50 miles west of Chicago.

Today Richardson Electronics, Ltd. (an ISO 9002 registered supplier) continues to stay one step ahead of the competition by providing unique services and products. The Company is a global provider of "engineered solutions."

This term is used to describe Richardson Electronics' core engineering and manufacturing expertise in identifying and supporting cost-effective solutions for its customers, which may include product manufacturing, systems integration, prototype design and manufacture, testing and logistics. Approximately 50 percent of the Company's sales consist of products that are designed-in, modified, manufactured or assembled for customer specific requirements.

The Company has come a long way from its humble beginnings in a barn. It continues to thrive and evolve as the technology advances. The expertise, experience and relationships Richardson Electronics has acquired over the past five decades has positioned the Company to provide customers with solutions for their needs for many years to come.

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About the Author

Ed Kurtz received Bachelor of Science degrees in Engineering Science and Electrical Engineering from Hofstra University in 1968.

In 1973, he earned a Master of Science degree in Engineering Management, Electrical Engineering from CW Post University. He joined Amperex Electronics Corporation in 1968, which was a division of Philips Electron Tubes, as the Operations Manager for tube design and production. Ed joined Richardson Electronics as Engineering Manager in 1989, when Richardson acquired the Philips Electron Tube division. He retired from Richardson Electronics in 2005.

Ed has thousands of hours working with OEM's in tube design, as well as helping individual customers in troubleshooting their RF generators. It is from his depth of knowledge that the documents that make up this guide were derived.

In addition to Ed Kurtz, Richardson Electronics has an entire team of educated and qualified engineers to serve all your tube needs. Call Richardson Electronics today with all your tube requirements.

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My New Tube Just Arrived: Now What?

The new tube that was just ordered has arrived, now what do we do with it? Regardless of the reason it was ordered, to replace a defective tube, or one that is suspected of being defective, or as a back-up to insure the equipment has minimum downtime, there is a procedure to follow when inspecting the new tube.

First, before the package is accepted, the box should be inspected. Is it dented, torn or broken? Are the shock and vibration telltales activated? If it's a large tube, is the box still mounted on the pallet? Is there any indication the box was shipped on its side? None of the above are necessarily reasons to outright reject the tube, but the condition of the shipping container should be noted pending a possible claim with the carrier. By far, the primary reason tubes are rejected is due to damage in shipment.

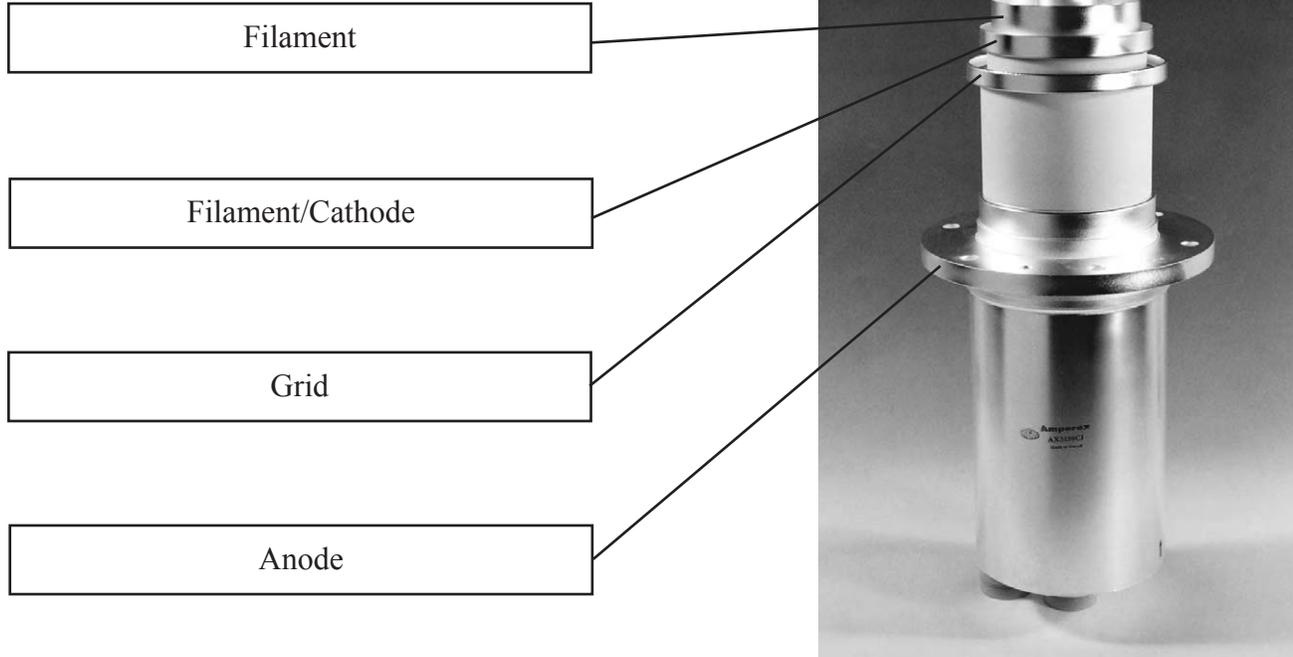
Next, remove the tube from the packing and give the tube a good visual inspection. Store the original packing material so the tube will be protected if it ever has to be shipped again! In the case of a glass tube, is there any indication of cracks in the glass? Are there any dents in the tube? If the tube had been mishandled there might be deformation of the radiator fins in an air-cooled tube or the outer jacket of a water-cooled tube. Grid flanges are another area to inspect. If all has passed the visual checklist, shake the tube lightly and listen for rattles that might indicate a broken filament. The filament in general is the weakest element in the tube and, therefore, the most susceptible to breakage. Fortunately, most tube manufacturers have designed the filament to be less massive while having more surface area for emission. The lighter filament, generally in the shape of a mesh cylinder with welds at the wire intersects, will withstand many times the shock and vibration resulting in fewer broken filaments.

To perform the next set of tests, it will be necessary to identify the tube filament connections, the grid connection and anode connections. In the case of a multigrid tube such as a tetrode or pentode, there will be more than one grid connector. The data sheet for the tube will identify the above mentioned elements. If a data sheet was not included, contact Richardson Electronics and one will be provided. The minimum piece of equipment that should be available is an ohmmeter. For the incoming tests, the ohmmeter does not have to be of the highest quality. A meter selling for a few dollars at a discount tool supplier is adequate. However consideration should be given to purchase a higher quality meter that could be used for troubleshooting the equipment.

Figure 1 (see page 6) is a typical triode tube configuration. The data sheet indicates the two outermost coaxial connectors on the tube are the filament contacts. The data sheet further notes the larger of the two contacts is also the cathode connection. Although this is irrelevant for preliminary testing, it is extremely important to note for installation purposes. The first test is to connect the ohmmeter leads, one to each of the filament contacts. The ohmmeter should deflect full scale indicating there is continuity between the two connectors. Next, locate the grid contact. In the example in Figure 1, the grid contact is the third concentric ring. Connect one ohmmeter lead to the

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Figure 1



filament contact and one to the grid contact. The ohmmeter should indicate infinite resistance (no meter deflection). This indicates there is no mechanical contact between the grid and filament wires inside the tube. It may also be referred to as “open circuit” or “not shorted.”

Last, the anode contact will have to be identified. In this example, the tube is water-cooled and the entire mounting ring and cooling jacket is an anode connection. If it is an air-cooled tube, the radiator shell and fins are electrically part of the anode. One lead of the ohmmeter should be connected to the anode and the other lead alternately connected to the grid and filament connections. Again, there should be no meter deflection which indicates an open circuit.

The preceding is the absolute minimum testing that should be done on a tube when it is first received. If there is a piece of test equipment available that is known as a Hipot tester, there is another series of tests that should be performed before the tube would be installed in the equipment. The procedure is beyond the scope of this paper but is available for the particular tube being tested. The test procedure is type specific.

At this point, the tube should be placed in the equipment. With the popularity of the digital camera, the location and connections to the tube should be photographed before removal. Most of the tubes we are concerned with in industrial applications are installed essentially the same. The tubes are usually identified by cooling method and power levels.

Radiation cooled tubes are typically large glass bottles that rarely exceed 3kW output power. They employ no extra cooling method but depend on natural radiation of waste heat into the air.

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Vapor cooled tubes are rare but still used in some applications, usually shortwave broadcast. They employ water as a cooling medium but depend on the heat of vaporization of the water to remove excess heat. They employ a boiler, condenser and a water make-up mechanism.

Air-cooled tubes are typically used in dielectric applications. The tubes depend on forced air blown through a series of cooling fins connected to the anode. These are very popular in equipment up to a power level of about 120kW.

Water cooled tubes are found in induction applications and dielectric applications where power levels typically exceed about 50kW. They use a closed system to keep the cooling water at a high conductivity level and release waste heat through an external heat exchanger.

Since air and water cooling make up the large majority of tube types used in industrial applications these will be the only types considered at this time. **Figure 2** (see page 8) depicts 4 different tube arrangements. Going clockwise, the first is a water-cooled tube with filament leads as integral parts of the tube. These leads are designed to connect directly to a filament transformer. The grid ring may have a flange attached with mounting holes for the grid connection or will have a separate grid clamp to secure the grid wire. The anode has a heavy mounting flange to connect the tube to the equipment. It also has an integral water jacket that only requires a water hose to be connected for cooling. The second example is similar to the first but coaxial rings are used for grid and filament connections. This is a typical installation on larger tubes where the actual connectors are part of the equipment and are not integral to the tube. This eliminates the cost of replacing the connectors as the tube is replaced. It also affords the possibility of using a socket for the filament and grid connections when the tube is used in high frequency applications. The third case is similar to the first but is an air cooled version. The anode shell and fins are placed in an air directing chimney to cause the air to flow uniformly over the fin surface. The last case is also of an air cooled tube that would be used in a dielectric application where the pins merely plug into a socket. It is usually used for high frequency applications but at lower power levels.

Connect the tube into the RF circuit as required and operate under full RF power levels. This is the ultimate test to determine if the tube will perform under operating conditions. In addition, a tube typically has to operate about 300-500 hours under RF conditions to completely form the filament so it develops a stable, uniform output. This process is rarely noticeable since most oscillator circuits are self correcting to some extent and will automatically adjust for changes in filament output. More important, a manufacturing defect within the tube will usually show up well before 500 hours so this small percentage will be detected. At this time, the tube can be removed from the equipment and stored on the shelf, in the original packing container, with the confidence there is really a good tube available when necessary. If a preventive maintenance program has been established the tube and spare can be cycled as recommended in industry specific papers available from Richardson Electronics on request.

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Figure 2



Flying filament leads with coaxial grid ring — integral water jacket



Coaxial inner/outer filament rings and coaxial grid ring — integral water jacket



Pin connectors with air cooled fins around the anode



Flying leads with grid flange and air cooled fins around the anode

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Preliminary Tube Testing Procedures

The testing of a modern vacuum tube of the type normally found in an industrial RF generator is an extremely detailed procedure that requires specialized and sophisticated equipment. However, there are instances where a very basic testing procedure can be done at the user facility. Some examples would be during a repair when the tube is suspected of being at fault or to determine if a particular tube may be a good candidate for rebuilding. The following is a procedure that can be used to determine if the tube experienced a catastrophic failure.

Visual

Perform a good visual inspection of the tube. Pay particular attention to broken seals, arc marks on the tube surfaces, water inside the tube, a white or yellow powder inside the tube and any discoloration on the inside metal or insulating surfaces. Overheated components will exhibit dark brown or black discoloration and extreme overheating will result in a flaky material on the metal surfaces.

Shorts & Continuity

With an ohmmeter, check for shorts and continuity between the cathode, grid and anode. The method is to connect one ohmmeter lead to the filament terminal and the other to the Filament/cathode terminal. The cold resistance of the filament should be indicated. Since the cold resistance of this filament is in the milli-ohm range, the reading will show on a typical commercial ohmmeter as a short or zero resistance. However, the filament of the RS3500CJ is made of multiple strands of wire that are woven into a mesh-like structure and any one intact strand will indicate that the entire filament is good. This problem will be addressed in a later test.

Next, remove the test lead from the filament/cathode terminal and place it on the grid terminal. The resistance should be infinite indicating an open circuit. Remove the lead from the grid and connect it to the anode. Again, the reading should be infinite. Then, remove the lead from the filament terminal and connect it to the grid and, again, there should be no continuity.

If the tube fails to pass any of the above tests, it isn't good to be placed in the equipment and no further testing is necessary. However, this testing isn't adequate to determine if a tube is a candidate for rebuilding. This will be determined in the next section.

High Pot Testing

The equipment required for this test is a high voltage power supply capable of supplying 30kV limited to 5mA. For preliminary tube testing, it doesn't matter if the supply is AC or DC but care must be taken to ensure the AC type supply has the voltmeters calibrated in peak volts not RMS volts. The purpose of this test is to determine the condition of the vacuum in the tube, check for gas, leakage across the insulators and/or whether there is any cold emission of the elements in the tube. It will also test for loose wires on the grid and/or cathode that exist but were not making contact with other elements during the short/continuity tests done previously.

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Connect the negative, neutral or ground lead to the filament/cathode terminal. Connect a short jumper wire between the filament connector and the negative lead. Connect the positive lead to the grid. Turn up the voltage to 6kV in about 15 seconds. A few different possibilities can occur. Normally, as the voltage increases the current will increase roughly in a linear relationship and will stabilize at less than 1 mA. If the voltage remains at zero and only the current increases, there is a grid-filament short. This can happen when the high voltage has attracted a broken filament or grid strand to make contact with the other element. This is cause for rejecting the tube. If the voltage increases to less than 6kV and the current exceeds 1 mA, there is gas, and/or leakage and/or grid emission present. It is possible to have all three conditions simultaneously and this can occur when a tube is stored on a shelf for a long period of time. All three conditions can be improved by leaving the voltage applied and gradually increasing the voltage until the 6kV is reached and the current falls below 1 mA. Even if the current can't be reduced, it doesn't necessarily mean the tube is a reject but requires further attention and evaluation. Operation in the generator at a reduced power level of operation with filament only applied to the tube will often re-process the tube. This is an operation termed "aging" and is a usual part of the manufacturing process. It is also possible to see jumps in the voltage and current meters on the hipot tester. This can be caused by bursts of gas or arcing across high points on the grid and filament. Again, this condition is not in itself a reason to reject a tube. The tube will usually "age in" over a short time. This is also a normal part of the manufacturing process known by many different names; sparking, debarnacling and spot-knocking being some examples. Essentially an arc on a sharp point of a tube element causes a locally high temperature that melts the point flat.

The next step is to connect the Hipot Tester negative lead to the grid, connect a jumper between the grid and filament and connect the positive lead to the anode. Slowly increase the voltage to 30kV. The observations will be similar to that seen during grid testing but will be more pronounced because of the higher voltages. If the voltage increases to a point and falls off as there is a corresponding increase in current, the tube probably has a vacuum leak and should be rejected. The readings indicate there is gas (air) inside the tube that is ionizing as the voltage is increased similar to a neon or fluorescent lamp. This ionization can be seen in a glass envelope tube as a purple or blue glow.

One side note — there is an instrument commonly called a Megger. It was originally developed to test insulation breakdown on wire that would typically be found on motor windings, transformers electrical wiring runs, etc. They usually generate the voltage with a hand crank although there are now electronic units available. In general, the output voltage is low, 1000 – 1500 volts. These units are only marginally better than an ohmmeter for testing and are not a substitute for a Hipot tester.

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Power Tube Conditioning

The term “conditioning” of power tubes refers to a series of procedures that are done to the elements of the tube to return them to the condition they were in when received from the manufacturer.

During the manufacturing of power tubes, various processes introduce different gases into the material the tubes are made of. One example is the many brazing operations that are done in a hydrogen atmosphere to ensure the materials are in an ultra-pure environment to clean the materials and remove any residual oxides. Some of this hydrogen permeates through the grain boundaries of the material and must be removed during the exhaust process. After a tube is finally assembled, it must go through an exhaust process. During this exhaust procedure, the different tube elements are raised to temperatures that far exceed those at which they can expect to operate. The first part of the exhaust processing generally is a bake-out where the tube is exposed to 500-600 deg. C, often for 12 hours or more. Then each element is operated with high power to heat them. The purpose of these operations is to drive the gases from the material to ensure there will be a high vacuum in the tube over its life.

However, even after being subjected to all this processing, there will always be some residual gas trapped inside the tube that will evolve during operation. This evolution usually will not be noticed on a tube that has been operated on a periodic basis. Tubes that are installed for the first time or those that have been in a reserve stock for a long period (greater than 4-6 months) should be conditioned. In addition to the gas situation, there is another phenomenon that appears in vacuum devices. Some elements will grow “whiskers” on their surfaces that must be removed before they are placed in service.

In general, the conditioning process can be divided into a filament conditioning, often referred to as simply aging, and a high voltage aging. The filament aging is usually done first and effectively soaks up some of the residual gas and reforms a good emission layer on the cathode. The high voltage aging is to “bury” any remaining gas and to burn off the whiskers that may have formed. This process is also referred to as “deburring”, “hipotting”, “spot-knocking” or “debarnacling.”

Equipment for the filament aging already exists, if it can be freed up for a few hours. The equipment that uses the tube is the ideal place to do the processing. The power required is certainly there and the cooling system is in place. Remember, the cooling **MUST** be on even though only the filament is being operated. Of course, the filament circuit can be duplicated but does require a separate transformer and associated contactors, breakers, etc. It also requires another cooling system. This would constitute an expense that probably can’t be justified.

Fortunately the equipment for spot-knocking is relatively simple, inexpensive and readily available. It is a current limited high voltage power supply, 5mA at 30 kV is usually sufficient. Either an AC or DC supply can be used with only minor differences in procedure (AC voltages must be

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peak voltage). Since high voltages are involved during this processing, there should be some kind of interlocked enclosure for safety and be constructed from steel approximately 2mm thick to eliminate any radiation hazard. Since the typical high power tube is usually quite heavy, the enclosure should be large enough to accommodate a cart. This will also help prevent the accidental shocks the tube might experience from rough handling.

When conditioning a tube, the filament aging should be done first. Although it is sufficient to only heat a filament for about 5 minutes during normal operation, a fresh tube should be operated for 3-4 hours before any high voltage is applied. The voltage should be monitored for a variation of +/-5% during its life. If it's suspected that a tube is close to the end of its life, up to 120% of the filament voltage can be applied for 5 minutes and then 3-4 hours at rated voltage may give a few hundred more hours of life. This is not a repair and should only be done in an emergency since there is a very real danger the filament will burn out.

After the filament aging, the spot-knocking can be done. Connect the positive lead of the power supply to the anode and the ground lead to the grid and filament terminals simultaneously. Never apply voltage to a tube when a grid or filament terminal is "floating." Slowly raise the voltage and allow arcing to occur between the elements. This arcing will drive any gas molecules into the inner materials as well as burn off the whiskers. Most large power tubes will easily withstand 30kV when operated in this manner but the purpose of the aging is to expose the tube elements to a higher voltage than they will ever experience in operation. The next step in the process is to connect the filament to the ground lead of the power supply and the positive lead to the grid terminal. Nothing need be connected to the anode. Again, slowly raise the voltage to 6kV. If there is an indication of excessive current during the 30kV or the 6kV test (>2mA), further tests may be required to determine if there is a more serious problem.

Even after all this conditioning, it is still a good policy to slowly increase the power when the tube is first being used in the equipment. This will ensure any residual arcing that may occur will only occur at the lowest energy level of the equipment. Although this processing may appear time consuming, it usually only requires 1-2 hours of operator time and will pay back many times in minimizing down time.

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Dielectric RF Generator, Preventive Maintenance

In the simplest terms, dielectric heating is the application of radio frequency energy (RF) to an insulator or semi-conductor material to increase its temperature. The system depends on the material having a high enough loss factor that will allow the RF energy to be converted to heat. There are four general areas that utilize this technique:

1. Plastic welding
2. Wood glue curing
3. Plastic preheating
4. Moisture removal or drying

The machines may be designed to perform a particular task but the differences are usually in the mechanical mechanisms. Except for frequency and power levels, the same maintenance techniques can be applied universally. The subject of this article is primarily the radio frequency (RF) generator that supplies the power to heat the dielectric material. This generator outputs power to some type of work coil, platen or similar device that is in close proximity to the dielectric and effectively transmits the RF energy to the dielectric to be absorbed. The dielectric need not be in intimate contact with the work coil.

At first glance, a dielectric machine can be intimidating. Even an experienced technician will stop and analyze an RF generator before blindly proceeding to disassemble any of the components. As with most mechanical or electronic devices, separating the unit into functional sections will usually allow a better understanding of its operation.

The analysis can begin by separating the RF welding generator into its major pieces or subassemblies. Most generators include the following;

1. Housing or cabinet in which all the components are placed.
2. Power supply to convert the line voltage to DC.
3. Oscillator section that includes the power tube and its associated circuitry.
4. Cooling system to remove heat from the power tube and other related components.
5. Matching section.
6. Control section that includes circuit breakers, power adjustment knobs, and other external adjustment controls or information displays.
7. Mechanical and output section that contains any special fixtures, robotics, loading, positioning devices, etc. These are usually not directly part of the generator but work in conjunction with it.

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If possible, allow a maintenance technician to go beyond general maintenance when he first works on a unit. You probably have a machine that could use a lot of maintenance, almost to the point of rebuilding the machine completely. Rebuilding does not take much longer than extensive maintenance, and will result in a more thorough repair job. It will also allow the technician a chance to really learn how the various parts of the generator work and provide an opportunity for a preventive maintenance program to be started.

This article explains how to get each section of an RF generator into good working order. Once the generator is repaired and put on a preventive maintenance schedule, it should stay in top condition.

Remember safety cannot be stressed enough. Tube mill welding generators operate at high voltages and must be disconnected or locked out before any maintenance can be performed.

Before starting, you must complete a few general tasks. First, locate the schematic diagram for the generator. If it is not available, draw one as detailed as possible. Include all numbers on components, values, types of materials used, even the dimensions of the coils that are used. Then photograph the unit inside and out.

Pay particular attention to component placement. Take time to identify each component and its purpose. This, of course, is much easier with a schematic but must be done regardless.

During this time, the unit should be vacuumed to remove all the accumulated dust & dirt. This dirt may have to be loosened with a brush first. Do not use an air hose to blow the dust out, because you will probably just blow it further into the generator. Look at all the connections, components and insulators for any signs of overheating or arcing. Check screw heads to see if they have loosened and if corona is being generated around them. Eventually the corona will start to track carbon across insulators and arcing will occur. Most of the time a problem of this type can be determined by a good visual inspection.

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Cabinet

The cabinet of the RF generator is much more than a case in which to store everything. Most of the safety interlocks are located someplace on the cabinet doors. These interlocks, whether mechanical mercury switches or pin-and-socket types, should be tested for operation. The doors should also include some RF gasket or spring stock material to keep energy from radiating from the enclosure. The inside enclosures should also be checked to ensure energy isn't getting into other components like timers, meters, or controls that could cause false triggers and erroneous readings.

Some units also have mechanical shorting mechanisms connected to the doors to automatically connect all high voltage components to ground if the enclosure is opened. Most of the other components are somehow connected to the cabinet, so double-check for tight, clean connections and signs of arcing.

Although they are part of the cooling section, the air filters are located on the cabinets and should be checked for dirt that will block proper airflow. Also, objects such as boxes should be cleared away so they do not block the vents. Some systems have an air flow and/or pressure switch interlocked to the power to prevent operation with improper airflow. This should also be checked for operation.

Power Supply

This section develops the high voltage required for the operation of the oscillator tube, as well as filament voltage. In most cases, it also contains the connections to the outside power source and has the main disconnect switch and circuit breakers. It may also include auxiliary power sources for special equipment associated with the output section. All connections should be cleaned, tightened, inspected for oxidation, discoloration, pitting or arcing, and repaired or replaced as required.

Filament voltage is generally alternating current (AC) and is supplied through a step down transformer. Since most power tube filaments operate at low voltage and high current, the interconnection cables will not necessarily be highly insulated but will be made of heavy gage wire (usually stranded copper for current carrying capability and heat dissipation). Terminations are typically heavy spade lugs and kept as short as possible.

Clean and tight connections are particularly important due to the high currents involved. For example, a resistance of only 1/100 ohm on a typical tube that requires 100 amperes will result in a loss of one volt to the tube filament. Since a modern tube requires a filament voltage of 7-13 volts, the voltage loss will almost always result in insufficient output power to the load. Filament voltage should always be checked at the tube terminals with a high quality meter.

High voltage (DC for the power tube anode) can be generated by tube circuits (vacuum, mercury vapor or hydrogen filled tubes), or by solid-state rectifiers. In this case, the voltages will be high, normally thousands of volts, and the currents relatively low. Clean, tight connections are also important here to prevent corona.

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Spacing of components is also important to prevent arcing. Spacing will differ depending on the voltage, insulation material used etc., so original material should be replaced at the same distance as that originally provided by the manufacturer.

Oscillator

This oscillator contains the power tube and the associated circuitry. All oscillators of this type will have a tank circuit consisting of at least one capacitor and a coil in parallel that determines the frequency of operation. They also contain some method of feedback to the grid circuit to sustain oscillations and connections to the tube filaments. Other components, called suppressors, are connected to prevent spurious oscillations at unwanted frequencies. Suppressors can be capacitors connected to various tube elements or frequency traps made up of any combination of resistors, capacitors or inductors. Beads of ferrite material are also used to absorb unwanted RF energy.

It is not important which components are used, as long as they are repaired and replaced as necessary. Often, the technician will not know the purpose of these components and will leave them out of the circuit or replace them with whatever components are available, not necessarily of the same value. The generator might work fine without the correct components. However, they are there to protect against a transient condition, as a fuse is, so it is important that they be used correctly. The purpose of the photographs taken before disassembly is to ensure that the components, including routing of interconnecting wires, are replaced in their exact original positions. A component or wire placed incorrectly can act as an antenna and channel RF energy to an inappropriate area. This danger can be minimized by replacing things exactly as they were.

Again, a good visual inspection is the technician's best ally. The RF causes most of the ionization and carbon tracking found in a generator. It often starts in an area that's covered, such as under a screw head, so disassembly is needed. Cleaning can be done only with certain chemicals, and alcohol is probably the safest. Although it is not a solvent for all materials it won't leave a residue and is relatively safe from flash fires. Some insulators may have to be completely removed and cleaned with a detergent or sandblasted to remove carbon. If insulators show any signs of deterioration, they should be replaced with the same material.

Cooling Systems

Overheating is probably the biggest enemy of components, especially power tubes. Over-voltage on the filament will shorten life considerably and improper cooling will cause out gassing of the other elements. In extreme cases, melting of the tube anode and/or grids may occur. Most of the generators used in dielectric applications rely on air- or radiation-cooling while induction-heating applications typically use water-cooling.

If the previous recommendations have been followed, the blower motors, air directors and filters have been inspected and/or changed. Air is also used to cool the filament and grid terminals. The air blowers must be positioned so the air is directed uniformly over the surface of the terminals to prevent the chance of strain being set up by improper cooling.

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Tubes can be removed, washed in water, and scrubbed with a medium bristle brush. They must be completely dried, dipped in alcohol to displace the water, and then air dried or blow dried (a warm hair dryer is sufficient). Radiation cooled tubes (large glass bottles without fins that are usually limited to rectifiers in power supplies) can also be washed the same way. Gloves should be worn when handling all insulators, including glass envelopes and tube ceramics, to prevent them from being touched by oils from the skin. These oils contain carbon that will cause problems when exposed to RF and high voltages, eventually tracking as discussed previously.

Temperature sensitive paint or labels placed on the tube seals will give a good indication of any potential overheating problems. An air velocity meter is also available to check airflow. Also, make sure the airflow interlocks are operating. Some generators have a time delay system that will keep the air blowers and water-cooling pumps operating for a few minutes after the filament and high voltages are shut off. Insure these circuits are not bypassed.

Water cooling is the other typical way of cooling RF tubes. As mentioned, water cooling is common for induction heating applications but air is the primary cooling medium for dielectric generators. However, tubes become physically very large beyond about 50kW and water cooling becomes more common. Two elements are needed for proper operation and long life: water purity and sufficient coolant flow. The cooling pumps supplied by the equipment manufacturer, by design, will be adequate to provide the minimum flow rate specified on the tube data sheet. Pump size and hose diameters must be maintained. The coil of cooling hose connected to the tube water jacket acts as a high resistance isolating the high anode voltage from ground. The hose is specified to be carbon free to prevent any RF coupling into the hose. Any maintenance will require the hose be replaced with the same length and type of material.

Ordinary tap water is not sufficient for cooling systems. Distilled water must be used. Even de-ionized water is not sufficient due to the high concentration of oxygen. Water purity can easily be compromised by oxygen, which can form a copper oxide on the anode cooling surfaces, destroying the heat conductivity of the copper, or cause electrolysis. Electrolysis can actually destroy the cooling passages in the tube as well as other system components. In extreme cases, oxide deposits can plug up cooling passages and stop coolant flow. Water quality must be periodically checked to ensure proper resistivity. Since the water column is exposed to the anode high voltage at one end and grounded at the other, it acts as a resistor. The more pure the water, the higher the resistance and the less power wasted by heating the water. Water should be maintained at a minimum of 1 megohm-cm at 25 deg C.

Any components that are replaced in the cooling system should be replaced with the same material. Avoid using iron or galvanized fittings or pipe, since their use will contaminate the water system in a matter of hours.

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Matching Section

The matching section ensures the maximum possible power available is transferred from the generator to the load by matching the two sections by impedance. The impedance of the generator is essentially constant but the load changes depending on the particular work piece being used. Matching is either done automatically or set for optimum conditions manually.

This section can be identified by controls labeled “Load tuning”, “Load matching” or “Output tuning.” The section can contain any combination of capacitors, coils, transformers, variable ratio transformers or auto-transformers. There are probably as many schemes to match impedance as there are generator manufacturers, but all have the components mounted in an enclosure to insure all connections remain clean and tight.

This section requires little maintenance except to be sure everything is making good electrical contact. Since all the power must pass through this section, it is possible to have power losses even because of a mismatch of impedances. This is usually obvious since some components will quickly overheat, which causes heavy discoloration.

Control Section

Machine controls come in many different configurations, from very elaborate, to a simple on-off switch. In general, they require little care except for an occasional vacuuming and wiping down with alcohol. The voltages and currents involved are relatively low so arcing or corona is rarely a problem.

Any circuit breakers located in this section should be tested for proper operation, as should indicator lamps and other switches. Meters on the panel should be calibrated periodically. These meters might be part of the cabinet section and usually measure anode voltage, anode current and grid current. Since they are the first indication of some variance in the operation of the equipment, they should be kept in proper repair and calibrated on a periodic basis.

More machines are now being produced or retrofitted with programmable logic controls. Essentially, they are embedded computer controlled devices that receive operating status information from various sensors regarding open interlocks, over-voltage, currents or temperature, low or high air or water flow, etc. Depending on their programming, they can also adjust parameters, shut down the equipment, sound alarms, etc. Programmable logic controls are usually purchased by the generator manufacturer for inclusion in the generator, so they will have their own maintenance/repair instructions.

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Mechanical & Output Section

The mechanical and output section is a catch-all section for the other parts to the system where the actual work is done. In the case of a dielectric heating machine, this section can consist of a relatively simple locating fixture to weld plastic components, to a highly automated system that will pick, position cure and inspect wood assembly and veneering products. Machine vision and inspection systems are recently beginning to appear on some of the machines.

Maintenance is similar to that for the control panel, although it is often more complicated because of the combination of motors and mechanical devices that may be used. Motors need controllers and limit switches that require testing and adjusting, as well as mechanisms that have to be inspected for smooth operation and proper lubrication. Again, much of this equipment is purchased by the generator manufacturer or even adapted locally by the owner.

The electronics portion has high RF on it, which is the output from the matching section, so the same rules apply as on the other RF carrying elements. During operation of the equipment, watch for arcing at the work coils or platens. Not only could arcing ruin the work, but the RF can be reflected through the matching section and into the oscillator and cause arcing on some of the components.

Preventive Maintenance

It certainly would not be effective to rebuild a generator and then fail to maintain its rebuilt condition. Each tube manufacturer must determine their own conditions, but following is a recommended program for a 40-hour-a-week operation:

Weekly

1. Check and record all meter readings, looking for any obvious changes.
2. Check and/or replace filters and inspect all cooling fans and water pumps for proper operation.
3. Ensure the resistivity of the water system meets minimum requirements
4. Open the cabinet and give the oscillator section a good visual inspection.

Monthly

1. Inspect and test all interlocks, limit switches, and other safety related items.
2. Check and record oscillator tube filament current.

Quarterly

1. Rotate the oscillator tube with the spare tube, following proper start-up procedures. Note that all high voltage components exhibit an out gassing of the internal elements and after a short period of time a growth of “whiskers” on their surface may appear. Rotating tubes allows them to be re-aged to a like-new condition with little chance of damage. This will ensure a working spare is available and will force the cleaning of the tube connections.
2. Disassemble, inspect and clean all RF related components and contacts.

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Semiannually

1. Inspect and test all other components, connections and contacts.
2. Disassemble and clean as necessary.

Conclusion

The RF generator is one of the most complicated and least understood sections in a dielectric heating machine. To ensure the machine will provide the proper quantity of heat at the proper location, the generator must be kept in proper repair. That can best be accomplished through a well-organized preventive maintenance program.

Generators are designed to provide many thousands of hours of trouble-free service. Users can help ensure their equipment meets this goal by having a thorough understanding of the operation of each component and section and perform periodic checks on them.

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Induction Heating RF Generator, Preventive Maintenance

Induction heating is the application of radio frequency energy (RF) to electrically conductive material to increase its internal temperature. The system depends on the magnetic flux component of the RF energy to generate eddy currents in the material. These eddy currents generate the losses in the material that result in the heating effect.

Except for frequency and power levels, most generators are essentially of the same design and the same maintenance techniques can be applied to all of them. It is usually the mechanical mechanisms that are different and allow the generator to perform a particular task. The subject of this article is primarily the radio frequency (RF) generator that supplies the power to heat the conductive material. This generator delivers power to some type of work coil, platen or similar device that is in close proximity to the material and effectively transmits the RF energy to the material. The work coil and work piece are essentially acting as an air core transformer. The material will not be in intimate contact with the work coil.

The first time you look at an induction machine, it can be intimidating. Even an experienced technician will stop and analyze an RF generator before blindly proceeding to disassemble any of the components. As with most mechanical or electronic devices, separating the unit into functional sections will usually allow a better understanding of its operation.

The analysis can begin by separating the RF heating generator into its major pieces or subassemblies. Most generators include the following;

1. Housing or cabinet in which all the components are placed.
2. Power supply to convert the line voltage to DC.
3. Oscillator section that includes the power tube and its associated circuitry.
4. Cooling system to remove heat from the power tube and other related components.
5. Matching section.
6. Control section that includes circuit breakers, power adjustment knobs, and other external adjustment controls or information displays.
7. Mechanical and output section that contains any special fixtures, robotics, loading, positioning devices, etc. These are usually not directly part of the generator but work in conjunction with it.

If possible, allow a maintenance technician to go beyond general maintenance when he first works on a unit. You probably have a machine that could use a lot of maintenance, almost to the point of rebuilding the machine completely. Rebuilding does not take much longer than extensive maintenance, but it guarantees a thorough repair job, allows a preventive maintenance program to be started, and will allow the technician a chance to really learn how the various parts of the generator work.

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This article explains how to get each section of an RF generator into good working order. Once the generator is repaired and put on a preventive maintenance schedule, it should stay in top condition.

Remember safety cannot be stressed enough. Induction heating generators operate at high voltages and must be disconnected or locked out before any maintenance can be performed.

Before starting, you must complete a few general tasks. First, locate the schematic diagram for the generator. If it is not available, draw one as detailed as possible. Include all numbers on components, values, types of materials used, even the dimensions of the coils that are used. Then photograph the unit inside and out.

Pay particular attention to component placement. Take time to identify each component and its purpose. This, of course, is much easier with a schematic but must be done regardless.

During this time the unit should be vacuumed to remove all the accumulated dust & dirt. This dirt may have to be loosened with a brush first. Do not use an air hose to blow the dust out because you will just blow it further into the generator.

Look at all the connections, components and insulators for any signs of overheating or arcing. Check screw heads to see if they may have loosened and if corona is being generated around them. Eventually the corona will start to track carbon across insulators and arcing will occur. Most of the time, a problem of this type can be determined by a good visual inspection.

Cabinet

The cabinet of the RF generator is much more than a case in which to assemble everything. Most of the safety interlocks are located someplace on the cabinet doors. These interlocks, whether mechanical, mercury switches or pin-and-socket types, should be tested for operation. The doors should also include some RF gasket or spring stock material to keep energy from radiating from the enclosure. The inside enclosures should also be checked to ensure energy isn't getting into other components like timers, meters, or controls that could cause false triggers and erroneous readings.

Some units also have mechanical shorting mechanisms connected to the doors to automatically connect all high voltage components to ground if the enclosure is opened. Most of the other components are somehow connected to the cabinet, so double-check for tight, clean connections and signs of arcing.

Although they are part of the cooling section, the air filters are located on the cabinets and should be checked for dirt that will block proper airflow. Also, objects such as boxes should be cleared away so they do not block the vents. Some systems have an air flow and/or pressure switch interlocked to the power to prevent operation with improper airflow. This should also be checked for operation.

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Power Supply

This section develops the filament voltage and high voltage required for the operation of the oscillator tube. In most cases, it also contains the connections to the outside power source and has the main disconnect switch and circuit breakers. It may also include auxiliary power sources for special equipment associated with the output section. All connections should be cleaned, tightened, inspected for oxidation, discoloration, pitting or arcing, and repaired or replaced as required.

Filament voltage is generally alternating current (AC) and is supplied through a step down transformer. Since most power tube filaments operate at low voltage and high current, the interconnection cables will not necessarily be highly insulated but will be made of heavy gage wire (usually stranded copper for current carrying capability and heat dissipation) and will be kept as short as possible. Terminations are typically heavy spade lugs or special filament connectors supplied by the tube manufacturer.

Clean and tight connections are particularly important due to the high currents involved. For example, a resistance of only 1/100 ohm on a typical tube that requires 100 amperes will result in a loss of one volt to the tube filament. Since a modern tube requires a filament voltage of 7-13 volts, depending on the particular tube, the voltage loss will almost always result in insufficient output power to the load. Filament voltage should always be checked at the tube terminals with a high quality meter.

High voltage DC for the power tube anode can be generated by tube circuits (vacuum, mercury vapor or hydrogen filled tubes), or by solid-state rectifiers. In this case the voltages will be high, normally thousands of volts, and the currents relatively low. Clean, tight connections are also important here to prevent corona and arcing.

Spacing of components is also important to prevent arcing. Spacing will differ depending on the voltage, insulation material used etc., so original materials should be replaced at the same distance as that originally provided by the manufacturer.

Oscillator

The oscillator section contains the power tube and the associated circuitry. All oscillators of this type will have a tank circuit consisting of at least one capacitor and a coil in parallel that determines the frequency of operation. They also contain some method of feedback to the grid circuit to sustain oscillations and connections to the tube filaments. Other components, called suppressors, are connected to prevent spurious oscillations at unwanted frequencies. Suppressors can be capacitors connected to various tube elements or frequency traps made up of any combination of resistors, capacitors or inductors. Beads of ferrite material and short lengths of Nichrome wire are also used to absorb unwanted RF energy. It is not important which particular method is used, as long as the components are repaired and replaced with the identical kind and quantity as the original. Often, the technician will not know the purpose of these components and will leave them out of the circuit

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or replace them with whatever components are available, not necessarily of the same value. The generator might work fine without the correct components. However, they are there to protect against a transient condition, like a fuse, so it is important that they be used correctly.

The purpose of the photographs taken before disassembly is to ensure the components, including routing of interconnecting wires, are replaced in their exact original positions. A component or wire placed incorrectly can act as an antenna and channel RF energy to an inappropriate area. This danger can be minimized by replacing things exactly as they were.

Again, a good visual inspection is the technician's best ally. The RF causes most of the ionization and carbon tracking found in a generator. It often starts in an area that's covered, such as under a screw head, so disassembly is needed.

Cleaning can be done only with certain chemicals, alcohol probably being the safest. Although alcohol is not a solvent for all materials it won't leave a residue and is relatively safe from flash fires. Some insulators may have to be completely removed and cleaned with a detergent or sandblasted to remove carbon. If insulators show any signs of deterioration, they should be replaced with the same material.

Cooling Systems

Overheating is probably the biggest enemy of electronic components. Power tubes are especially sensitive to excess heating. Over-voltage on the filament will shorten life considerably and insufficient cooling will cause out gassing of the other tube elements. In extreme cases, melting of the tube anode and/or grids may occur. Most generators used in induction heating applications use water cooling, however, generators with output power of up to 50kW that use air as the primary cooling medium are not uncommon. Air cooled tubes are more often found in dielectric or broadcast applications. It is very common to see air cooling on the filament and grid contacts, even on water cooled tubes. If the previous recommendations have been followed, the blower motors, air directors and filters have been inspected and/or changed. The air blowers must be positioned so the air is directed uniformly over the surface of the terminals to prevent the chance of strain being set up by improper cooling.

Tubes can be removed, washed in water, and scrubbed with a medium bristle brush. They must be completely dried, dipped in alcohol to displace the water, and then air dried or blow dried (a warm hair dryer is sufficient). Radiation cooled tubes (large glass bottles without fins that are usually limited to rectifiers in power supplies) can also be washed the same way. Gloves should be worn when handling all insulators, including glass envelopes and tube ceramics, to prevent them from being touched by oils from the skin. These oils contain carbon that will cause problems when exposed to RF and high voltages, eventually carbon tracking as discussed previously.

Temperature sensitive paint or labels placed on the tube seals will give a good indication of any potential overheating problems. Air velocity meters are available to check air flow. Also, make sure

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the airflow interlocks are operating. Some generators have a time delay system that will keep the air blowers and water-cooling pumps operating for a few minutes after the filament and high voltages are shut off. Insure these circuits are not bypassed.

Two elements are needed for proper operation and long life: water purity and sufficient coolant flow. The cooling pumps supplied by the equipment manufacturer, by design, will be adequate to provide the minimum flow rate specified on the tube data sheet. Pump size and hose diameters must be maintained. The coil of cooling hose connected to the tube water jacket acts as a high resistance isolating the high anode voltage from ground. The hose is specified to be carbon free to prevent any RF coupling into the hose. Any maintenance will require the hose be replaced with the same length and type of material.

Ordinary tap water is not sufficient for cooling systems. Distilled water must be used. Even de-ionized water is not recommended due to the high concentration of oxygen. Water purity can easily be compromised by oxygen, which can form a copper oxide on the anode cooling surfaces, destroying the heat conductivity of the copper. Oxygen is also one of the elements that will contribute to electrolysis or galvanic corrosion. Electrolysis or corrosion can actually destroy the cooling passages in the tube as well as other system components. In extreme cases, oxide deposits can plug up cooling passages and stop coolant flow. Water quality must be periodically checked to ensure proper resistivity. Since the water column is exposed to the anode high voltage at one end and grounded at the other, it acts as a resistor in the anode circuit. The more pure the water, the higher the resistance and the less power wasted by heating the water. Water should be maintained at a minimum of 1 megohm-cm at 25 deg C.

Some larger tubes (150kW+) also use water for cooling the filament terminals. The usual method is to tap off a small portion of the anode cooling water with a “tee.” Any components that are replaced in the cooling system should be replaced with the same material. Avoid using iron or galvanized fittings or pipe; their use will contaminate the water system in a matter of hours.

Matching Section

The matching section ensures the maximum possible RF power available is transferred from the generator to the load by matching the impedance of the two sections. The impedance of the generator can be considered constant but the load will change, depending on the particular work coil and product used. Matching can be done automatically or set for optimum conditions manually.

This section can be identified by controls labeled “Load tuning”, “Load matching” or “Output tuning.” The section can contain any combination of capacitors, coils, transformers, variable ratio transformers or auto-transformers. There are probably as many schemes to match impedance as there are generator manufacturers, but all have the components mounted in an enclosure to insure all connections remain clean and tight. In smaller generators, this section may be located in the cabinet or be an integral part of the oscillator section. This section requires little maintenance except to be sure everything is making good electrical contact. Since all the power must pass through this section,

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it is possible to have power losses because of an impedance mismatch. This is usually obvious since some components will quickly overheat, which causes heavy discoloration. A mismatch can also be seen as an increase in anode cooling water temperature.

Control Section

Machine controls come in many different configurations, from very elaborate, to a simple on-off switch. In general, they require little care except for an occasional vacuuming and wiping down with alcohol. The voltages and currents involved are relatively low so arcing or corona is rarely a problem. Any circuit breakers located in this section should be tested for proper operation, as should indicator lamps and other switches. Meters on the panel should be calibrated periodically. These meters might be part of the cabinet section and usually measure anode voltage, anode current and grid current. Since they are the first indication of some variance in the operation of the equipment, they should be kept in proper repair and calibrated on a periodic basis.

More machines are now being produced or retrofitted with programmable logic controls (PLCs). Essentially, they are embedded computer controlled devices that receive operating status information from various sensors regarding open interlocks, over-voltage, currents or temperature, low or high air or water flow, etc. Depending on their programming, they can also adjust parameters, shut down the equipment, sound alarms, and perform any number of similar functions. Programmable logic controls are usually purchased by the generator manufacturer for inclusion in the generator and they will have their own maintenance/repair instructions. Being primarily solid-state units, they have few user serviceable components.

Mechanical & Output Section

The mechanical and output section is a catch-all section for the other parts of the system where the actual work is done. In the case of an induction heating machine, this section can consist of a relatively simple locating fixture and work coil to a fully automated load, heat, quench and unload system. Machine vision and inspection systems have begun to appear on some of the machines recently.

Maintenance is similar to that for the control panel, although it is often more complicated because of the combination of motors and mechanical devices that may be used. Motors need controllers and limit switches that require testing and adjusting, as well as mechanisms that have to be inspected for smooth operation and proper lubrication. Again, much of this equipment is purchased by the generator manufacturer or even adapted locally by the owner.

The electronics portion has high RF on it, which is the output from the matching section, so the same rules apply as on the other RF carrying elements. During operation of the equipment, watch for arcing at the work coils or platens. Not only could arcing ruin the work, but the RF can be reflected through the matching section and into the oscillator and cause arcing on some of the components.

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Preventive Maintenance

It would not be cost effective to rebuild a generator and then fail to maintain its rebuilt condition. Each induction-heating user must determine their own conditions, but following is a recommended program for a 40-hour-a-week operation:

Weekly

1. Check and record all meter readings, looking for any obvious changes.
2. Check and/or replace filters and inspect all cooling fans and water pumps for proper operation.
3. Ensure the resistivity of the water system meets minimum requirements.
4. Open the cabinet and give the oscillator section a good visual inspection.

Monthly

1. Inspect and test all interlocks, limit switches, and other safety related items.
2. Check and record oscillator tube filament current.

Quarterly

1. Rotate the oscillator tube with the spare tube, following proper start-up procedures. Note that all high voltage components exhibit an out gassing of the internal elements and after a short period of time a growth of “whiskers” on their surface may appear. Rotating tubes allows them to be re-aged to a like-new condition with little chance of damage. This will ensure a working spare is available and will force the cleaning of the tube connections.
2. Disassemble, inspect and clean all RF related components and contacts.

Semiannually

1. Inspect and test all other components, connections and contacts.
2. Disassemble and clean as necessary

Conclusion

The RF generator is one of the most complicated and least understood sections in an induction heating machine. To ensure the machine will provide the proper quantity of heat at the proper location, the generator must be kept in proper repair. That can best be accomplished through a well-organized preventive maintenance program. Generators are designed to provide many thousands of hours of trouble-free service. Users can help ensure their equipment meets this goal by having a thorough understanding of the operation of each component and section and perform periodic checks on them.

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Steel Mill RF Generator, Preventive Maintenance

In the simplest terms, tube and pipe is produced by a mill that rolls flat stock material into a round shape and welds the two edges together, and cuts the resulting homogeneous pipe to some predetermined length.

The subject of this article is the radio frequency (RF) generator that supplies the power to heat the edges of the material sufficiently to cause a weld. This generator outputs power to a multitermed coil around the pipe, which transfers the power to the point at which the material edges first come together.

At first glance, a tube and pipe-welding generator can be intimidating. Even an experienced technician will stop and analyze an RF welding generator before blindly proceeding to disassemble any of the components. As with most mechanical or electronic devices, separating the unit into functional sections will usually allow a better understanding of its operation.

The analysis can begin by separating the RF welding generator into its major pieces or subassemblies. Most generators include the following;

1. Housing or cabinet in which all the components are placed.
2. Power supply to convert the line voltage to DC.
3. Oscillator section that includes the power tube and its associated circuitry.
4. Cooling system to remove heat from the power tube and other related components.
5. Matching section.
6. Control section that includes circuit breakers, power adjustment knobs, and other external adjustment controls or information displays.
7. Mechanical and output section that contains any special fixtures, robotics, loading, quenching devices, etc. These are usually not directly part of the generator but work in conjunction with it.

If possible, allow a maintenance technician to go beyond general maintenance when he first works on a unit. You probably have a machine that could use a lot of maintenance, almost to the point of rebuilding the machine completely. Rebuilding does not take much longer than extensive maintenance, and will result in a more a thorough repair job. It will also the technician a chance to really learn how the various parts of the generator work and provide an opportunity for a preventive maintenance program to be started.

This article explains how to get each section of an RF welding generator into good working order. Once the generator is repaired and put on a preventive maintenance schedule, it should stay in top condition.

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Remember safety cannot be stressed enough. Tube mill welding generators operate at high voltages and must be disconnected or locked out before any maintenance can be performed.

Before starting, you must complete a few general tasks. First, locate the schematic diagram for the generator. If it is not available, draw one as detailed as possible. Include all numbers on components, values, types of materials used, even the dimensions of the coils that are used. Then photograph the unit inside and out.

Pay particular attention to component placement. Take time to identify each component and its purpose. This, of course, is much easier with a schematic but must be done regardless.

During this time the unit should be vacuumed to remove all the accumulated dust & dirt. This dirt may have to be loosened with a brush first. Do not use an air hose to blow the dust out, because you will probably just blow it further into the generator.

Look at all the connections, components and insulators for any signs of overheating or arcing. Check screw heads to see if they have loosened and if corona is being generated around them. Eventually the corona will start to track carbon across insulators and arcing will occur. Most of the time a problem of this type can be determined by a good visual inspection.

Cabinet

The cabinet of the RF welding generator is much more than a case in which to store everything. Most of the safety interlocks are located someplace on the cabinet doors. These interlocks, whether mechanical mercury switches or pin-and-socket types, should be tested for operation.

The doors should also include some RF gasket or spring stock material to keep energy from radiating from the enclosure. The inside enclosures should also be checked to ensure energy isn't getting into other components like timers, meters, or controls that could cause false triggers and erroneous readings.

Some units also have mechanical shorting mechanisms connected to the doors to automatically connect all high voltage components to ground if the enclosure is opened. Most of the other components are somehow connected to the cabinet, so double-check for tight, clean connections and signs of arcing.

Although they are part of the cooling section, the air filters are located on the cabinets and should be checked for dirt that will block proper airflow. Also, objects such as boxes should be cleared away so they do not block the vents. Some systems have an air flow and/or pressure switch interlocked to the power to prevent operation with improper airflow. This should also be checked for operation.

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Power Supply

This section develops the high voltage required for the operation of the oscillator tube, as well as filament voltage. In most cases, it also contains the connections to the outside power source and has the main disconnect switch and circuit breakers. It may also include auxiliary power sources for special equipment associated with the output section. All connections should be cleaned, tightened, inspected for oxidation, discoloration, pitting or arcing, and repaired or replaced as required.

Filament voltage is generally alternating current (AC) and is supplied through a step down transformer. Since most power tube filaments operate at low voltage and high current, the interconnection cables will not necessarily be highly insulated but will be made of heavy gage wire (usually stranded copper for current carrying capability and heat dissipation). Terminations are typically heavy spade lugs and kept as short as possible.

Clean and tight connections are particularly important due to the high currents involved. For example, a resistance of only 1/100 ohm on a typical tube that requires 100 amperes will result in a loss of one volt to the tube filament. Since a modern tube requires a filament voltage of 7-13 volts, the voltage loss will almost always result in insufficient output power to the load. Filament voltage should always be checked at the tube terminals with a high quality meter.

High voltage (DC for the power tube anode) can be generated by tube circuits (vacuum, mercury vapor or hydrogen filled tubes), or by solid-state rectifiers. In this case the voltages will be high, normally thousands of volts, and the currents relatively low. Clean, tight connections are also important here to prevent corona.

Spacing of components is also important to prevent arcing. Spacing will differ depending on the voltage, insulation material used etc., so original material should be replaced at the same distance as that originally provided by the manufacturer.

Oscillator

This oscillator contains the power tube and the associated circuitry. All oscillators of this type will have a tank circuit consisting of at least one capacitor and a coil in parallel that determines the frequency of operation. They also contain some method of feedback to the grid circuit to sustain oscillations and connections to the tube filaments.

Other components, called suppressors, are connected to prevent spurious oscillations at unwanted frequencies. Suppressors can be capacitors connected to various tube elements or frequency traps made up of any combination of resistors, capacitors or inductors. Beads of ferrite material are also used to absorb unwanted RF energy.

It is not important which components are used, as long as they are repaired and replaced as necessary. Often, the technician will not know the purpose of these components and will leave them out of the circuit or replace them with whatever components are available, not necessarily of the

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same value. The generator might work fine without the correct components. However, they are there to protect against a transient condition, as a fuse is, so it is important they be used correctly.

The purpose of the photographs taken before disassembly is to ensure the components, including routing of interconnecting wires, are replaced in their exact original positions. A component or wire placed incorrectly can act as an antenna and channel RF energy to an inappropriate area. This danger can be minimized by replacing things exactly as they were.

Again, a good visual inspection is the technician's best ally. The RF causes most of the ionization and carbon tracking found in a generator. It often starts in an area that's covered, such as under a screw head, so disassembly is needed.

Cleaning can be done only with certain chemicals, and alcohol is probably the safest. Although it is not a solvent for all materials, it won't leave a residue and is relatively safe from flash fires. Some insulators may have to be completely removed and cleaned with a detergent or sandblasted to remove carbon. If insulators show any signs of deterioration, they should be replaced with the same material.

Cooling Systems

Overheating is probably the biggest enemy of components, especially power tubes. Over-voltage on the filament will shorten life considerably and improper cooling will cause out gassing of the other elements. In extreme cases, melting of the tube anode and/or grids may occur. Most of the generators used in induction heating applications use water cooling while dielectric generators rely more on air or radiation cooling.

If the previous recommendations have been followed, the blower motors, air directors and filters have been inspected and/or changed. Air is often used with water to cool the filament and grid terminals. Tubes can be removed, washed in water, and scrubbed with a medium bristle brush. They must be completely dried, dipped in alcohol to displace the water, and then air dried or blow dried (a warm hair dryer is sufficient).

Radiation cooled tubes (large glass bottles without fins that are usually limited to rectifiers in power supplies) can also be washed the same way. Gloves should be worn when handling all insulators, including glass envelopes and tube ceramics, to prevent them from being touched by oils from the skin. These oils contain carbon that will cause problems when exposed to RF and high voltages, eventually tracking as discussed previously.

Many of the larger tubes use air to cool the filament and grid terminals even though the anode is water-cooled. Temperature sensitive paint or labels placed on the tube seals will give a good indication of any potential overheating problems.

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An air velocity meter is also available to check air flow. Also, make sure the air flow interlocks are operating. Some generators have a time delay system that will keep the air blowers and water cooling pumps operating for a few minutes after the filament and high voltages are shut off, insure these circuits are not bypassed.

Water cooling is the other usual way of cooling RF tubes. Two elements are needed for proper operation and long life: water purity and sufficient coolant flow. The cooling pumps supplied by the equipment manufacturer are adequate to provide the minimum flow rate specified on the tube data sheet. Pump size and hose diameters must be maintained.

Ordinary tap water is not sufficient for cooling systems. Distilled water must be used. Water quality must be periodically checked to ensure resistivity. Since the water column is exposed to the anode high voltage at one end and grounded at the other, it acts as a resistor. The more pure the water, the higher the resistance and the less power wasted by heating the water. Water should be maintained at a minimum of 1 megohm-cm at 25 deg C.

Water purity can easily be compromised by oxygen, which can form a copper oxide on the anode cooling surfaces, destroying the heat conductivity of the copper, and cause electrolysis. Electrolysis can actually destroy the cooling passages in the tube as well as other system components. In extreme cases, oxide deposits can plug up cooling passages and stop coolant flow.

Any components that are replaced in the cooling system should be replaced with the same material. Avoid using iron or galvanized fittings or pipe, since their use will contaminate the water system in a matter of hours.

Matching Section

The matching section ensures the maximum possible power available is transferred from the generator to the load by matching the two sections by impedance. The impedance of the generator is essentially constant but the load changes depending on the particular work piece being used. Matching is either done automatically or set for optimum conditions manually.

This section can be identified by controls labeled “Load tuning”, “Load matching” or “Output tuning.” The section can contain any combination of capacitors, coils, transformers, variable ratio transformers or auto-transformers. There are probably as many schemes to match impedance as there are generator manufacturers, but all have the components mounted in an enclosure to insure all connections remain clean and tight.

This section requires little maintenance except to be sure everything is making good electrical contact. Since all the power must pass through this section, it is possible to have power losses even because of a mismatch of impedances. This is usually obvious since some components will quickly overheat, which causes heavy discoloration.

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Control Section

Machine controls come in many different configurations, from very elaborate, to a simple on-off switch. In general, they require little care except for an occasional vacuuming and wiping down with alcohol. The voltages and currents involved are relatively low so arcing or corona is rarely a problem.

Any circuit breakers located in this section should be tested for proper operation, as should indicator lamps and other switches. Meters on the panel should be calibrated periodically. These meters might be part of the cabinet section and usually measure anode voltage, anode current and grid current. Since they are the first indication of some variance in the operation of the equipment, they should be kept in proper repair and calibrated on a periodic basis.

More machines are now being produced or retrofitted with programmable logic controls. Essentially, they are embedded computer controlled devices that receive operating status information from various sensors regarding open interlocks, over-voltage, currents or temperature, low or high air or water flow, etc. Depending on their programming, they can also adjust parameters, shut down the equipment, sound alarms, etc.

Programmable logic controls are usually purchased by the generator manufacturer for inclusion in the generator, so they will have their own maintenance/repair instructions. Contrary to popular belief, they are not 100% maintenance free; there is a battery that must be replaced about every 3-5 years.

Mechanical & Output Section

The mechanical and output section is a catch-all section for the other parts to the system where the actual work is done. In the case of a tube and pipe mill, this section is the relatively simple multiturned coil previously discussed and does not contain elaborate mechanisms.

Maintenance is similar to that for the control panel, although it is often more complicated because of the combination of motors and mechanical devices that may be used. Motors need controllers and limit switches that require testing and adjusting, as well as mechanisms that have to be inspected for smooth operation and proper lubrication. Again, much of this equipment is purchased by the generator manufacturer or even adapted locally by the owner.

The electronics portion has high RF on it, which is the output from the matching section, so the same rules apply as on the other RF carrying elements. During operation of the equipment, watch for arcing at the work coils or platens. Not only could arcing ruin the work, but the RF can be reflected through the matching section and into the oscillator and cause arcing on some of the components.

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Preventive Maintenance

It would not be effective to rebuild a generator and then fail to maintain its rebuilt condition. Each tube manufacturer must determine their own conditions, but following is a recommended program for a 40-hour-a-week operation:

Weekly

1. Check and record all meter readings, looking for any obvious changes.
2. Check and/or replace filters and inspect all cooling fans and water pumps for proper operation.
3. Ensure the resistivity of the water system meets minimum requirements.
4. Open the cabinet and give the oscillator section a good visual inspection.

Monthly

1. Inspect and test all interlocks, limit switches, and other safety related items.
2. Check and record oscillator tube filament current.

Quarterly

1. Rotate the oscillator tube with the spare tube, following proper start-up procedures. Note that all high voltage components exhibit an out gassing of the internal elements and after a short period of time a growth of “whiskers” on their surface may appear. Rotating tubes allows them to be re-aged to a like-new condition with little chance of damage. This will ensure a working spare is available and will force the cleaning of the tube connections.
2. Disassemble, inspect and clean all RF related components and contacts.

Semiannually

1. Inspect and test all other components, connections and contacts.
2. Disassemble and clean as necessary.

Conclusion

The RF generator is one of the most complicated and least understood sections in a tube and pipe mill. To ensure the weld formed on the pipe is of a high and uniform quality, the generator must be kept in proper repair. That can best be accomplished through a well-organized preventive maintenance program.

Generators are designed to provide many thousands of hours of trouble-free service. Users can help ensure their equipment meets this goal by having a thorough understanding of the operation of each component and section and perform periodic checks on them.

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Vacuum Tube Liquid Cooling System

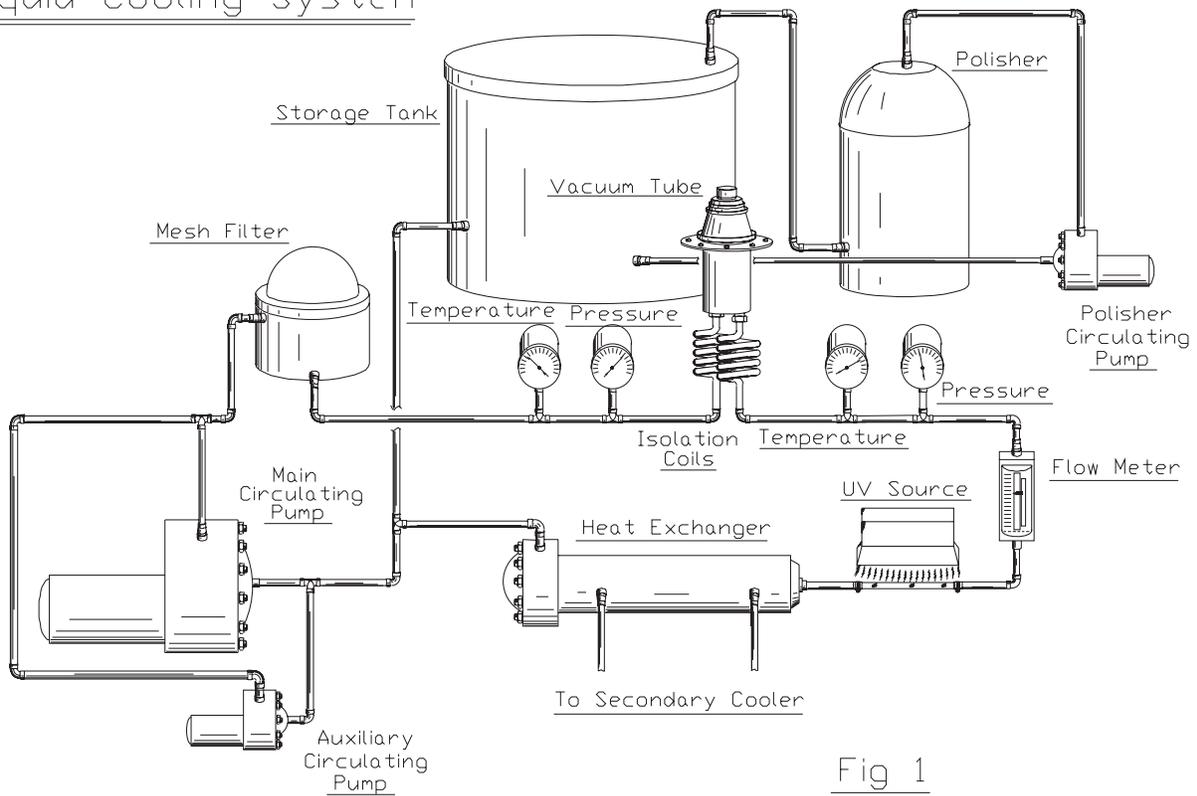


Fig 1

EJK

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Vacuum Tube Liquid Cooling Systems

The power going into a vacuum tube must be accounted for in order to conserve energy. In general, the power will be distributed in four different places;

- A. There will be useful work to the load. (70% - 75%)
- B. A small percentage of the input power will be used to sustain oscillation of the circuit. (2% - 5%)
- C. There will be circuit losses due to resistance of components, interconnecting wire, connection resistance etc. (usually <1%)
- D. The internal elements of the tube will dissipate power. (20% - 25%)

The power that is dissipated in the internal tube elements will appear as heat. Some of the power will heat the filament seals and grid seals but most will appear at the anode. The purpose of the cooling system is to remove this heat and insure the vacuum seals on the tube do not exceed the maximum temperature recommended by the manufacturer.

A liquid cooling system has many advantages; it is silent, relatively inexpensive, requires minimal maintenance, is energy efficient and will not increase the temperature of the surrounding work place. To operate properly, the system must provide an adequate quantity of coolant with a minimum purity level. The particular tube used will determine the quantity of coolant and water quality should be maintained at a minimum resistance of 1 megohm-cm. The system should be an isolated, closed system with a primary (tube) side and a secondary, externally cooled side. The two sides are interconnected through a heat exchanger. It is recommended the typical system will be similar to the pictorial shown in **Fig 1**.

In addition to the heat exchanger, the system will contain circulation pumps, temperature, pressure and flow gages, interconnecting pipes, isolation and check valves, a reservoir or storage tank, a liquid “polishing” system, secondary circulating pumps and a number of loops that are required to insure the liquid is maintained at the proper purity level. It will also contain a source of secondary cooling. The secondary cooling can be air cooling as would be found in an automobile, (**Fig. 2**), or liquid cooled as typically found on a marine engine (**Fig. 3**). Regardless of the method used, the secondary system must be isolated from the primary system to insure there is no contamination between systems.

The interconnecting pipes and fittings, as well as pumps and gages, in the primary side must be made from copper or stainless steel. Brass or bronze is often used with success but they contain zinc that can leach into the water and parts must be checked more often to ensure electrolysis or galvanic corrosion is not attacking the material. Galvanized iron pipe or fittings are particularly bad to use since the zinc and iron will contaminate a system in only a few hours. Regardless of the

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Heat Exchanging Systems

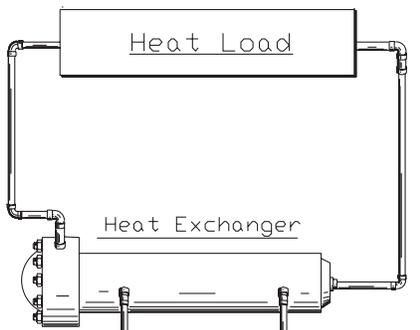


Fig. 2

Radiator

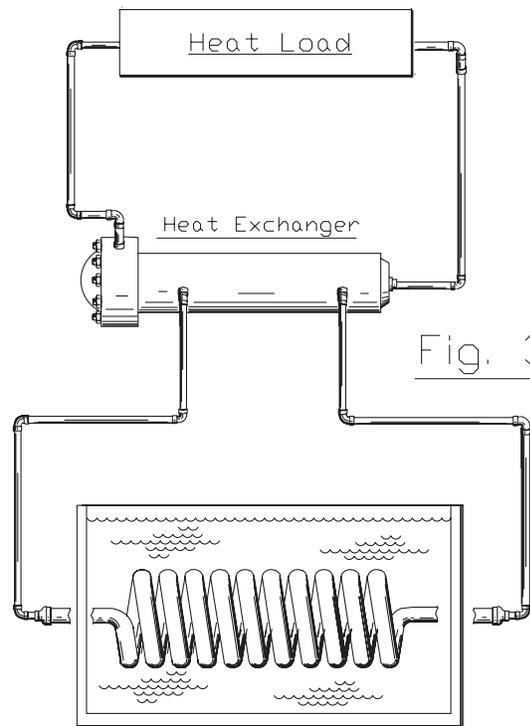


Fig. 3

Chiller

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material used, all pipe and fittings should be made of the same material to minimize the possibility of galvanic action. The high temperature and voltage gradients involved with power tubes only make the selection of proper materials more critical. Recently the use of chlorinated poly vinyl chloride, (CPVC) piping has been gaining in popularity as has polyethylene and polypropylene fittings and valves. Any of these materials will work fine if they are able to withstand the elevated temperatures they will encounter and do not have free carbon that will allow RF to be absorbed.

The secondary cooling system connected to the heat exchanger is not subject to high RF voltages or high temperatures and is otherwise completely isolated from the tube side. The strict requirements for purity are not necessary but, there is a minimum coolant flow and pressure required and the system must be maintained to ensure these conditions be present.

In general, the coolant on the primary side will be water. Chemically pure water at 25° centigrade will have a theoretical resistance of about 18.3 megohm-cm but the resistance will decrease rapidly as the water temperature increases. For example, the resistance will be about 5 megohm-cm at 50° C. and about 2 megohm-cm at 80° C. The water from the municipal water system is not nearly pure enough for a cooling system. De-ionized (de-mineralized) water should not be used unless a secondary purification is performed to remove the dissolved oxygen. All water cooled tubes for induction heaters use copper as the anode material. Oxygen, especially at elevated temperatures, will rapidly form copper oxide, which is an electrical semiconductor and a thermal insulator. In extreme cases the oxides formed can be heavy enough that they can restrict water flow. Filling the system with distilled water will eliminate all of the previously listed problems, providing the initial conditions are maintained.

In the few cases where the primary side water is exposed to the outside and there is a danger of the water freezing, the primary cooling side can use a mixture of water and ethylene glycol. The ethylene glycol must be reagent grade. Normal automobile antifreeze is mostly glycol but contains rust inhibitors that will instantly contaminate the system. Plain antifreeze is adequate for the secondary side. The mixture of water and ethylene glycol does not have the cooling capacity of pure water. A 50% - 50% mixture would be a typical solution and is about 75% as effective as pure water. The pump size would have to be increased about 25% to provide adequate coolant flow and pressure.

Referring to Fig. 1 and beginning at the heat exchanger primary side, the first item connected to the system will be the circulating pump. The size will provide for adequate cooling of the tube chosen by the equipment manufacturer. The impeller and case of the pump will be made from stainless steel or bronze. There must not be any chance of grease contaminating the system. Ensure there aren't any motor seals that are leaking. Grease will act as a thermal insulator similar to copper oxide and will result in premature component failure due to overheating. All piping connections should be dry-seal type using Teflon tape or equivalent, not a paste sealing compound. The pump must be interlocked to the filament supply. The filament power on most tubes will be enough to overheat a tube if it isn't cooled. It is also good practice to keep the cooling pump energized for 3 - 5 minutes after the system is shut off. A second pump, in parallel with the main pump, and sized

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to provide 5 - 10% of the primary pump capacity can be added to keep the coolant flowing through the system when it is de-activated. It should be interlocked to switch on when the main pump is turned off and will help eliminate the formation of mineral deposits and algae in the system.

A storage tank can be interconnected to the inlet side of the primary cooling pump if desired. It should be positioned above the tube cooling jacket so there will be a gravity feed of coolant if the rest of the system should malfunction. Its purpose is to prevent the tube from operating “dry”. It will also provide a convenient place to connect a water “polisher” that will be discussed later. In series with the flow, should be a coarse filter to remove any heavy deposits that may form. It is usually an inexpensive cartridge type filter that can be easily replaced. The equivalent to a 50 - 60 mesh filter is sufficient. Further in the system should be a temperature gage and a pressure gage. Both should be interlocked to the generator power supply so any malfunction detected by either gage will de-energize the power supply.

The next item in the series is a metallic feed-through hose barb that will connect the water column to chassis (earth) ground. All high power tubes of the type under discussion are referred to as external anode types. In this design, the coolant is directly connected to full anode DC and RF voltages. The two coils that connect to the anode are essentially two large resistors, dropping the DC and RF voltage to ground through the hose and water column. The hose must be a good insulator to DC and be carbon free to prevent RF coupling. The water column also has to have a high resistance and maintaining the water at 1 megohm-cm will insure there is minimum power loss due to extraneous heating.

The typical mounting position of this type of tube is vertical with the anode down. All tube manufacturers will indicate the recommended inlet and outlet ports with arrows or other descriptions. The intent is to keep pressure on the coolant that is in contact with the anode. This will prevent air bubbles from forming on the anode that will allow boiling of the coolant and will keep coolant on the anode in the event of coolant flow interruption. Besides the lack of cooling that occurs with boiling, the tube can be damaged from the resulting shock. If the tube is mounted with the anode up, the water connections must be interchanged, IN becomes OUT and OUT becomes IN. Incidentally, all tubes of this type should be mounted as vertical as possible to prevent sagging of the grid and filament wires during operation. The outlet coolant coil is also connected to the chassis ground, effectively isolating the entire cooling system from the rest of the generator. The minimum length of hose that should be considered is 1 meter of hose for each 1.0kVDC of anode voltage. This length can be decreased as the water purity increases providing the leakage currents in the coolant don't increase. Typically the hose is formed into a coil about 2' in diameter with the coils slightly separated to prevent arcing between coils.

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The coolant, now hot, should pass through a flow meter and a second temperature gage and finally another pressure gage. The difference of the readings between the pressure gages will yield the pressure drop in the tube cooling jacket and the isolation coils. Monitoring an increase will instantly indicate the beginning of a blockage in the system. The difference in temperature gages and the flow meter reading will indicate the efficiency of the generator, as well as provide an early warning of possible problems. All of these gages should also be interlocked to shut down the generator power in the event of a detected difference that exceeds a preset limit. By using the following formula:

$$P = Q (T_{out} - T_{in}) / 14.3$$

Where: P = Anode dissipation in kilowatts

Q = Water flow in liters / minute

T_{out} = Temperature of the outlet water in degrees Centigrade

T_{in} = Temperature of the inlet water in degrees Centigrade

the power being dissipated in the anode can be determined. The efficiency can be determined by comparing the dissipation to the input or output power of the generator. Too low an efficiency will indicate an abnormal condition, improper impedance matching between the generator and load or water with too low a resistivity being two very common conditions. Either condition will result in heat stressing other system components and wasted energy.

Operating a cooling system with very pure water at an elevated temperature provides an ideal environment for bacteria and algae to grow. Prior to returning the water to the heat exchanger, the coolant line can have a piece of quartz tubing inserted in series with the coolant flow. Exposing the water to ultra-violet light (UV) or “black light” will act to destroy both contaminants. The auxiliary by-pass pump will also act to prevent a stagnant condition and will continuously expose the water to the UV light source.

Two additional items that should be added to the system would be a “polisher” and a purity meter. A polisher is a generic term to describe any number of deionization, distillation, filtering or resin bed systems whose purpose is to maintain the water quality as that originally placed into service. Many sources are available for these units and each individual installation will have unique requirements to be considered. The ideal connection for the polisher in any system is in parallel with the storage tank and connected to operate continuously. A purity meter can also be installed in the storage tank and will continuously indicate the quality of the water. They are also available from many manufacturers in several configurations. One of the more useful is a resistivity meter with the output indicating megohm-cm directly. A more elaborate system can also be developed that would use a Programmable Logic Controller (PLC) that would activate various sub-systems when any monitored parameter drifts beyond pre-established limits.

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At times, regardless of all the controls instituted, the coolant system must be shut down and cleaned. Invariably it is due to a build-up of scale or contamination caused by a foreign material, most often from oxygen and/or carbon dioxide mixing with the coolant. Scale is a term that refers to the formation of copper or iron compounds, silicates, bicarbonates or chlorides being the most common. Scale tends to form in overlapping layers similar to fish scales. Cleaning is done by circulating a weak acid through the system in one direction and then reversing the flow to dislodge the particles. High pressure or flow isn't necessary or desired. A flow rate of 1 - 2 liters / minute is sufficient. A 10% - 15% hydrochloric or citric acid solution is adequate. After processing, the acid must be thoroughly flushed out and the system adjusted for a pH reading of 7 - 9.

The cooling system discussed is typical of that found on an RF generator. They are essentially the same in operation and maintenance procedures. They differ primarily in flow rate and components are sized proportionally. Equipment manufacturers are well aware of the cooling requirements of the various components but they must be maintained to provide the long life the components are capable of providing.

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Measuring Generator Efficiency

The power input to a tube is equal to the anode voltage multiplied by the anode current. Ideally, all this input power would be transferred, without loss, to the work that is to be heated. In reality, there are four general areas where the power will be dissipated:

1. Output power to the work piece
2. Anode dissipation of the tube
3. Feedback power to keep the oscillator functioning
4. Various circuit losses

The useful power to the work piece in a well designed, well tuned generator will be greater than 75% and will usually approach 80%. The largest loss of energy is in the anode dissipation, usually accounting for > 80% of all system losses. The energy necessary to sustain oscillation of the generator (feedback) will be < 5% and the balance of the energy will be lost as heat in various circuit components, tube filament power, circuit contact resistance, etc. The input and/or output heat must be measured to determine the generator efficiency.

There are primarily two types of cooling in use on a generator; air-cooling and water-cooling. Since most of the waste heat is generated as anode dissipation that is the area where the cooling system is concentrated. Except for the larger generators, typically >150kW, most other elements in the tube or associated circuitry are radiation cooled. The difficulty of making any measurement is being unable to account for all the heat losses.

It is generally easier to measure a water-cooled tube than one that is air-cooled so that type will be considered first. If the generator is being used in an induction heating application the work coil can be mounted around a calorimeter and the output measured by determining the differential temperature of the water and flow rate. By substituting these values in the formula:

$$P = QT / 14.3 \quad \text{where } Q = \text{the flow rate in liters / min}$$
$$T = \text{the temperature rise in deg. C}$$

output power, P, in kilowatts can be determined. If this value is about 0.7 times the product of anode voltage and current, it can be assumed the system is reasonably tuned. The system operating with the particular anode voltage, anode current and grid current as on the generator meters can now be used to determine the generator efficiency *providing no other tuning is done to the system*. This measurement is only an estimate, but it will allow for reasonable circuit efficiency since none of the other areas where heat was lost were measured. If it is easier to measure the anode cooling water, the formula will yield the anode dissipation. Dividing the resulting value by 0.3 will also give a reasonable indication of the output power.

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Measurements in air-cooling systems are more difficult. Most air-cooled tubes are used in dielectric heating applications where platens are used instead of a work coil. Replacing the platens with a coil will change the loading too much to be of value so measuring the anode dissipation is the only reasonable approach. The air flow and the temperature rise have to be determined and substituted in the formula:

$$P = QT / 50 \quad \text{where } Q = \text{the air flow in cubic meters / min.}$$
$$T = \text{the temperature rise in deg. C}$$

and the anode dissipation, P, in kilowatts can be calculated. Dividing this result by 0.3 will yield a good indication of the generator output power.

In general it is better to measure the anode dissipation because the measuring sensors for flow and temperature can be left in place to constantly monitor that parameter. If the dissipation increases, it is a good indication that the system tuning has changed due to a load change or that one of the circuit components has changed value or setting. If the dissipation changes, invariably there will be a change in the grid current that is required to deliver a given output power. In any event, it is an indication that something in the process has changed and maintenance is required.

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Amperex

General Procedures for Treatment of Ceramic Tubes

TUBE RECEIPT

Damage by transport: Transportation must be done with the tube set in a vertical position. When packaging is done with double packing, the external box must never be removed for any reason.

Tube inspection in its packing: Upon receipt of a tube, and before removing it from its container, check for any damage that may have occurred during transportation.

- inspect the inside and outside of the container
- check tilt detectors and shock detectors whenever provided on the container

Tube inspection out of its packing: Visually inspect the tube for breakage or cracks of ceramics. Test filament continuity and absence of short circuits between different electrodes. This must be checked with a circuit detector (ohmmeter) or with a 500-volt (or 1500-volt) insulation tester set. Whenever possible, operate the tube for about 4 hours in the equipment in which you intend using them. This method may reveal faults which would otherwise remain undetected.

IN CASE OF DAMAGE

Any damage, either visible external damage or suspected internal damage, should immediately be reported to the last transport company. In any event, the transport company should be informed of any tube defect, even when this is only revealed during the first test. You should also inform the insurance company immediately.

HANDLING

During installation of a tube, as well as during transport and handling, care should be taken so the ceramic is not damaged by jolts, blows or incorrect handling of tools or metallic objects. Frequent handling of the tube should be avoided to protect it from exposure to shocks.

It is also important that all ceramic parts be handled **ONLY** with clean hands or preferably gloves.

While ceramic tubes are not in operation, they should be protected from dirt or careless handling with a protective cuff made from stiff paper or cardboard.

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STORAGE

Tubes should be stored in a dry, clean, dust free room where the temperature does not vary unduly. Tubes are best stored in their original packing and should always be stored upright.

Never use an abrasive or metal pad to clean the tube.

When a tube has been stored for more than 2 years, we strongly recommend the tube filament be heated during 1 hour only before applying the HV (see also next paragraph).

TUBE OPERATION

The first time a new tube is operated, the following procedure should be carried out, after having made the above checks:

- Apply ventilation and cooling systems
- Switch on V_f for 15 minutes
- Apply V_a in steps over 15 minutes, or better still, continuously up to operating value

Tube should then be operated for one hour at full V_a and nominal load.

For high power tubes ($P_a > 20$ kW) at high anode voltages ($V_a > 10$ kV), times should be extended from 15 to 30 minutes.

PROTECTIVE MEASURES

The tube has to be protected by means of instantaneous interruption of anode voltage and an over current tripping device.

When operating voltages above 5 kV, regulations governing protection from X-ray in the country of use must be applied.

TUBE WARRANTY

If a tube fails, the tube report sheet must be completed in detail and sent without delay. Further instructions will be issued after the report has been reviewed.

Even if the warranty has expired, it is recommended that a tube report is sent whenever a tube is taken out of service, including number of service hours and probable cause of failure. This information will contribute to ongoing tube improvements.

When it is decided to return the tube to the supplier, it is recommended to ship the tube inside the original packaging.

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