High Power Pulse Klystron
E3730A
Operating Instructions

* We are appreciating your purchase of our klystron product.
* Please read carefully this instruction manual before operating the klystron tube to use it properly.
* Please keep this instruction manual carefully not to lose.

Aug, 2020

CANON ELECTRON TUBES & DEVICES CO., LTD.

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1. SAFETY PRECAUTIONS

This operation manual describes important information for preventing injury to users, personnel at manufactures employing this electron tube, and other personnel, as well as for preventing property loss and ensuring safe operation. Fully understand the meanings of the following indications and symbols before reading this manual and observe all precautions to ensure safe operation.

[Description of indications]

Indication	Meaning
 **DANGER:**	Indicates an imminently hazardous situation which, if not avoided, will result in death or serious injury.
 **WARING:**	Indicates a potentially hazardous situation which, if not avoided, could result in death or serious injury.
 **CAUTION:**	Indicates a potentially hazardous situation which, if not avoided may result in minor or moderate injury or extensive property damage (e.g. damage to machinery, units, and accessories or occurrence of a fire).

[Usage limitation and exception clause]

This electron tube is intended and designed for use in combination with amplifier for industrial devices and scientific equipment. If this electron tube is to be used with equipment other than the above, contact CANON ELECTRON TUBES & DEVICES CO., LTD. (CETD) in advance. CETD will not be held responsible for malfunction or damage caused by the use of this electron tube in applications other than those specified without prior approval.

When designing or operating equipment employing the electron tube, do not attempt to modify the electron tube and do not allow the electron tube to be operated beyond its ratings. CETD will not be held liable if these precautions are not observed.

[Warning labels]

(1) Warning labels as described in this instruction manual are attached to the electron tube. Confirm that they are attached correctly before operating the electron tube. If incorrectly attached or missing labels are found, Contact CETD.
(2) Read all the labels and fully understand their meanings to ensure safe operation of the electron tube.
(3) Maintain the labels so that they can be seen easily. Do not remove any labels or allow them to become dirty, covered, or otherwise obscured.

[Manufacturing equipment, warning indications for equipment, use of the electron tube]

(1) All equipment incorporating this electron tube must be equipped with safety mechanisms as described below.
(2) All equipment incorporating this electron tube and their operations manual must include the warning indications described below to ensure safe operation of the electron tube.
(3) To ensure safe operation of this electron tube, observe the precautions described below.
(4) For any questionable points, consult with CETD before operating this electron tube.

DANGER

(High voltage)

High voltage is supplied to the electron gun section and the ion pump section of this electron tube.

(1) The main body (body terminal) of this electron tube is used as the circuit return wire (ground wire). Securely connect it with the circuit return wire (ground) of the equipment together with the focusing coil to ensure proper grounding.
(2) Place a cover or cage around the high-voltage section to prevent it from being touched. The circuit must be designed so that a switch on the door cuts off high voltage and discharges the capacitor of the high-voltage section when the cover or cage is opened.
(3) Before replacing or performing maintenance work on the electron tube, be sure to turn OFF the power switch and discharge all residual charge by touching each electrode of the electron tube with a ground rod. Pay particular attention to the charge in the capacitor of the high-voltage section.
Never disable the door switch when the cage is open. At least two workers are required for replacement or maintenance work to ensure safety. (A person who has received training in cardiopulmonary resuscitation should be present.)
(4) When connecting / disconnecting the ion pump, be sure to turn OFF the ion pump power supply and confirm safety.

(Electromagnetic radiation)

Observe the following precautions to prevent exposure to harmful high-frequency electromagnetic radiation (in particular, to avoid the risk of eye damage) and to prevent telecommunication devices from being adversely affected:

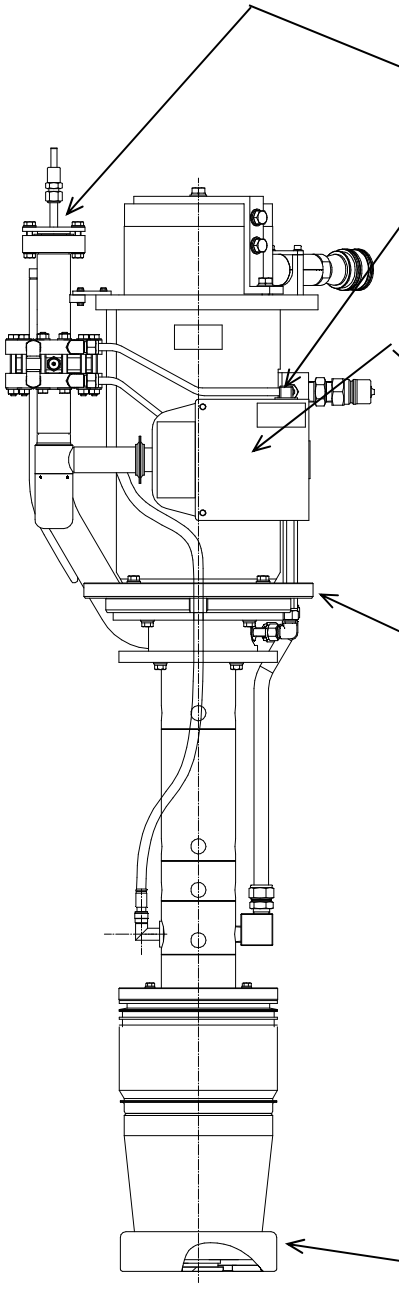
(1) Never supply high voltage when the high-frequency load (output waveguide) is not connected to the high-frequency output section.
(2) To prevent high-frequency leakage due to connection failure in the high-frequency output section and the high-frequency load, securely connect the coaxial tube, the waveguide, and the shield cover.
(3) Do not modify or remove the high-frequency contact elements such as the gasket of the cavity/output sect ion, the finger, etc. of the electron tube.
If an electromagnetic shield is mounted, do not remove or modify it.
(4) Evaluation of electromagnetic radiation leakage must be performed with the electron tube and the high-frequency load mounted in the equipment.

WARNING	
 **(X-ray radiation)**	An electron tube with a tube voltage of more than 10 kV will generate X-rays. X-ray generation increases as the voltage and current are increased. (1) Perform thorough evaluation for X-ray leakage for the equipment used in combination with this electron tube. Add shielding appropriate for the installation and operating conditions as required. Checks for X-ray generation must be performed both when high frequency output operation is performed and when it is not performed. (2) If an X-ray shield is already mounted, do not remove or modify it. (3) Since the amount of X-ray generation may change over time, perform X-ray checks periodically.
 **(Magnetic field)**	About 0.3-tesla intense magnetic field is used for this electron tube. The ion pump magnet used in this electron tube generates 0.13-tesla intense magnetic field. (1) Persons with cardiac pacemakers must not engage in the handling, operation, or maintenance of this electron tube. (2) The magnetic field of the focusing coil has been precisely adjusted. Do not allow any permanent magnets or magnetic objects to come near the electron tube or focusing coil. They will be attracted by the magnetic field, possibly resulting in personal injury or damage to the electron tube. (3) Do not place magnetic cards, hard disk drives, etc. near the electron tube.

CAUTION	
 **(Handling)**	Only qualified engineers or persons who have received the specialized training listed below are permitted to handle this electron tube. The types of specialized training required are as follows: (1) High-voltage work (4) Slinging work (2) X-ray work (5) Crane operation (3) High-frequency work (6) Electrical device work Read the operation manual carefully and fully understand the contents before handling the electron tube.
 **(Temperature, Heat)**	The following sections of the electron tube become very hot during operation: Surface of the output waveguide : about 60 degrees centigrade Surface of the focusing magnet : about 60 degrees centigrade (Room temperature of 20 degrees centigrade) (1) Do not touch any of the sections listed above during operation or immediately after operation. (After operation is stopped, the above parts will remain hot for a while.) The high temperature of these sections may cause a burn. (2) In tubes with evaporative cooling, the cooling water in the cooling-water tank is very hot, reaching temperatures near 100 degrees centigrade. Be extremely careful when handling it. Before disconnecting tubing, confirm that the cooling water has cooled sufficiently.

CAUTION	
(Weight)	Weight of this electron tube is about 35 kg. Be careful when handling this electron tube because it is very heavy. (1) Be extremely careful to ensure safety when shifting, moving, or installing this electron tube. (2) Be careful not to subject this electron tube to excessive vibration or shock because it is a precision device. (3) Use the standard packing case provided by CETD to carry or store the electron tube.
(Caution)	Use the frequency specified by laws, regulations, or standards.
(Caution)	Note the following when handling damaged or used electron tubes: (1) When handling a tube that has fractured, wear protective gloves, protective glasses, etc. because the ceramic or metal fragments are sharp and very dangerous. (2) Dispose the scrapped products according to the requirement of local regulation. If you have any questions, please contact to our local sales representatives for further information. (3) The main materials used in this electron tube are as follows: Copper, Stainless steel, Malleable iron, Nickel/iron alloy, Tungsten, Molybdenum, Alumina ceramics Note that no radioisotopes or beryllia porcelain are used. (4) Lead is used for the X-ray shield of this electron tube. Do not abrade or melt the lead because lead powder or vapor is harmful if it comes into contact with the skin or is ingested. For lead disposal, consult with specialized disposal personnel.
(Caution)	Before operating this electron tube, confirm that the cooling unit operates normally. (1) Excessive temperatures due to interruption of cooling air or water may result in damage to the tube, smoking, or a fire. (2) It is recommended that various sensors such as an airflow sensor, a water flow sensor, a pressure sensor, a thermometer, and/or a smoke sensor be provided to protect the tube.
(Caution)	Perform periodic inspection. (1) Dust from the air may build up on the electron gun section or collector section over time, leading to deterioration of withstand-voltage characteristics and interfering with cooling. (2) For devices in which insulation oil is used, dirty oil may lead to deterioration of the withstand-voltage characteristics. Ensure that the insulation oil is always clean.

Fig.1 Explanation diagram concerning safety



⚠ Danger Electromagnetic wave

Do not operate the klystron tube with the output waveguide disconnected. Output power of high frequency is about 7.5 MW and it can cause death or serious injury.

⚠ Danger High voltage

Do not remove the safety cover and touch while operating. DC voltage of 3.5 kV can cause death or serious injury.

⚠ Warning Magnetic field

The magnetic field of 0.13 tesla generated by the permanent magnet can cause to suck an iron product and scissors.

⏚ Ground

Please connect a ground line surely.

⚠ Warning X-ray radiation

X rays are radiated from all aspects of the klystron. There is fear of injury caused by the X-ray radiation.

⚠ Warning Magnetic field

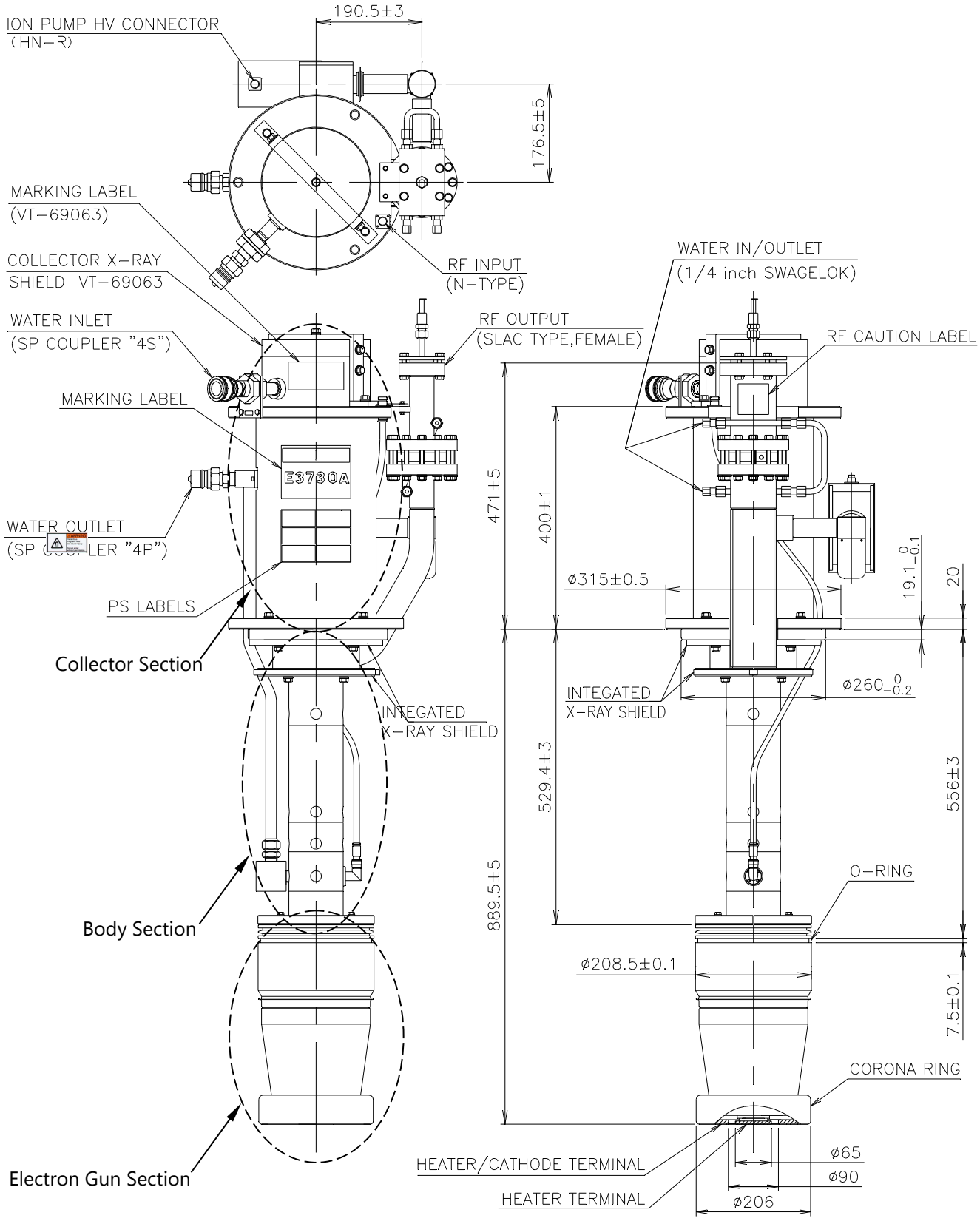
The magnetic field of 0.3 tesla generated by the focusing magnet can cause to suck an iron product and scissors.

⚠ Danger High voltage

Do not remove the safety cover and approach and touch this section. Pulse voltage of 155 kV can cause death or serious injury.

(All aspect of the klystron)

2. EACH PART NAME OF KLYSTRON TUBE



3. Marking labels

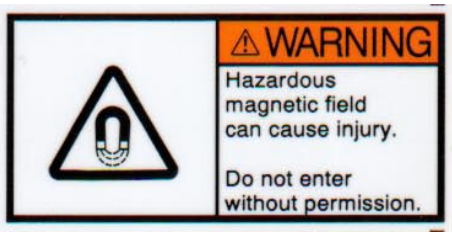
(1) Caution labels (Collector side)

Dimension : 125 x 95 mm
Material : Aluminum film

(2) Caution label (Terminal for the ion pump power supply)

Dimension : 63 x 32 mm
Material : Aluminum film

(3) Warning label (Magnet of the ion pump)

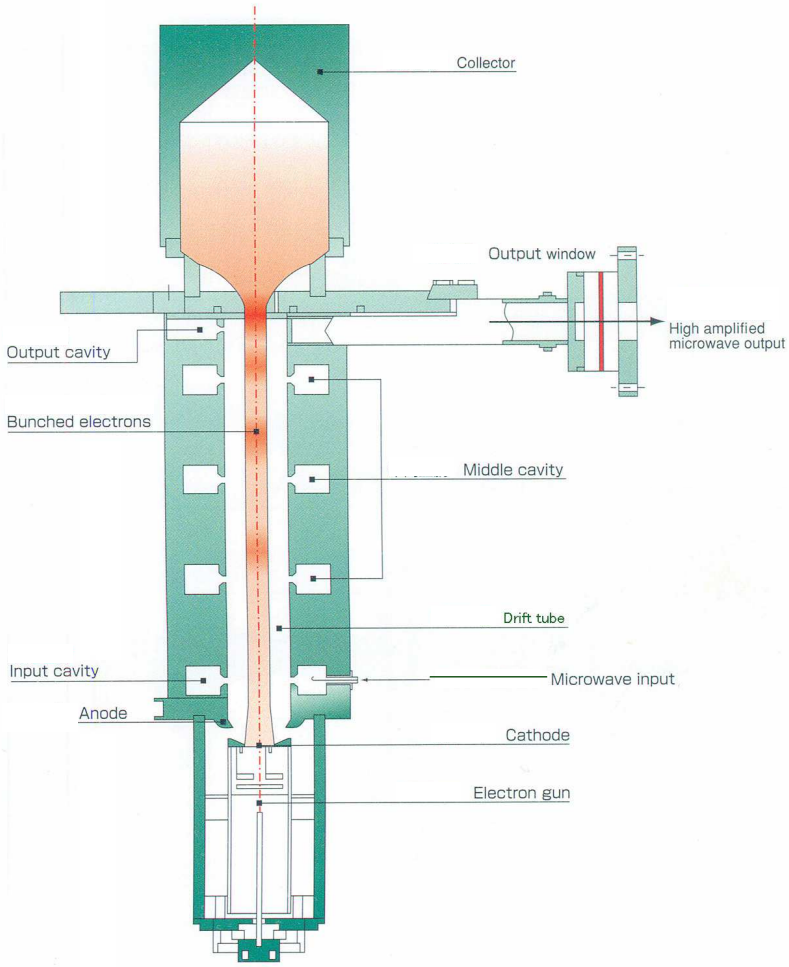


Dimension : 63 x 32 mm
Material : Aluminum film

4. Structure and theory of operation

4.1 Theory of operation

A high-power klystron with multi cavities consists of an electron gun, interaction cavities for Radio Frequency (RF), a collector, an output window and an ion pump. At the electron gun section, a heated cathode emits electrons and high voltage which is applied between the cathode and an anode generates an electron flow called an electron beam. The electron beam is focused by the electric field formed by the cathode and the anode electrodes under the influence of the magnetic field formed by a focusing magnet. Interaction section of RF consists of a drift tube and some cavities. When RF drive power is inputted into the input cavity which locates near the electron gun section, amplified RF power is outputted from the output cavity near the collector section. When RF drive is inputted into the input cavity, voltage is generated at the gap of the input cavity. This voltage modulates the velocity of the electrons. The electrons go forward in the drift tube and then density of the electrons is modulated by difference of the velocity. Resonant frequency of the intermediate cavity is tuned to frequency of the density modulation. The electrons reach next cavity and velocity is modulated further by voltage at the gap of the intermediate cavity. The electron beam has ingredient of RF power much higher than the drive power consequently. The electron beam passes through the output cavity finally and RF power of the modulated electron beam is outputted at this cavity. The amplified RF power passes through the waveguide and is outputted to outside. The electron beam which passed interaction cavities reaches collector section and the energy of the electrons is absorbed at this section. A large amount of heat is generated in the collector caused by the energy of the electron beam. Therefore, the collector needs to be cooled. According to amount of the loss, cooling method is selected to air-cooled, water-cooled, evaporation-cooled and so on.



4.2 Outline of the design

This klystron tube consists of following sections.

a. Electron gun section

The electron gun section consists of a cathode electrode, an anode electrode, and an insulating ceramic. An impregnated cathode (Iridium-coated M-type dispenser cathode) is adopted for E3730A.

b. RF interaction section

The RF interaction section consists of five resonant cavities and a drift tube. The cavities and the drift tube are cooled by water.

c. Collector

The collector is cooled by water.

d. RF Output section

The RF output section consists of an output waveguide and a pillbox type output window made from alumina ceramic.

e. Ion pump

The ion pump keeps high vacuum degree in the klystron tube.

4.3 Characteristics of the tube

E3730A is a high-power pulsed klystron especially designed to be used as a high-power microwave source for a linear accelerator. E3730A can deliver peak output power of 50 MW with a pulse width of 4.0 micro-seconds at frequency of 2856MHz. The focusing magnet of VT-68922 is available.

4.3.1 Mechanical characteristics

Dimensions	See outline drawing
Weight	Approx. 140 kg (without the X-ray shielding kit)
Mounting position	Vertical, cathode down
Cooling	Liquid water

4.3.2 Connections

RF input connector	Type “N” 50 ohms coaxial; UG-22D/U compatible
Output waveguide	WR-284
RF output flange	SLAC Rectangular type female
Ion pump	HN-R, UG-61B/U compatible
Filament/Cathode	Heater-Cathode (HK) and Heater(H) Terminals of the bottom of Electron Gun Spring Contact Rods with a pad of Monel meshed wire are available for a socket.
Cooling water	
Collector and Body	NITTO KOHKI "SP-type COUPLER" "4P" for the inlet, "4S" for the outlet
Waveguide	1/4 inch Swagelok

4.3.3 Electrical characteristics

Frequency	2856 MHz
Pulse width (RF)	4.0 μs
Peak RF output power	50 MW
Average RF output power	10 kW
Peak forward beam voltage	325 kV
Peak cathode current	400 A

Peak drive power	400 W typ.
Efficiency	40% min.
Heater voltage	17 V typ.
Heater current	18 A typ.

4.3.4 Absolute ratings

Parameters	Symbol	Units	Max.	Min.
Frequency	f	MHz	2857	2855
Heater voltage	Ef	V	20	---
Heater current	If	A	20	---
Heater current (surge)	If (surge)	A	40	---
Cathode warm-up time	tk	minutes	---	60
Peak forward beam voltage	epy	kV	325	---
Peak inverse beam voltage	epx	kV	100	---
Peak cathode current	ik	A	400	-55
Peak drive power	pd	W	1000	---
Peak RF output power	po	MW	52	---
Average RF output power	Po	kW	10.5	---
Collector dissipation	Pcol	kW	35	---
Pulse width(duration) (epy)	tp(epy)	μs	6.7	---
Pulse width(duration) (rf)	tp(rf)	μs	4.0	---
Pulse repetition rate	prr	pps	50	---
Ion pump voltage	V ip	kV	3.9	3.1
Load VSWR	σL	VSWR	1.4	---
Coolant flow Collector	Qw,c	L/min	---	30
Inlet coolant temperature	Tw,i	centigrade	35	5
Coolant pressure Collector	Pw,c	MPa	0.98	---
Waveguide pressure	PW/G	Pa	6.7×10^{-5}	---
(Gauge pressure)		(Torr	5×10^{-7}	---)

5. Related device and notes

5.1 Accessories

E3730A includes following accessories.

Magnet for the ion pump

5.2 Related devices

The following devices are needed to operate E3730A besides the accessories.

Focusing magnet VT-68922 (Optional)

X-ray shielding kit VT-69064 (Optional)

Ion pump power supply and cable (Optional)

5.2.1 Devices necessary for installation

a. Carrying device such as a hoist etc.

A crane whose height of lifting up is more than 2.7m plus the height of the oil tank is necessary for installing the klystron tube.

b. Stand for the klystron tube

5.2.2 Devices necessary for operation

a. RF Driver

Frequency: 2856 MHz, Output power: more than 120 W (measured at the input terminal of the klystron tube)

b. DC power supply for the focusing magnet

No.1 Coil : max. voltage 16.5Vdc, max. direct current 25.0A

No.2 Coil : max. voltage 33.0Vdc, max. direct current 38.0A

No.3 Coil : max. voltage 27.5Vdc, max. direct current 18.5A

No.4 Coil : max. voltage 38.5Vdc, max. direct current 24.0A

No.5 Coil : max. voltage 22.0Vdc, max. direct current 16.5A

No.6 Coil : max. voltage 10.0Vdc, max. direct current 10.0A

Stability of current: +/-2% max.

c. Ion pump power supply

Voltage: 3.5 +/-0.4 kV

d. Heater power supply

Voltage: 20 V max. Current: 20 A max.

e. High voltage power supply

Voltage of the High voltage power supply must be continuous from 100 kV to the rating voltage. The accelerating electrode (tube body) must be connected to ground since accelerating electrode and output waveguide are same potential in the klystron tube. The cathode electrode must be connected to high voltage with negative polarity. Inverse voltage of HV pulse must be less than 100 kV.

5.2.3 Measurement item

To operate the klystron tube, measure following items.

a. Heater voltage, Heater current

A voltmeter and ammeter to check the filament voltage and current. Since the klystron filament has a common point with the cathode and is brought to a very high voltage, the voltmeter and the ammeter used for this check should be inserted in the primary circuit of the filament-heating transformer and the pulse transformer. A calibration should be made to determine the accuracy of these readings.

b. Waveforms of the HV pulse

Measure the peak voltage, peak current and width of the HV pulse imposed to the tube.

c. RF pulse
Measure peak power of the input RF pulse, peak power of the output RF pulse and pulse width of the input and output RF pulse.
d. Vacuum
Measure current of the ion pump.
e. Vacuum degree in the waveguide
Measure pressure in the output waveguide.

5.2.4 Load condition
Evacuate the output waveguide to a good vacuum. The voltage standing wave ratio (VSWR) must be less than 1.4 : 1. A Protection interlock which detects discharge or reflection power and stop inputting RF power or applying the high voltage is necessary to prevent the VSWR from exceeding 1.4 : 1. Output power of the klystron is measured under the condition of the VSWR with 1.2 : 1 or less at the factory test.

5.2.5 Oil tank
The electron gun section must be operated in insulating oil with insulation voltage of 30kV/2.5mm or more. Be sure that oil level exceeds the regulated level.

5.2.6 Cooling
The cooling circuits are two (2) for the tube and they cool the collector, the body. Coolant shall be LCW (Low Conductivity Water). When coolant flow is less than the regulated value, the interlock should stop applying the high voltage and the heater voltage. If there is a risk of freezing, drain the coolant. Please follow the following ratings about cooling the klystron tube and the focusing magnet. Cool the output waveguide if necessary.

	Collector	Waveguide	Focusing magnet
Coolant flow min.	30 L/min.	2 L/min.	10 L/min.
Coolant temperature max.	40 degrees	40 degrees	40 degrees
Coolant pressure max.	0.98 MPa	0.98 MPa	0.98 MPa

The coolant water requires the following quality.

pH factor	7 - 9
Dissolved oxygen	max. 1 - 6 ppm
Resistivity	min. 10 kΩ-cm
Particle-matter size	max. 50 μm (325 mesh)

5.3 Operating hazards
E3730A is a klystron operated with high output power and high voltage. Therefore, please note the following points for safety and protection of the tube.

5.3.1 High voltage
This tube operates at high voltage. So that, equipments, electromagnet and klystron must be designed so that personnel cannot come in contact with operation voltages.

5.3.2 X-ray radiation
Operating personnel must be protected by appropriate X-ray radiation shielding. Adequate X-ray shielding should be installed for this tube. X-ray signs or labels must be permanently attached on the equipment to notify operating personnel never to operate this device without X-ray shielding in place.

5.3.3 Microwave radiation
Exposure of the human body to microwave radiation in excess of 1mW per square centimeter is unsafe

and can result in blindness or other injury. Personnel must be fully protected from the microwave energy which radiates from this device. All input and output RF connections, waveguide flanges, and gaskets must be RF leak proof and properly engaged. Never operate this device without a microwave-energy-absorbing load. Personnel must be prevented from looking into open waveguide or antennas while this device is energized. Equipment must be designed to protect all the personnel from the hazards. The label and caution notices must be provided on the equipment and tin the manuals warning clearly of these hazards.

5.3.4 Protecting instrument

The following protection interlock is necessary to protect the klystron tube from change of the power-supply voltage, breakdown of the focusing magnet and the cooling system, and unexpected abnormal circumstances.

Item	Protection action value	Point of action	Action Speed
Cathode warm-up time	Within specified time	No application by high voltage	—
Oil level	Oil surface is under the specified surface level	Beam high voltage application paused	Medium
Ion pump current	More than a specified value（Regular operation value plus 2 μ A）	Beam high voltage application paused	High
Water-coolant Flow （Collector and body）	Less than minimum ratings	Heater high voltage application paused Bean high voltage application paused	Medium
Inlet coolant Temperature	Maximum rate more than（40℃）	Heater high voltage application paused Beam high voltage application paused	Medium
Heater Voltage	Out of the specified rate ±5% for each klystron	Beam high voltage application paused	Medium
Heater Current	Out of the specified rate ±5% for each klystron	Beam high voltage application paused	Medium
Beam Voltage	Exceed the normal value plus 5% or the maximum rating	Beam high voltage application paused	High
Beam Current	Exceed the normal value plus 10% or the maximum rating.	Beam high voltage application paused	High
Beam Inverse Voltage	Exceed the rated value（100kV）	Beam high voltage application paused	High
Load Waveguide Arc	Discharge within waveguide	RF application paused	High
Focusing magnet current	Out of the specified rate ±5% for each klystron	Beam high voltage application paused	High
Focusing magnet voltage	Out of the normal value ±10%	Beam high voltage application paused	High
Water-coolant flow for focusing magnet	Less than the specified value	Beam high voltage application paused Power supply for magnet paused	Medium
Inlet coolant temperature for focusing magnet	Less than the specified value	Beam high voltage application paused Power supply for magnet paused	Medium
Load waveguide pressure	Out of rated value	RF application paused	High

(Attention) The definition of action speed indicated in the table is as following.
Medium Speed - Have a high velocity with about 100 ms
High Speed - Activate as fast within 30 ms（possibly next pulse will not be applied）

6. OPERATING AND MAINTENANCE INSTRUCTIONS

6.1. Installing an E3730A klystron

6.1.1. General

6.1.1.1. Equipment-room preparation

Installation of the klystron requires the use of an appropriate handling system. Most recommended is a system consisting of a rail, fastened to the ceiling, upon which moves a hoist, whose hook when fully raised must be at least 2 meters above the electromagnet and 3 meters above the oil-tank plate supporting the electromagnet. When unpacking the klystron from the crate, the hook must be at least 4 meters above the floor where the crate is placed. The rail must have a length and a disposition such that it is possible to move the klystron from its maintenance cart to above the electromagnet.

6.1.1.2. Accessories necessary for the installation

One VT-68922 Electromagnet
One VT-69240 series Ion pump high voltage power supply
One VT-69045 Output flange copper gasket
One VT-69064 X-ray shield kit
(VT-69063 :X-ray shield kit is factory furnished)
One VT-69065 Lifting attachment
Bolts described in this chapter
One thermocouple monitoring for electromagnet

6.1.2. Unpacking the klystron

First of all, the klystron with its X-ray shielding lead blocks is so heavy more than 280kg, lifting or supporting the klystron by hands is dangerous and must be strictly forbidden. Lifting devices such as hoists are necessary. Checking all the lifting devices must be taken before unpacking or installing the klystron.

The klystron is packaged in double crates with cushions between them. The crates and the klystron will be freighted in vertical position.

Unpack the outer crate and then remove the cushions on the inner crate. Lift up the inner crate from the outer crate and move to an open space to stand up the crate in vertical position securely. Remove the top and front lids from the inner crate.

Fasten the klystron lifting attachment at the collector shielding bracket. Remove "collar" half board on top of shielding bracket side and the electron gun side, and six pairs of fixing bolts and nuts (M12) from the collector pole-piece. Lift the klystron several centimeters up, then remove “collar” half board below the collector pole piece and slowly move the klystron off from the crate in horizontal direction.

During handling, the protective covers for output window must be left on the tube. Be careful not to apply any pressure or shock on the tube. The klystron is designed to be supported at the collector shielding bracket or the collector pole-piece. Ceramic-metal seals at the electron gun assembly are the most vulnerable part of the klystron. Especially the filament terminal at the bottom center of the tube is very weak to break and must not be shocked at any time. Placing the klystron on its electron gun assembly may cause a perfect damage to the tube and must be avoided. Be careful not to apply any pressure on the electron gun assembly, output waveguides, ion pump assembly, and copper pipings of cooling channels.

6.1.3. Installing the klystron

6.1.3.1. Install the electromagnet

Before placing them, check the spring contact rods of the socket be properly positioned. Put six guiding rods of the electromagnet into every two threads of 12 threads in total, which are threaded at the pitched circle diameter of 500mm on the top plate of the oil tank. Be sure that a sealing elastic[O-ring type:“AS 465(ARP465)” to be prepared by an equipment manufacturer] is securely engaged in place. Place the electromagnet on the oil-tank. Fasten six bolts with the clamps into the threads between guiding rods to the oil tank.

6.1.3.2. Install the klystron into the electromagnet

Lift up the klystron with the lifting device in vertical position, the electron gun should be in the bottom. Be sure the klystron is not tilted and is located just on the center of the electromagnet when lifted. Remove plastic cover of the electron gun seal. Check the sealing elastic around the electron gun housing is properly employed in place. Install the klystron into the electromagnet so that the cut-away of the electromagnet may properly correspond the klystron output waveguide. Fasten the X-ray shielding jacket and the electromagnet with six M12 hexagon-head bolts of stainless steel.

6.1.3.3. Ground the klystron and the electromagnet

Ground the klystron and the electromagnet with wires to the oil-tank, unless the electrical connection through the flange is sufficient. The oil-tank must be properly grounded and must be connected to the modulator so as to close the klystron high voltage returning loop.

6.1.3.4. Fill the oil tank with oil

Fill the oil tank with certified insulation oil which has sufficient dielectric strength more than 50kV/2.5mm. Be sure the oil level is within the specified range.

6.1.3.5. De-gas oil tank

Usually insulation oil contains a little amount of volatile component that may produce bubbles by temperature rise during klystron operation.
Evacuate inside of the oil tank in order to reduce the residual volatile components dissolved in the oil, to ensure the expected dielectric strength. The oil must be evacuated down to 1mmHg or lower pressure until no visible bubbles come up.

After de-gassing, inlet dry and clean air into the oil tank. Check again the oil level. If the oil level is lower than the specified level, pour additional oil into the oil tank and de-gas it again. Repeat the procedure mentioned above until the oil tank is filled with sufficient volume of oil without bubbles.

6.1.3.6. Connect the klystron to the waveguide

Before operation, the cover protecting the output waveguide flange must be removed. The waveguide shall be filled with nitrogen gas to keep the cleaned surface of the waveguide and the output windows. Be sure to keep the cover and the sealing elastic in order to use them again when the klystron is dismounted from the station for standby or storage.

Connect the klystron output to the station waveguide, inserting the copper gasket between them. This operation must not entail any strain on the klystron output window. It is recommended that the klystron, the electromagnet, and the oil tank assembly can be adjusted its position against the station waveguide, unless the station waveguide position is adjustable.

Inside of the waveguide is supposed to be evacuated to high vacuum. The electric field is so high that any small particles or irregularity may cause electric break down. Be careful not to leave any dust, dirts, particles, or fibers in the waveguide. Be careful never to touch inside the waveguide and the flanges. Be sure the surfaces of the sealing edges of the waveguide flanges and the copper gasket are clean and free from scratches, oxidation or corrosion.

When the waveguide is evacuated up to 1.3x10-6 Pa (10-8 torr) or lower pressure, it is recommended to check the vacuum leak with suitable devices such as Helium leak detector.

6.1.3.7. Evacuate the waveguide

The E3730A klystron must not be operated at the output waveguide pressure higher than 10^{-5}Pa (10^{-7} torr). It is recommended the output waveguide pressure is kept at less than or equal to 2.6x10^{-6} Pa (2x10^{-8} torr) even in klystron operation at full power. The ultimate pressure of the waveguide system should be less than 1.3x10^{-6} Pa (10^{-8} torr) when the klystron is not energized. Operation under a less quality vacuum causes severe electric break down. Especially the klystron output window may be seriously damaged. Under poor vacuum in the waveguide, the full ratings or life of the E3730A klystron are not guaranteed.

6.1.3.8. Install X-ray shielding kit

Install X-ray shielding kit around the klystron collector pole-piece and the output waveguide. Be careful not to apply any stress on the output waveguide, output windows, or ion pump assembly.

6.1.3.9. Connect RF input

Connect RF input to the coaxial cable from the driver.

6.1.3.10. Connect the ion pump power supply

Be sure the ion pump power supply and the associated circuitry connected to the power supply are not energized and properly grounded.

Connect the ion pump power supply with the HV feeder cable and connector assembly.

Check the ion pump current. The klystron has been conditioned for weeks in ultra-high vacuum. Out-gassing from the tube body is very little. The ion pump current is far less than ten micro-amperes. When ion pump does not start because of very low residual gas pressure, ion pump can be started when the filament is lit on. Do not give mechanical or electrical shock or vibration to the ion pump in order to start it.

After long period of storage without pumping, residual gas may give a large ion pump current more than tens of micro-amperes. Usually the ion pump easily evacuates this residual gas in several minutes.

6.1.3.11. Connect the cooling water pipings

Connect the cooling water pipings to the water inlet and the outlet of the klystron. The connectors of the klystron mate with "SP-coupler" size 4S for the inlet and 4P for the outlet of NiTTO KOHKI COUPLER from NITTO KOHKI Shanghai Office [#1117 Ruijin Building, 205 Maoming South Road, Shanghai, China, TEL(21)6415-3935&(21)-6415-3922, FAX(21)6472-6957].

6.1.3.12. Electrical connection of the electromagnet

Be sure all the power supplies connected to the electromagnet and the associated circuitry are not energized and properly grounded. Make the electromagnet electrical connection. Connect a pair of wire to the terminal board on the side wall of the electromagnet. Make the connections of the thermal interlock output.

6.1.3.13. Electromagnet water piping

Connect the cooling water piping. The connectors mate with "SP-coupler" size 4S for the inlet and 4P for the outlet of NITTO KOHKI COUPLER from NITTO KOHKI U.S.A. INC.

6.1.4. Checks

6.1.4.1. Ion-pump power supply

Check the overcurrent relay is set for the value of 2 microamperes. This relay cuts off the klystron high voltage when actuated. Apply the rated voltage of 3.5 plus minus 0.4kV to the pump. Wait for several minutes until the current decreases to less than 1 microamperes, after a current peak that may reach several tens of microamperes. In case that the voltage is much less than the nominal value and the current still takes tens of microamperes 10 minutes later, the tube is very suspicious of poor vacuum. Please call immediately Electron Tube Division.

6.1.4.2. Output waveguide vacuum

The E3730A klystron is designed with waveguides evacuated to less than 1.3×10^{-5} Pa (10^{-7} torr). Check the evacuating system is in normal operation and the vacuum gauge is correctly operating. Be sure that the vacuum pressure is less than the value described above. Check the interlock relay of the vacuum gauge is set for the value described above, and the interlock system does properly cut off the klystron HV.

6.1.4.3. Water flow

Check the water flow is more than the value indicated in the following table. Adjust the flow interlocks in order to operate for the values equal to the flow rate indicated in the following table. Check that the interlocks do properly cut off the filament power supply and electromagnet power supply. Check that the water temperature interlocks operate for 35 degree centigrade.

	Flow rate
Klystron body and collector, min.	30 L/min.
Klystron waveguide, min.	2 L/min.
Electromagnet, min.	10 L/min.

6.1.4.4. Klystron heating

Adjust the heater voltage to within plus minus 5% of the value indicated on the individual tube Test Report. When heater power is applied to a cold tube, the heater voltage shall be adjusted from zero to prescribed value so that the heater voltage should not exceed 40A. Set the min. and max. of filament current protection relays to the rated value given in the Test Report, minus 5% and plus 5% respectively. Check these interlocks operate in order. The interlock must cut off the HV for the klystron.

6.1.4.5. Electromagnet power supply

The electromagnet power supply must current-regulated to better than 1%. Check the regulation before using the power supply. The resistance of the coils may increase between the application of the voltage and temperature stabilization. Apply the voltage to the electromagnet and adjust the current to within 1% of the prescribed value. Set the min. and max. protection relays for the current to the prescribed value minus 5% and plus 5% respectively. Check the interlocks operate in order.

6.2. Operating Instructions

6.2.1. Starting a new tube

The operation described below should be applied to a new tube and a restored tube from standby.

6.2.1.1. Heater warm-up

Turn on the filament power supply and gradually up the filament voltage in the manner that the filament current does not exceed the rated rush current. Wait for at least one hour to heat up the cathode to the operating temperature. Check the klystron ion pump current. It is not abnormal that the ion pump current exceeds 10 microamperes due to outgassing from cathode assembly, when the filament is turned on. Check the ion pump current, after one hour of heat up, to be less than 1 microampere.

6.2.1.2. Waveguide conditioning

When starting a new station waveguides or dummy load, careful conditioning of the waveguide system is necessary. The E3730A klystron is designed to operate with output waveguide system, in which ultra-high vacuum is kept even during RF power is on.

Check the ultimate pressure in the waveguide system is less than $1.3x10^{-6}$ Pa (10^{-8} torr), and evacuating speed of the vacuum pump and pumping conductance of the vacuum channel is large enough to keep the waveguide pressure at the klystron output window less than $1.3x10^{-5}$Pa (10^{-7} torr) even in the full power operation.
The waveguide outside of window must be conditioned with RF output power of the klystron. The surface of the new waveguide may be contaminated with foreign material, or may absorb gas molecules, and may have fine scratches or metallurgical defect. If high power RF with long pulse duration, that means high RF energy, is applied to the waveguide, these irregular points can be origins of electric break down, and may sputter metals onto the surface of the ceramic disk of klystron output windows. The metal layer on the ceramic disk causes excessive heat onto the output window and results in window failure such as puncture or crack due to thermal strain.
To avoid a serious damage in the early stage of conditioning, short pulse conditioning is recommended. Make the RF pulse width shorter, less than 1 micro second preferable.
Apply high voltage pulse to the klystron. Less than 150kV is recommended in the first stage of conditioning, especially after long period of storage. Apply drive power to the klystron. Be careful the klystron ion pump current as well as the output waveguide pressure not to exceed the prescribed limit. In many cases non-conditioned waveguide shows serious electric break down even at the power level of a few MW or hundreds kW, accompanied with tremendous amount of out-gassing. In case of a large break down, a part of or almost of the output power is reflected backward to the klystron. Interlock system to detect the backward power must be provided and must cut off the drive power or the HV by pulse-to-pulse basis.
If the waveguide material, finishing, cleaning, and evacuating system are properly designed and successfully operated, it is not so difficult to overcome the outgassing. When the waveguide is well conditioned, the klystron output power is rather easily increased up to tens of MW or more. If the vacuum in the waveguide is poor, the conditioning will take much longer hours or even days.
When the waveguide system and the klystron is stably operated at its full rating for several hours, then make the RF pulse width longer to the required pulse width. Start conditioning with longer pulse width again from a reduced power level of hundreds kw. Raise the output power gradually by means of raising the HV or1 raising drive power up to the rated power. Be careful the waveguide and klystron pressure not to exceed prescribed limit.
Measurement of the klystron performance should be made with the well-conditioned waveguide.

6.2.1.3. Conditioning of electron gun

The electron gun is carefully designed and fabricated with certified materials and special processes, and already conditioned. However, there may still occur arcing (high voltage discharge) in the electron gun assembly at some possibility. Start conditioning at the beam voltage less than 150kV and gradually raise the beam voltage up to the value indicated in the individual Test Report for each tube.
When arcing occurs almost all of the electric energy stored in the PFN capacitors is concentrated between the anode and cathode and may give a damage to the electrodes. Once arcing occurs, large amount of gas or ion is emitted and some are still in the vicinity even when the next HV pulse is applied. That means the possibility of successive arcing is very high, and the

damage by arcing is accumulated to a particular part of electrodes. As the E3730A klystron produces very high output power, the PFN energy is dangerously high enough to give serious damage to the electron gun electrodes with a very small number of successive arcing.
To prevent the electrodes from the serious damage, the modulator system must provide a fast, pulse-to-pulse basis, interlock system that detects the arcing in the electron gun, and immediately cuts off the HV, or more conveniently turns off the triggering of the main switching device, usually thyratron. Measuring device based on the average quantity measurement is not suitable for this purpose unless the pulse repetition rate is quite low. There are some possible ideas to detect arcing of the electron gun; peak current detection of shunt circuit of the PFN, or peak inverse current detection is recommended.
Before resuming operation after arcing, be sure the ion pump current has been less than or equal to the steady state level. It is recommended to reduce the HV to a certain extent and gradually raise the HV for the prescribed value for secure start up.

6.2.2. Normal operation

When the station waveguide or dummy load is new or exposed to air, the waveguide conditioning operation must be taken. When the tube has been used recently or when it has already been put through the conditioning period described in the preceding paragraph, starting of the tube can be very fast, even instantaneous. The klystron can be operated after one hour of cathode heat up. However, gradual increase of the high voltage and drive power is recommended. It is far better for the tube to keep the reliability, especially for the klystron output window.

6.2.3. Protective device operation

In case of protective device operation, that means some fault occurred, certain additional precautions should be taken, as outlined in the following table.

Interlock	Precautions
Ion pump current	Check the focus-coil currents and tube cooling are correct. Make sure that the ion pump current has returned to the normal value.
Tube water flow	Make sure there is no leakage in the circuit.
Heater current	Make sure there is no open or short circuit.
Electromagnet water flow	Make sure there is no leakage in the circuit.
Electromagnet currents	Make sure there is no open or short circuit.
Waveguide pressure	Check that evacuating system is in normal operation. Make sure that the pressure has returned normal level. In case of SF_6 pressurization, check the gas pressure level is in the proper range.
Beam current	Make sure the ion pump current has returned to the normal level. Check the applied high voltage is in the normal operation range.
VSWR in waveguide	Check that evacuating system is in normal operation. Make sure that the pressure has returned normal level.

	In case of SF_6 gas pressurization, make sure the pressure gauge is in normal operation range.
Electromagnet temperature	Check the electromagnet water flow is in normal range. Check the focus coil current is in normal operation range.

3.2.4. Shutting down

When shutting down the equipment, it is necessary to leave the coolant flowing in the focusing magnet cooling system. Otherwise, let the focus coils cool down before stopping the flow of cooling water.

3.3. Maintenance

The non-observation of these maintenance instructions can cause the manufacturer's guarantee to become null and void in the case of an irremediably fault of the klystron.

3.3.1. Periodically check

That the dielectric strength of the insulating oil is at least 50kV/2.5mm.
That the cooling water is sufficiently clean : Check the quality of the cooling water.

3.3.2. Shut down for a long period of time

If the equipment is shut down for a long period of time, make sure that the cooling water remaining in the tube or in the focus coils is not likely to freeze. Otherwise, or if the tube is to be stored, the water circuit should be drained and dried, if possible, by means of a jet of compressed air, injected successively at the inlet and outlet of the cooling-water circuit. In case the output waveguide is opened to air, clean and dry nitrogen gas must be inlet to the waveguide before the waveguide is opened to air. In case the klystron output waveguide is exposed to air for hours, the protecting cover and sealing elastic must be fastened to the output waveguide, and the air inside the waveguide must be replaced with clean and dry nitrogen gas. The pressure inside the waveguide must not exceed 0.02MPa (0.2kgf/cm^2) by gauge to avoid damage to the output windows. This operation is very important for maintaining the delicate surface of the output window ceramics.

3.4. Storage

When in storage, it is recommended to store the klystron in the double crates in which klystron has been freighted. For a short period, it is possible to stand the klystron on a service cart or a platform. The klystron must be supported at the collector shielding bracket or the collector pole-piece in vertical position. Placing the klystron on its electron gun assembly may cause a perfect damage to the tube and must be avoided.
The water circuit should be drained and dried, if possible, by means of a jet of compressed air, injected successively at the inlet and outlet of the cooling-water circuit.
The protecting cover and the sealing elastic must be fastened to the output waveguide, and the air inside the waveguide must be replaced with clean and dry nitrogen gas. The pressure inside the waveguide must not exceed0.02MPa (0.2kgf/cm^2) by gauge to avoid damage to the output windows. This operation is very important for maintaining the delicate surface of the output window

ceramics. The electron gun assembly must be sealed with a plastic cover preventing the insulating ceramics from stains.

Because of the size of this tube, it is not abnormal to observe changes in the internal vacuum during storage. To be able to put the stored klystron into operation quickly, the klystron ion pump shall be operated all the time. It is mandatory that the ion-pump current be verified every month.

When the stored tube comes back to operation, the same conditioning operation as for a new tube must be applied.

The non-observation of these storage instructions can cause the manufacturer's guarantee to become null and void in the case of an irremediably fault of the klystron.

7. Inquiries

For further information, please contact CETD at following address.

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