OAK RIDGE NATIONAL LABORATORY

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ORNL/FTR--3722

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ORNL
FOREIGN TRIP REPORT

ORNL/FTR-3722

DATE: September 18, 1990

SUBJECT: Report of Foreign Travel of E. K. Ohriner, Metallurgical Engineer, and C. R. Howell, Senior Engineering Assistant, Metalworking Theory and Practice Group, Metals and Ceramics Division

TO: Alvin W. Trivelpiece

FROM: E. K. Ohriner and C. R. Howell

PURPOSE: The purpose of this travel was to observe acceptance testing of the 150-kW electron-beam furnace purchased from Leybold (Hanau) Technologies and to receive initial training in its operation.

SITES VISITED: 8/13-17/1990 Leybold (Hanau) Technologies
Hanau, West Germany

ABSTRACT: The travelers observed the acceptance testing of the 150-kW electron-beam (EB) furnace constructed by Leybold (Hanau) (LH) Technologies prior to disassembly and shipping. The testing included: (1) operation of the mold withdrawal system, (2) vacuum pumping and vacuum chamber leak-up rates, (3) power stability at full power, (4) x-radiation monitoring at full power, and (5) demonstration of system interlocks for loss of water cooling, loss of vacuum, loss of power, and emergency shutdown. Preliminary training was obtained in furnace operation, EB gun maintenance, and use of the programmable logic controller for beam manipulation. Additional information was obtained on water-cooling requirements and furnace platform construction necessary for the installation. The information gained and training received will greatly assist in minimizing the installation and startup operation costs of the furnace.

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COMPREHENSIVE TRIP REPORT

1. Introduction

The purpose of the travel was to conduct the acceptance testing of the 150-kW EB furnace at the site of the seller, LH, Hanau, West Germany. The acceptance testing described in the furnace specification includes verification of conformance to approved drawings, vacuum system tests, full power testing, melt testing, and demonstration of safety systems and interlocks. In addition, the travelers gained experience in the operation of the furnace and use of the programmable controls.

2. Detailed Report of Travelers' Activities

2.1 Meeting and Vacuum System Testing on August 13, 1990

ORNL Attendees: E. K. Ohriner
C. R. Howell

LH Attendees: H. Pannen, Product Group Manager
D. Bethge, Project Engineer
M. Bauer, Manager, R&D EB Metallurgy
J. Heimerl, Chief Process Engineer
V. Baur, EB Development and Process Engineer
M. Klem, Furnace Operator

Mr. Pannen informed the travelers that H. Stumpp had recently left LH and that the engineering and R&D staff were very familiar with the EB furnace. The EB furnace had been operated the previous week for melting niobium buttons and at somewhat higher power (70 kW) using tungsten plate. The travelers were shown the furnace which had been assembled at floor level with the diffusion pump suspended over a floor pit. The mold withdrawal system was operated at both atmospheric and low pressure. The operation of the vacuum system was reviewed. The 3-h pumpdown and leak test were conducted. Although the conditions under which the testing was performed were as severe as can be expected (i.e., an ambient temperature in excess of 30°C with relatively high humidity, use of cold water in the furnace system, and significant residual splatter of niobium in the interior of the chamber), the vacuum measurements were well within the specified limits. The detailed results of all tests are shown in Appendix B. The vacuum system was vented and the 17-h pumpdown was performed during the night. Several drawings copied by LH for the construction of the EB furnace platform under construction by a domestic subcontractor were reviewed. The recirculating water-cooling requirements were discussed. LH agreed that periodic treatment of the 2 m² of water in the system through a small mixed rosin bed deionization system using disposal cartridges would be cost effective.

2.2 System Testing on August 14, 1990

The vacuum testing following a 17-h evacuation was successfully completed as shown in Appendix B. Afterwards, a special crucible was installed for the full power test. Mr. Heimerl outlined the operation of the programmable logic control for beam

manipulation. Dr. Bauer reviewed the design and principles of operation of the EB gun. Three tungsten plates, each 6-mm thick, were placed over a 100-mm-diam by approximately 70-mm-high tantalum ingot in the special crucible. A full power melt test on the tungsten was conducted for only a few minutes when it was observed that the stainless steel plate, put in to prevent overheating of the region of mold transfer port, had melted through. In the full power tests, the mold transfer valve was closed. It was agreed to remove the tungsten plates and perform the test directly on the tantalum ingot. A 15-min test performed at full power, 35 kV, 4.3 A, showed acceptable stability. Monitoring of x-radiation levels at all flanges, feed throughs, and ports showed no values above 0.1 mR/h. As a demonstration, the beam current was reduced to zero and the leaded glass covering one site port was removed. At full power a radiation level in excess of 100 mR/h was measured at the site port, emphatically demonstrating the need to check the condition of the leaded glass prior to any melting. It was agreed that the special crucible and tantalum ingot would be loaned to us for full power tests at ORNL and returned to LH after testing. A tungsten ingot could be used in place of the tantalum should it be deemed necessary.

Following removal of the special crucible, the operation of system interlocks and emergency shutdown was verified. The following fault situations were intentionally produced with high voltage to the EB gun to demonstrate proper interlock functioning:

1. loss of cooling water to chamber,
2. loss of cooling water to diffusion pump,
3. loss of cooling water to gun, and
4. loss of vacuum due to leak.

All produced immediate shutdown of the high voltage and appropriate vacuum system response. In the event of very large leaks, all power to the system must be turned off prior to restarting. Proper interlocking of vacuum valves and high voltage with the mold transfer system was also demonstrated. The two emergency shutdown switches shut down the high voltage supplies as required, but also announced an invalid "power supply overtemp" indication. LH will relabel the panel light. Six additional annunciator lights and contact slots are installed and available for future use with a second gun. LH will show their location on the electrical drawings they supply at shipment.

2.3 Discussions and Training on August 15, 1990

The gun cathode assembly was removed from the EB furnace and disassembled. Replacement of the filament and the block cathode element, as well as the degassing operation, were demonstrated. The strategy for button melting was discussed. Simultaneous heating of all buttons during the initial outgassing of sintered compacts is recommended in order to avoid deposition of any outgassed impurities on previously melted buttons in the chamber. This must be balanced against the need to avoid vaporizing any copper from the mold when the beam moves between buttons. The cathode block requires about 30 s to cool following the switch-off of the filament current, during which time the beam power gradually decays. A workable sequence for button melting includes simultaneous outgassing of six groups of powder compacts at low power (approximately 5 kW) followed by melting of one button at a time with an allowed 30 s for beam decay following each melt before traversing the beam to the next button. The programming of the controller for beam motion and beam power was discussed. Initial training was conducted and programs for melting each of six buttons were entered. They included ramping of

power to avoid rapid melting of the center of an inverted button which can allow the beam to contact the copper under the button when the molten metal begins to flow. The use of a fluorescent screen for checking the beam manipulation programs at low power (manual filament heating only) was demonstrated. The replacement of site glasses in the stroboscopic view ports was also shown.

2.4 Discussions and Training on August 16, 1990

The drawings provided by LH for construction of the EB furnace platform were reviewed. The program for consecutive melting of six buttons of niobium was demonstrated. The program for simultaneous degassing of six buttons was entered and run. The programs were stored on an Erasable Programmable Read Only Memory chip. Measurements of x-radiation were made in the mold transfer chamber, which could not be properly checked in the full power test, using tungsten plate placed on the button mold and heated with 60 kW.

2.5 Discussions on August 17, 1990

The protocol of acceptance was reviewed and signed. Documentation of the furnace performance is provided by means of chart recordings, copies of which were retained by the travelers. A preliminary packing list was provided. LH agreed to videotape the disassembly of the furnace. In the afternoon the travelers toured LH production facilities for EB vaporization equipment and induction-heated crystal-growth equipment used in the semiconductor business. The vaporization equipment includes EB guns up to 18-kW power operating at 6 kV. Multistation vaporization units with up to six interconnected vacuum chambers are built. Silicon single crystals up to 15 cm in diameter were shown. LH also manufactures sputtering equipment at the same site.

APPENDIX A
ITINERARY

1990

(C. Randy Howell)

8/11 Travel from Knoxville, TN, to Frankfurt, West Germany
8/12 Drive from Frankfurt airport to Hanau, West Germany
8/13-17 Participate in acceptance testing of electron-beam furnace purchased from
LH
8/18 Drive from Hanau to Frankfurt, West Germany
8/18 Travel from Frankfurt, West Germany, to Knoxville, TN

(Evan K. Ohriner)

8/11 Travel from Knoxville, TN, to Frankfurt, West Germany
8/12 Drive from Frankfurt airport to Hanau, West Germany
8/13-17 Participate in acceptance testing of electron-beam furnace purchased from
LH
8/18 Drive from Hanau to Frankfurt, West Germany
8/18 Travel from Frankfurt, West Germany, to Knoxville, TN

APPENDIX B

PROTOCOL OF ACCEPTANCE FOR ELECTRON-BEAM MELTING FURNACE

P R O T O C O L O F A C C E P T A N C E

about

Electron Beam Melting Furnace

ES 1/12/150 B

tested in Hanau, West Germany,

manufactured under the LH-Order No. 303-19-1159

for

MARTIN MARIETTA ENERGY SYSTEMS, INC.

Oakridge, Tennessee, USA

The undersigned parties agree that the statements and data given in this protocol of acceptance reflect the results of the acceptance tests performed in Hanau from August 13 till August 17, 1990 and that the above mentioned furnace is accepted.

August 17, 1990

Being the authorized representative of the Buyer
MARTIN MARIETTA ENERGY SYSTEMS, INC.

iA V. J. Sauer

Being the authorized representative of the Deliverer
LEYBOLD AG, Hanau, West Germany

Hanau, August 17, 1990

Acceptance tests carried out according to respective paragraphs of specification at the Seller (LH):

5.4 Functional Tests

5.4.1 Vacuum Tests

All vacuum tests will be done with dry, empty, unloaded, and clean vacuum chamber. The pumping down test will be done after venting the chambers with dry air. To demonstrate that the chambers are vented completely, the door of the melt chamber will be opened for 10 seconds.

a) Ultimate Pressure:

after 3 hours pumping time:

(chamber, barmagazine, and gun space)

	<u>Specified</u>	<u>Measured</u>	
	in 5.4.1 a	LH-Hanau	
	(mbar)	(<u>mbar</u>)	(<u>Torr</u>)
Melt chamber pressure	$<1.0 \times 10^{-5}$	7.5×10^{-6}	5.6×10^{-6}
Gun chamber pressure	$<1.0 \times 10^{-5}$	1.2×10^{-6}	0.9×10^{-6}

after 17 hours pumping time:

<u>Pressure</u>	<u>Specified</u>	<u>Measured</u>	
		LH-Hanau	
	(mbar)	(<u>mbar</u>)	(<u>Torr</u>)
Melt chamber	$<8.0 \times 10^{-6}$	1.4×10^{-6}	1.06×10^{-6} * Point A
Gun chamber	$<6.0 \times 10^{-6}$	4.0×10^{-7}	3.04×10^{-7} ** Point B

b) Leak- and Degassing Rate: $Q = \frac{V \cdot \Delta p}{t}$

Q = Leakrate mbar l/s; V = Volume l;

Δp = Pressure difference; t = Time sec

after 3 hours pumping time:

(Chamber, bar magazine, and gun space)

<u>Specified</u>	<u>Measured</u>	
in 5.4.1 b	LH-Hanau	
Chamber volume	$\Delta p = 1 \times 10^{-3}$ mbar	$\Delta p = 1 \times 10^{-4}$ mbar
1700 l	(4 -> 5×10^{-3} mbar)	(2 -> 3×10^{-4} mbar)
	$t = 82$ sec	$t = 510$ sec
$Q = 1 \times 10^{-3}$ mbar ls ⁻¹	$Q = 2.1 \times 10^{-4}$ mbar ls ⁻¹	$Q = 3.3 \times 10^{-4}$ mbar ls ⁻¹
	$= 1.6 \times 10^{-4}$ Torr ls ⁻¹	$= 2.5 \times 10^{-4}$ Torr ls ⁻¹

after 17 hours pumping time:

<u>Specified</u>	<u>Measured</u>
	LH-Hanau
$V = 1700$ l	$\Delta p = 1 \times 10^{-3}$ mbar
	(2 -> 3×10^{-3} mbar)
	$t = 215$ sec
Not specified	$Q = 7.9 \times 10^{-3}$ mbar ls ⁻¹
	$= 5.9 \times 10^{-3}$ Torr ls ⁻¹

5.4.2 Electron Beam Guns, High Voltage Power Supply Unit, and Beam Control System

The following test has demonstrated the performance of the heat source equipment:

- a) Beam focussing, deflection and oscillation of the gun
- b) Full beam power test of the gun at 150 kW at 35 kV.
During this test the diagram of filament current - emission current was elaborated by measuring at 5 points.
- c) As a heat sink, a Ta-plate of 100 mm diameter and 60 mm thickness delivered by the Seller was applied.
- d) Constant beam current control over a period of 15 min: max. deviation $\pm 2\%$, 150 kW power.
- e) Constant beam voltage over the beam power of 5-150 kW: max. deviation $\pm 2\%$.

5.4.3 Demonstration of Safety and Interlockings

The following interlocking and security systems described in paragraph 3 of the Specification was demonstrated.

- a) The x-ray dose was be measured on the tank, the chamber door, the stroboscope, and the gun at a power of 150 kW and a voltage of 35 kV.

The measured dose was lower than 0.5 mr/h. The Tantalum base plate served as x-ray emitter.

Measuring points:

Stroboscope front door	< 0.1 mr/h
Stroboscope side door	< 0.1 mr/h
EB Gun	< 0.1 mr/h
Melt chamber front door	< 0.1 mr/h
Melt chamber side door	< 0.1 mr/h
Magazine (measured at 60 kW at a W-plate as X-ray emitter)	< 0.1 mr/h

LH measuring instrument type Berthold LB 1310

Callibration system A, No. 672-7-80

0.1 μ Ci; 90 Sr

Measuring scale: 0 --> 0.3 mr/h

- b) Interlocking and Annunciator

The electrically operated vacuum valves close automatically on loss of power where necessary and remain closed when power is restored. A manual reset is provided to open the valves after power restoration. The isolation valve on the horizontal feed system will not close if the hearth is in the melting chamber.

The controls are interlocked where necessary to protect against injury to operating personnel and/or damage to the equipment resulting from improper operation sequence or equipment malfunction.

An interlock is included to require shutoff of beam current before venting the chamber to atmosphere and to prevent "beam on" when vacuum is above a vacuum level adjustable in the pressure range of 2×10^{-3} to 1×10^{-1} torr.

Water cooling is interlocked with the power supplies to prevent energizing supplies when the cooling water is less than a preset value.

c) Further interlocks:

Gun power is interlocked against crucible water cooling flow

Gun power is interlocked against lack of cooling water in the gun anode

The high voltage protection hood of the gun is key-interlocked with the high voltage and can only be opened when the high voltage power supply is switched off

The diffusion pump heaters are interlocked against minimum cooling water flow

The heaters of the diffusion pump are interlocked against a minimum pressure in the fore vacuum line

The chamber vent valve is interlocked against the diffusion pump high vacuum valve

Drive systems are interlocked against overdrive by means of limit switches.

- d) A flush-mounted annunciator is provided that utilizes both normally open or normally closed field contacts with auxiliary contacts on each point to provide an audible and visible signal when any abnormal or alarm condition occurs. Provisions are made for silencing each new audible signal but leaving the visible signal until it automatically resets. The annunciator also contains acknowledge, test, and reset features. At least five spare points will be provided.

APPENDIX C

DISTRIBUTION

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