STATE OF THE ART ADVANCED MAGNETRONS FOR ACCELERATOR RF POWER SOURCE

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Abstract

X ray sources for linear accelerators continue to be a necessary requirement for industries such as medical, inspection, and non-destructive test equipment. Future requirements for such sources are; low cost, compact packaging and high performance of the RF source for electron acceleration. The magnetron has proven to be a perfect source over other RF sources for linear accelerator use. It advantageous are; simple design, low cost per output, small size and proven performance. These meet all required characteristics for accelerator designers. New Japan Radio Co., Ltd. has improved and modified its linac magnetrons' performance and characteristics enabling easy matching to the linac modulator, high stability, long life and maximum output power.

This paper will provide a detailed explanation on the improved magnetron design methodology and its effects on the performance of these magnetrons installed in linac systems. These technologies have been utilized successfully on a commercial level worldwide over the last few years. The technology has been deployed into linac systems operating in S and X band and soon C band, at various output power levels.

INTRODUCTION

Magnetrons have been practically installed into electron accelerator systems since the 1950's. [1] In that period, out of all oscillating devices the S band magnetron was chosen for its proven performance at high output power, high efficiency and compact size. The design of a magnetron only requires a small interaction space to convert DC electrical power into high frequency microwaves by applying a magnetic field perpendicular to the electrical field.

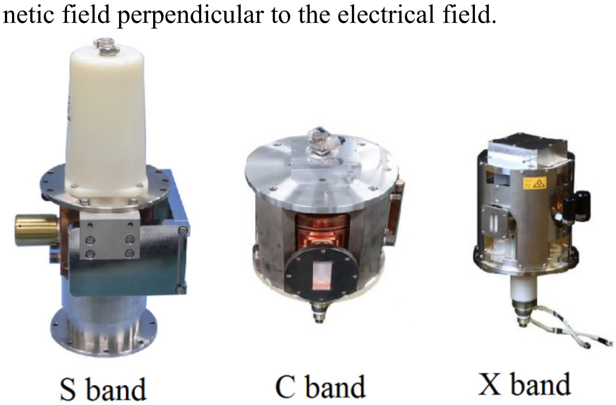

Figure 1: S band, C band, and X band magnetrons.

These photographs include external or built in magnet. The size of the resonant cavity can then be relatively small when designing for high frequency oscillation. The cavity size of magnetron is dependent on the oscillation frequency, so high frequency of microwave oscillation only requires a small resonant cavity. The chosen microwave oscillating frequency is left to the discretion of the linac designing engineer. The package size of a magnetron basically becomes compact in frequencies of S band, C band and X band as shown in Fig. 1. Each band of oscillation frequency for linac design is shown in Table 1.

Table 1: Each Band of Oscillation Frequency for Linac

Frequency band	S	C	X
Frequency (MHz)	2993 to 3002	5702 to 5722	9275 to 9325

High frequency of C band and X band offer an advantage for compact size and light weight design. These higher frequencies can reduce the size and weight not only for magnetron itself but also the RF circuit, RF transmission waveguide devices, accelerator, and shielding in the linac system. A compact light weight linac system can be easily deployed into portable systems, controlled movable radiation beam systems and utilized for installation into narrow spaces. [2] The cost of accurate piece parts required by the magnetron have been minimized by advanced high machining technology enabling high frequency output power at a reasonable cost.

Advanced thermal design of the interior of the magnetron avoids overheating allowing for higher average input power which will enable the magnetron to operate effectively at high frequency and high microwave power at high pulse duty cycles.

CONVENTIONAL DESIGN

Type of Designed Structures

The hole and slot type magnetron has been installed into S band linac systems since early development. [3] This type of design requires a large size of copper block material then mechanically cut the holes and slots to create the anode resonant cavity as shown in Fig. 2. This large size of anode has the advantage of high thermal endurance due to its large thermal capacity. This anode structure can accept high input power without overheating, so high average output power can be obtained easily for an S band hole and slot type magnetron. This hole and slot type design is difficult to deploy into C and X band high powered, tuneable frequency magnetrons because a wide cathode surface area is required for low current density which extends the cathode's lifetime of high power magnetrons. The hole and slot

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design for high power will require a larger number of anode segments to obtain high frequency resonance then, the tuneable frequency per segment will be narrowed. Therefore the coaxial cavity with a coaxial tuner design has been adopted for C band and X band high frequency linac magnetrons. [4] The coaxial type of design can reduce weight and extend the life time due to the large cathode surface area.

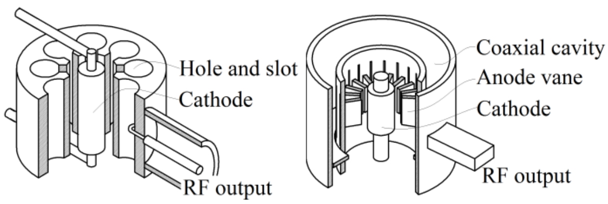

Figure 2: Structures of hole and slot type magnetron and coaxial magnetron.

Volume and Weight Comparison

The dimension and weight of each frequency band of magnetron is compared in Table 2. Whenever frequency rises, the volume and weight decreases. C band magnetrons are 36% less in volume and 13% less in weight then S band magnetrons. X band are 49% less in volume and 31% less in weight.

Table 2: Dimensions, Volume and Weight of Magnetrons.

Frequency band		S	C	X
Magnetron type		M1466A	M1630	MX7640
Dimensions	W	200	200	170
(mm)	D	186	217	175
	H	375	309	306
Volume (m^3)		0.0038	0.0024	0.0019
Weight (kg)		16	14	11

NEW DESIGN METHODOLOGIES

Cathode Temperature Reduction Design

Required high peak output power and high duty ratio operation normally decreases the magnetron's life time. An increase in high current and an increase in electron back bombardment increases the cathode's local temperature. The consumption ratio of the cathode's emitter material is the function of the anode current density and the cathode's temperature.

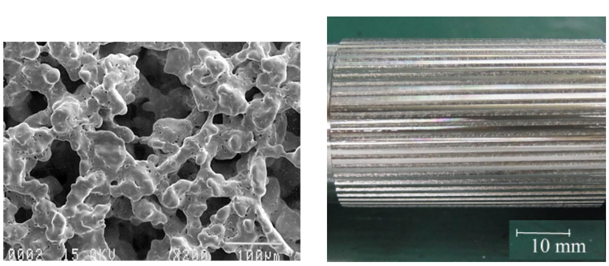

Figure 3: Cathode and cylinder for mash cathode.

Reduced emitter material causes low emission ability and unstable oscillation leading to premature end of life. We analysed the cathode temperature distribution and temperature profile to obtain high efficiency of thermal diffusion and avoid overheating of the cathode emitter materials. A new designed cathode used with the cathode, efficiently conducts the heat from the cathode. The mash of cathode is designed with an irregular configuration and wide surface area as shown in Fig. 3. A new designed cathode cylinder contains many groves on the surface area as viewed in Fig. 3. The increased surface area of the base metal mash cathode and BI (barium impregnated) cathode reduces the cathode temperature to a maximum 115 degrees under the same operating condition of high peak output power and high duty. New JRC deployed this design methodology to the mash cathode used in S band magnetron and BI cathode in C and X band magnetrons. Of course other conditions such as; average output power, heater voltage, load VSWR, anode temperature, and rrv (rate of rising of voltage) influence the lifetime of the magnetron.

Anode Cooling System

In a normal coaxial magnetron design, one end of anode cylinder is not joined to the sealing structure, therefore heat from the cathode and top of the anode vane is transferred to the other anode cylinder joined to the sealing structure.

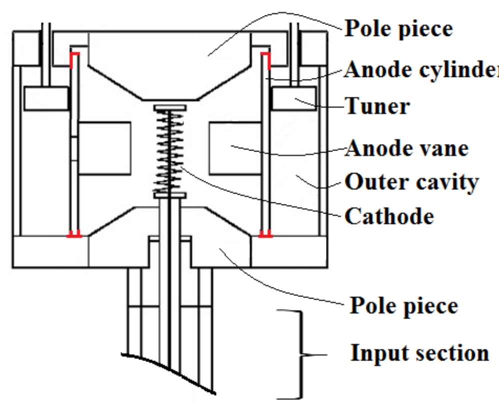

Figure 4: New designed structures of anode cylinder of coaxial magnetron.

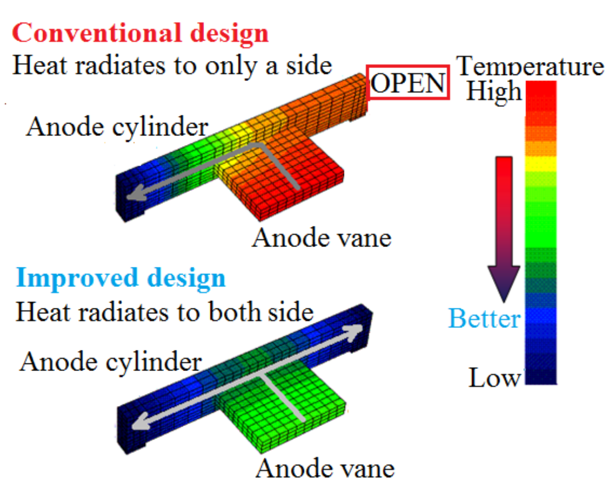

Figure 5: Temperature comparison between new designed anode cylinder and conventional design.

Then the thermal diffusion efficiency is degraded and the magnetron cannot operate under high output power and high duty. New JRC's design joins both ends of anode cylinders to the sealing structures as in Fig. 4. [5] The temperature at the top of anode vanes is decreased to160 degrees by use of this high efficiency of thermal diffusion design methodology as shown in Fig. 5. This high efficiency of thermal conduction allows high peak output power and high pulse duty operating for the magnetron and extends the magnetron's life time.

For Dual Energy Mode Operation

Dual energy modes of linac systems require stable oscillation during a wide frequency range at different output powers of a magnetron. This large different in output power creates a wide different of dual energy dose rates allowing linac systems to functionally operate with high dynamic range of energies. The offset frequency at low energy mode from the resonance frequency of linac cavity creates a wider dynamic range of dose rate. The expected dual level of dose rates can be obtained if this offset frequency can be controlled by the magnetron's current pushing characteristics. [6] New JRC controls this current pushing characteristics by controlling the electron space charge in the magnetron interaction space as Fig. 6. The increased space charge caused by increased anode current, effectively changes the capacitance in the interaction space. Then a small increase in anode current dynamically reduces the oscillation frequency.

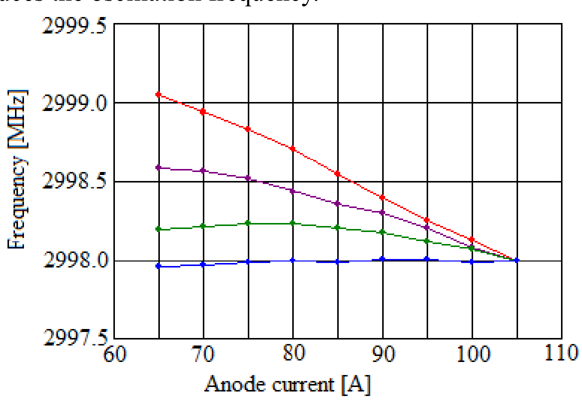

Figure 6: Anode current pushing characteristics.

Matching to Modulator

New JRC has the ability to adjust the design of their C band and X band magnetrons so that its impedance, at operating point is similar to an S band conventional magnetron as Fig. 7. Therefore, these 3 frequency bands of magnetrons can operate with a common modulator. Recently, very compact designed IGBT controlled solid state modulators have been installed into linac systems. [7] The solid state modulator modulates the rectangle pulse waveforms creating a very flat peak pulse top. New JRC magnetrons can be adapted to this pulse rising up edge by adjusted their transient impedance.

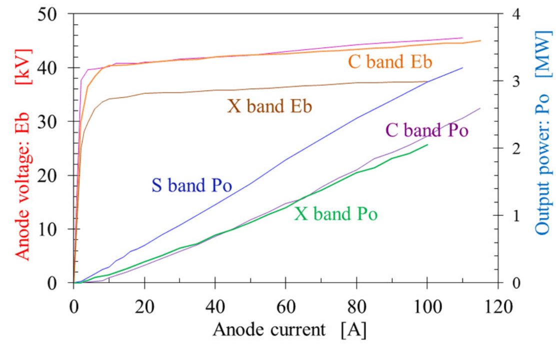

Figure 7: S, C, and X band magnetrons performance chart.

CONCLUSION

The improvements using new design methodologies for, C and X band high power magnetrons for linac systems has been confirmed. These magnetrons have especially been designed to improve and control anode and cathode temperature to avoid any possible overheating, thereby increasing the lifetime of magnetrons at high duty operation. Thus each frequency band of magnetrons will operate stable on any advanced designed dual energy mode system and any system using solid state modulators.

ACKNOWLEDGEMENT

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