ELECTRON BEAM WELDING OF WOLFRAM AND MOLYBDENUM COMPONENTS

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Abstract: This paper shows experimental research of the authors, concerning the realization of the cathodes of the magnetrons built at the University of Oradea. The magnetron cathodes comprise wolfram and molybdenum components, which are quite difficult to make, handle and assemble because of their special properties. The joints between these components can be made only under special conditions, in controlled environments and by means of specialized equipment.

Keywords: magnetron, wolfram, molybdenum, electron beam welding

1. INTRODUCTION

The m*agnetron* is a device that generates microwave energy, turning the network low-frequency energy (*f* = 50 Hz) into very high frequency energy (*f* = 2450 MHz). It consists of a vacuum electronic tube, with cylindrical symmetry, fitted with two electrodes:

- *anode* – made of copper, with 10 ÷ 20 inner cavities that form resonant circuits; one of the cavities contains an antenna, which allows the microwave energy to be extracted and transmitted to the exterior, for example to a waveguide;
- *cathode* – usually in helical shape, it is made of thorium-wolfram (direct heated), which heats to app. 2000°C when fed with a voltage of 5 ÷ 10 V; the cathode is connected to a negative potential of app. 6 ÷ 10 kV versus the anode.

The Microwave Collective, of which the authors are members, has managed to build a set of continuous operating magnetrons with powers of 200 ÷ 1500 W, *for the very first time in Romania*. By means of these magnetrons, several microwave installations were made, for medical, household and industrial use (breaking of hard rocks by microwaves, pre-polymerization of bakelite dust, wood drying, meat thawing etc). In order to make magnetrons, several devices and installations have been built at the University of Oradea, some of them being patented or awaiting patenting.

The magnetron component that requires the most care and attention is the cathode, because of the hard operating conditions, such as currents of tens of amperes and temperatures of about 2000°C in order to obtain electronic emission. This is why the cathode is made of high-melting materials, such as wolfram (melting temperature 3410°C) and molybdenum (melting temperature 2610°C). However, these materials are hard to work, and the assemblies are difficult to make.

2. PROPERTIES OF WOLFRAM AND MOLYBDENUM

Wolfram and molybdenum are diamagnetic metals, which make them suitable for using in magnetron construction; tab.1 shows some of their properties.

Wolfram is used for making electron tubes due to its properties, such as high melting point (3410°C), high emittance, low vapour pressure at high temperatures and the fact that it is refractory, thus useable in vacuum for temperatures up to 2560°C. Most often, wolfram is used for making the cathode filaments, which produce the thermo-electronic emission by direct or indirect heating. The cathode sustaining rods are also made of wolfram, which ensures a precise alignment due to its low thermal expansion coefficient. Tab.2 shows the physical properties of several kinds of wolfram. Because of its fragility and working difficulties, it is preferred that the wolfram components to be obtained by sintering; the chipping is possible only with hard alloys cutters, at temperatures of 700 ÷ 800°C.

Tab.1. Physical properties of pure wolfram and molybdenum [3].

Property	Wolfram	Molybdenum
Atomic number	74	42
Atomic mass	183.85	95.94
Melting point	3410°C	2610°C
Specific heat	0.032 cal/g·°C	0.059 cal/g·°C
Density	19.3 g/cm^3	10.22 g/cm^3
Elasticity modulus	$34.5 \cdot 10^{10}$ Pa	$32 \cdot 10^{10}$ Pa
Thermal linear expansion coefficient	$4.5 \cdot 10^{-6}$ cm/cm·°C	$5 \cdot 10^{-6}$ cm/cm·°C
Thermal conductivity	0.425 cal/s·cm·°C	0.34 cal/s·cm·°C
Resistivity	$5.65 \cdot 10^{-6}$ Ω·cm	$5.2 \cdot 10^{-6}$ Ω·cm

Tab.2. Mechanical characteristics of various kinds of wolfram [3].

Kind of wolfram	Density (g/cm^3)	Breaking strength (daN/mm^2)	Maximum specific elongation (%)	Yield point (daN/mm^2)	Vapour pressure (torri)
sintered at 1200°C	10 - 12				$14 \cdot 10^{-9}$ at 2130°C $5 \cdot 10^{-6}$ at 2530°C $4 \cdot 10^{-4}$ at 2930°C
forged	17.6 - 19.2			13	
drawn	19.2 - 19.4			<150	
annealed				72-83	
wire, after annealing and recrystallization		110			
monocrystalline wire with added thorium		108	<20		
monocrystalline wire with added thorium, cold-hardened		<180			
tape of various thickness, without thermal treatment	g = 1.00 mm	84			
	g = 0.50 mm	140			
	g = 0.25 mm	210			

Molybdenum is a metal similar to wolfram concerning its refractory properties, but it is less fragile and easier to chip. Wolfram is always fragile at room temperature, but the plasticity and breaking strength of molybdenum can be modified by recrystallization. Annealing at 1400°C lowers the breaking strength, increases the specific elongation of the drawn bars and provides a finer structure. The maximum operating temperature of molybdenum components is 1700 ÷ 1800°C.

The resistance at high temperatures, associated with a better mechanical workability, determines the main uses of molybdenum.

An important use of molybdenum is for filaments of the magnetron direct-heated cathodes where, because of the larger component diameter, wolfram cannot be used because of its fragility. Also, due to the low fragility of molybdenum, this metal is preferred rather than wolfram for making industrial and laboratory electric resistance furnaces in protective atmosphere, which work at temperatures up to 1700°C.

Molybdenum also features a good compatibility with iron, copper, nickel and platinum for spot-welding or for heterogeneous welding with other molybdenum, wolfram or kowar pieces, by means of these above-mentioned metals.

3. EXPERIMENTAL RESEARCH ABOUT THE CATHODE ASSEMBLING BY MEANS OF ELECTRON BEAM WELDING

At the first versions of cathodes, knowing that the wolfram and molybdenum elements are hard to weld, the authors have tried the mechanical assembling, such as threads. However, because of the very intense currents and very high temperatures, these assemblies failed and gave rise to electrical contact problems.

At room temperature, wolfram is hard and difficult to work, but its plasticity improves as the temperature increases. The behavior of wolfram at welding is not satisfactory, and welding is difficult because of the following causes:

- high melting point;
- high thermal conductivity;
- intense tendency to oxidation at temperatures over 500°C and high affinity to hydrogen and nitrogen up to the melting point;
- fragility of the thermally influenced zone, because of the coarse structure of the weld as well as of the thermally influenced zone, which makes both of them hard and fragile; this could be avoided by plastic deformations at app. 1000°C in vacuum or oxygen-free atmosphere, followed by cooling an annealing at 1250°C, but this treatment is extremely difficult to make.

Wolfram can be welded by direct-current WIG procedure or by electron beam welding. When using WIG welding, it is recommended to proceed into a controlled atmosphere chamber and, in order to avoid the occurrence of fissures, pre-heating at 425 ÷ 540°C is recommended.

Molybdenum is a refractory metal, characterized by high melting point and high mechanical resistance at high temperatures and thermal shocks. Also, it features good resistance to corrosion, easy chipping and cubical structure with centered volume and no allotropic transformations. Its welding behavior is influenced by the following particularities:

- high oxygen affinity at temperatures over 350°C;
- moderate nitrogen affinity, the reactions with nitrogen taking place at temperatures over 1000°C;
- the high melting point require the use of powerful thermal sources and of energy-intensive welding regimes; thus, the thermally influenced zone will considerably extend, leading to material fragility.

In order to weld molybdenum, WIG direct current welding and electron beam welding are used. However, these two methods are not exactly adequate to our purpose, because they require special work conditions and extended time intervals for effective achievement of the welding. For example, vacuuming at 10^{-4} torr, in order to execute electron beam welding, takes about 3 ÷ 4 hours, even if the welding operation itself takes only some seconds. When using WIG to weld sintered materials, as wolfram and molybdenum, there is the danger of cracks occurrence, which increases with the welding speed [4].

In order to assemble some versions of the indirect heating cathodes, the electron beam welding and WIG welding were experimented at the Welding and Material Testing Institute (ISIM) Timişoara (fig.1, fig.2).

Fig.1. Indirect-heated cathode, made by WIG welding (center) and by electron beam welding (left).

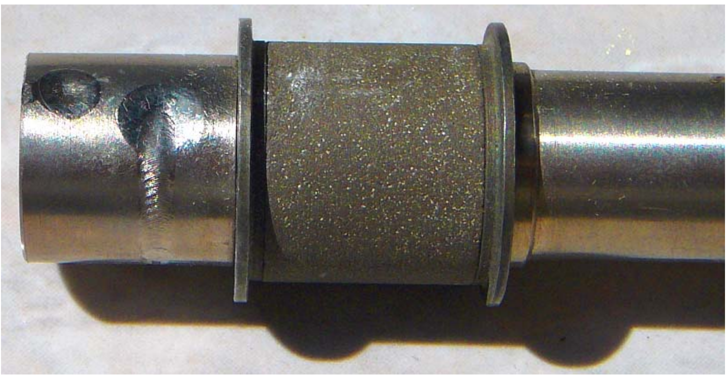

Fig.2. Electron beam welding, made at ISIM Timişoara (detail).

Inside these indirect-heated cathodes, the wolfram filaments are mounted on molybdenum fixing pieces (fig.3, fig.4).

Fig.3. The wolfram filament and the molybdenum fixing piece.

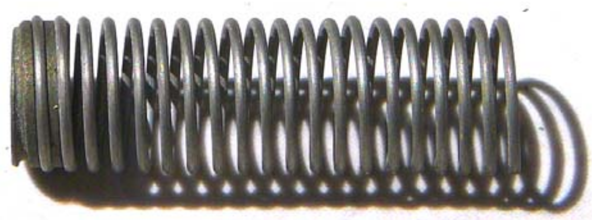

Fig.4. The wolfram filament, thread-mounted on the molybdenum fixing piece, in order to be welded.

We have attempted to assemble the wolfram filament on the molybdenum fixing pieces by means of WIG welding and electron beam welding, but we got good results only in the above-mentioned special conditions, available only at ISIM Timişoara or other specialized institutes. This is why the assembling of wolfram and molybdenum components was accomplished at the University of Oradea by means of spot-welding and high-frequency induction installations, self-made, some of them patented or awaiting patenting.

Our regretted colleague, conf.dr.ing. Ştefan Roman, together with whom we have worked for 20 years in the Microwave Collective, has also a special merit in designing and realization of these installations and for making of the very first functional Romanian magnetrons.

4. CONCLUSIONS

The metal-metal junctions based on short-time resistive heating, pressure and very intense currents (spot-welding), or the ones based on WIG welding, plasma welding or electron beam welding, can be applied only to certain types of assemblies and are conditioned by the pieces shapes and by the electrical and thermal properties of the metals to be joined. In spite of their advantages, these procedures are efficient only on industrial basis, because they require large investments.
In order to assemble the wolfram and molybdenum cathode components of the magnetrons made at the University of Oradea, where very large current and temperature values are implied, the most adequate method of these proved to be the electron beam welding in vacuum, with platinum as filler metal (fig.2) or without any filler metal (fig.4).

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