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THE FABRICATION OF A PLUTONIUM HELIX
FOR A DOPPLER EXPERIMENT

by

R. J. Dunworth, H. V. Rhude and L. R. Kelman

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THE FABRICATION OF A PLUTONIUM HELIX FOR A DOPPLER EXPERIMENT

R. J. Dunworth, H. V. Rhude, and L. R. Kelman

ABSTRACT

A helix constructed of plutonium was made to test the Doppler temperature effect in ZPR-III. The helix, 1 inch in diameter and 6-1/4 inches long, contained 240 grams of delta-phase plutonium alloy encapsulated in titanium tubing. Four plutonium rods were extruded, joined together, and pushed into a titanium tube. This tube was swaged tightly over the plutonium rod, and the assembly was wound into a coil. Electrical leads to the coil were made by swaging copper tubing over the ends of the coil. The helix was tested by cycling about 500 times between 50°C and 190°C. The coil was heated with a current of 130 amperes and cooled with a blast of chilled helium.⁽¹⁾ Several helices of uranium⁽²⁾ were cycled during the same tests. Despite the severity of the thermal cycles, the helices were undamaged.

EQUIPMENT FOR EXTRUSION

The Riehle Tensile Machine was used as a press to extrude the rods. The extrusion chamber, ram, die, and billet were assembled and put into a resistance furnace. The extrusion was made by the inverse method, that is, the billet remained stationary and the die was forced through the chamber against the billet. The assembly of these parts is shown in Figure 1.

The extrusion tools were made from Columbia "Clarite" tool steel, an 18 w/o W, 4 w/o Cr, 1.1 w/o V, and 0.70 w/o C alloy. These parts were drawn to 50 to 55 R_C (about 250,000 psi ultimate tensile strength). The chamber was four inches long and was ground to a diameter of 0.5000 inch after heat treating. The dies were 1/8 inch thick with a 0.110-inch diameter hole. The outer diameters of the dies varied from 0.5000 to 0.5010 inch. Two 0.4995-inch diameter lands were machined on the ram at one inch intervals along the length of the ram. The extrusion ratio was 20.6:1.

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EXTRUSION PROCEDURE

The extruded rods were 0.109 inch in diameter and 3 feet long. The distance between the top of the glovebox and the extrusion die limited the length of the rods to three feet. Four rods were extruded to make the 12 feet of rod required for the helix. The rods were to be threaded, tapped, and screwed together to make the twelve-foot rod.

Five delta-phase plutonium alloy slugs were supplied to make the extrusions. Each of the slugs was 0.34 inch in diameter and 3.8 inches in length. The isotopic analyses of the plutonium slugs are listed in Table I.

TABLE I

Isotopic Analysis of the Plutonium Slugs.
Composition in Atom Per Cent

Melt Number	% Pu ²³⁹	% Pu ²⁴⁰	% Pu ²⁴¹	% Pu ²⁴²
31	95.2	4.5	0.3	0.02
38	95.2	4.5	0.3	0.01
48	95.3	4.4	0.3	0.02

The same general procedure was followed to make each extrusion. The chamber was coated with "Molycote" lubricant, which is a suspension of MoS₂ in oil. The slugs were put into the chamber and upset from both ends to about 2.5 inches in length. To produce this upset, 45,000 psi were required at 20°C, and 20,000 psi were required at 150°C. The die and ram were coated with Molycote and pushed into the chamber. About 4000 psi were used to push the oversize dies into the chamber. The assembled equipment was heated to 380°C in a resistance furnace. This temperature was held for 15 minutes so that the die would expand fully and prevent any metal from extruding between it and the chamber. Before the extrusion was started, the temperature was measured at the bottom of the chamber and at the die. The die temperature was 40° hotter than the bottom temperature. Since only the bottom temperature could be measured during extrusion, the temperatures listed in Table II have been increased by 40° so that the die temperature would be indicated. When the assembly was at the extrusion temperature, a constant pressure of 60,000 psi was applied to the 1/2-inch ram.

The extrusion rate varied considerably for each extrusion, but the factors influencing the rate were not apparent until after all the extrusions had been made. A rapid initial rate was common to all the extrusions, as shown by the data listed in Table II. The extrusion rates of the rods varied

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from 0.12 to 0.74 inch per minute for the first ten inches, and from 0.0042 to 0.21 inch per minute for the last 15 inches. These variations were independent of the metal since the same casting, No. 38, was used for extrusions No. 3, 4, and 5. Some slight temperature differences were noted, but changes in extrusion rate were not consistent with temperature variations. The most important effect seemed to be the friction between the die and the chamber.

TABLE II

Extrusion Data for Delta-Phase Plutonium Alloy at 20 to 1 Reduction and 60,000 psi Pressure

Extrusion Number	Slug Number	Diameter of die (inch)	Length of Rod (in.)	Time for Extruding (hours)	Part of Rod	Rate of Extruding (inches of rod/minute)	Temperature Range for Extruding, °C ^a
1	31 (206)	0.5010	31-1/2	2.5	1st 10 inches 2nd 10 inches last 10 inches	0.25 - 0.125	348 to 380 ^b 380 ^b 380 ^b
2	48 (323)	0.5000	10	6	1st 10 inches Extrusion stalled		390 to 448 ^c
3	38 (232)	0.5005	35	15.5	1st 10 inches 2nd 10 inches last 15 inches	0.45 to 0.12 0.070 to 0.023 0.018 to 0.0042	374 to 376 376 to 372 372 to 368
4	38 (231)	0.5010	35-7/8	1.5	1st 10 inches 2nd 10 inches last 15 inches	0.74 0.50 to 0.47 0.35 to 0.21	378 to 386 386 to 382 382 to 367
5	38 (238)	0.5010	35-9/16	4	1st 10 inches 2nd 10 inches last 15 inches	0.42 0.29 to 0.15 0.10 to 0.06	380 to 388 ^b 388 to 384 ^b 384 to 380 ^b

^aThe temperature was measured in the bottom plug. The temperature values in the table have been increased by 40 degrees to approximate the die temperature.

^bThe furnace power was increased to hold this temperature.

^cThe furnace power was increased to raise the temperature.

The first extrusion was made using a die that was 0.0010 inch over-size, and the assembly was well lubricated with Molycote. The extrusion time was 2-1/2 hours. In extrusion No. 2, a 0.5000-inch diameter die was used with only a slight amount of Molycote. As a result, the extrusion stalled completely, even at 448°C. A section of the chamber was scored and pitted because the plutonium alloyed with the steel at this temperature. In extrusion No. 3, the die was 0.0005 inch oversize, insufficient Molycote was used, and the scored and pitted section of the chamber was used. Consequently, the extrusion time was 15-1/2 hours. The most rapid extrusion (1-1/2 hours) was obtained in extrusion No. 4, when a liberal quantity of Molycote, a 0.0010-inch oversize die, and the smooth section of the chamber were used. In extrusion No. 5, the extrusion rate was faster than in No. 3 because the die was 0.0010 inch oversize and Molycote was applied liberally to the extrusion tools. However, the corroded section of the chamber was again used in extrusion No. 5, which probably accounted for the four-hour extrusion time.

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FABRICATION OF THE HELIX

After the rods had been extruded, the rods had to be joined and encapsulated in a titanium tube. Then the tube was to be swaged tightly over the plutonium, and the assembly coiled into a helix. Finally, electrical leads were to be swaged to the ends of the helix. All these operations were planned so that no plutonium contamination would result.

In order to provide good electrical conductivity through the plutonium alloy core, the four 0.109-inch diameter rods were screwed together. After threading one end of the rod, the tip was machined to a cone so that it would seat in the bottom of the tapped hole in another rod. The hole was drilled with a No. 53 drill and then tapped. The thread size was Machine Screw No. 1-64, and the threaded length was 5/16 inch. When all the rods were joined, the total length was 11 feet 5 inches.

The titanium tube used for encapsulation was ten inches longer and 0.014 inch larger in diameter than the plutonium core. The outside diameter of the tube was 0.143 inch, the inside diameter was 0.123 inch and the length was 12 feet 3 inches. A 1/2-inch plug was welded into one end of the tube. The weld on this plug was stressed less by the extension of the core during swaging, because the tube was ten inches longer than the core. In a mock-up of the swaging without end plugs, an 1100 aluminum core extended about ten inches out of the titanium tube.

In order to prevent contamination, the tube was sealed to a pouch, and the plutonium core was loaded from the glovebox into the tube which was outside the glovebox. The assembly is shown schematically in Figure 2. Photographs of the loading operation are shown in Figures 3 and 4. The tube is shown in Figure 2, and the core is shown in Figure 3. About three inches of a Monel tube were put inside the titanium tube as a funnel to prevent plutonium contamination of the inside surfaces near the open end. The outside diameter of the Monel tube was 0.122 inch, the inside diameter was 0.119 inch, and the length was ten inches. The Monel tube also served as a guide for insertion of the plutonium through the pouch, as shown at the left in Figure 3. After the plutonium core was loaded into the titanium tubing, the Monel protection tube was taken into the glovebox, and the end of the pouch sealed off. No contamination resulted from these operations.

The loaded tube, which had the open end sealed with a part of the pouch, was carried to a high velocity (150 linear ft/min) fume hood. After carefully cutting the plastic away, a 1/2-inch titanium plug was welded into the open end of the tube. A 1/32-inch hole was drilled in this plug so that the air inside the tube could escape during swaging. There was no contamination detected in the weld or on the loaded tube.

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The rod was swaged and coiled in a "contamination risk" area. The titanium tube, which had an outside diameter of 0.143 inch, was readily swaged through a 0.125-inch diameter die. The area of the tube was reduced 5.7%, and the wall thickness was increased from 0.010 to 0.011 inch. The diameter of the plutonium rod was decreased from 0.109 inch to 0.103 inch, an 11% reduction in area. The closed end of the swaged rod was attached to a mandrel, chucked in a lathe, and wound into a coil. However, after twelve turns had been wound, the rod broke at the first joint. The lathe, mandrel, and bench top were contaminated by plutonium. The air count did not increase, nor were other surfaces contaminated. The coiling operation was discontinued, and the rod was brought back to the glovebox laboratory.

Since the rod had broken at the first threaded joint, the other two joints were radiographed to determine their soundness. In Figure 5 a small cavity is shown that was found at the bottom of one joint, and a sound joint is shown in Figure 6. The location of both joints was marked on the rod for use in the next coiling operation. The rod end that was closed with the vented titanium plug was also radiographed. The plutonium core had not been pushed completely to the plug by the swaging, but about a 1-1/2-inch gap was left. The excess tubing was cut off and a 3/4-inch plug was pushed against the rod and welded in the titanium tubing. The rod was machined and welded in a high velocity fume hood, and no plutonium contamination was detected.

The broken end of the rod was put through the pouch attached to the machine shop glovebox. About 1/2 inch of the plutonium core was drilled out and a titanium plug was welded in the tube. The rod was removed from the glovebox by sealing off the contaminated end in the pouch, and it was taken to the high-velocity fume hood for decontamination. The sealed pouch was removed, and the exposed rod was checked for contamination. The count was about 1500 M (1.5×10^6 disintegrations/min/100 cm²). Since the rod had been taped to within two inches of the weld, removal of the tape and swabbing with acetone-soaked cotton reduced the count on the rod to less than 1 M. The weld area could not be decontaminated below 500 M even after electropolishing several times. No contamination was detected on swipe tests of this weld; therefore, the plutonium was assumed to be fixed in the weld, and the copper electrodes, which were to be swaged over the end of the rod, would provide sufficient protection from this contamination.

After the plutonium had been resealed in the titanium tube, the assembly was heat treated to remove the work hardening that resulted from swaging. The rod was enclosed in a helium-filled nickel tube and was annealed at 450°C for two hours. The hardness of the swaged titanium rod decreased from 92 R_B to 80 R_B after annealing treatment.

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The annealed rod was wound into the complete helix by using the mandrel and coiling jig described by Yaggee.⁽²⁾ Radiographs of the coil showed that the plutonium core did not shift in the tubing as it was coiled.

The two copper electrodes were made from 3/16-inch diameter copper tubing. A two-foot length of No. 8 copper wire was silver-soldered at one end of each tube. The end of the coil was cleaned with emery paper, and one inch of the copper tubing was slipped over the titanium rod. The electrode was then swaged onto the rod through a 0.150-inch die. A strong electrical contact was made over about 1-1/2 inches of the titanium tube.

The coil was slipped over a porous glass tube to complete the assembly. Three fine wire thermocouples were spot welded onto the helix so that the temperature could be measured during the thermal cycling. The final assembly is shown in Figure 7. Two small depressions in the titanium tubing marked the location of the two joints in the plutonium rod. One of these dents is marked by the arrow in Figure 7 on the 12th turn; the other is on the back of the coil. Although these depressions were weak spots in the helix, the coil was thermal cycled some 500 times without breaking. The coil was heated to 190°C by a current of 130 amperes and cooled to 50°C by a blast of chilled helium. It took about 20 seconds for the complete cycle.⁽¹⁾

SUMMARY

A method of making a plutonium helix has been described. The mechanical weakness of the threaded joints was not realized until the first joint broke on coiling. The combination of a threaded joint and work-hardened metal apparently caused the rupture of the assembly. Even after annealing the joint produced a defect in the titanium tubing. Although this defect did not break during the tests, it is still a weak spot that should be monitored and examined to check for the start of fracture. If another rod were needed, every effort should certainly be made to extrude a continuous twelve-foot rod, or, failing that, to make the joints in the titanium tubing rather than in the plutonium core.

The delta-phase plutonium alloy used to make the rod was assumed to have properties similar to 1100 aluminum. A mock-up test on a swaged 1100 aluminum core in the titanium tube showed that this assembly could be wound into a coil and that the threaded joints were satisfactory. However, the hardness of the extruded plutonium alloy rod was 51 R_B, which is similar to 6061 aluminum alloy. When this aluminum alloy was coiled, the rod also broke at a joint. The 6061 aluminum alloy apparently represents the plutonium alloy more closely than the 1100 aluminum and should be used for mock-up work.

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The inverse extrusion method is well suited for glovebox operation. All the equipment can be assembled cold so that the operations are safer and require less space. The temperature of the extrusion was more accurately known because the chamber, ram, and billet were at about the same temperature. In these extrusions the pressure was held constant, but the extrusion rate decreased rapidly because the friction in the chamber increased. One disadvantage of this method is that the extrusion tools are at a high temperature, a factor which weakens the tool steel and increases the danger of alloying between the billet and the tools.

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Figure 1. The Extrusion Equipment is Shown at the Start of an Extrusion.

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Figure 2. Method of Attaching Titanium Tubing to the Pouch on the Glovebox.

Figure 3. The Titanium Tube, Which is Sealed to the Pouch at the End of the Glovebox, is Being Loaded With the Plutonium Rods From Inside the Glovebox at the Left.

AML Negative 106-2626

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Figure 4. The Plutonium Core is Being Loaded Into the Titanium Tube Inside the Glovebox. A Part of the Monel Protection Tube is at the Left of the Picture.

ANL Negative No. 106-2627

Figure 5. The Radiograph of a Joint in the Rod (After Swaging).

The hole is at the bottom of the threaded plug which has a small conical tip. The two white lines outline the titanium tube, and parallel to these, the grey lines mark the edge of the lead shields.

PU-93

Exposure: 6 minutes at 41 inches,
250 kv.

Figure 6. The Radiograph of the Other Joint in the Rod (After Swaging).

The threads of the joint can be seen. This joint had not been pulled apart by the swaging operation.

PU-92

Exposure: 6 minutes at 41 inches,
250 kv.

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Figure 7. The Finished Coil, Mounted for Testing on a Porous Pyrex Tube.

PU-85

1/2-X

Two of the three thermocouples are visible. One of the joints is visible on the coil as a small depression on the 12th turn, indicated by the arrow.

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