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DETERMINATION OF FUEL ELEMENT WARP AND HOT SPOT ORIENTATION

7

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DETERMINATION OF FUEL ELEMENT WARP
AND HOT SPOT ORIENTATION

BY

T. L. Deobald

June 10, 1959

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DECLASSIFIEDAbstract

The angular relationships of warp to rib marks and warp to hot spots were measured for a large number of fuel elements. The data was analyzed and found to provide information regarding the formation of warp and hot spots.

Introduction

A large number of irradiated fuel elements have been measured at HAPO to determine the effects of irradiation on their dimensional stability. Diameter changes and warp, two indications of the dimensional stability, are routinely measured using the Profilometer installed in the Metal Examination Facility at 105-C. In very few cases has there been any attempt to accurately relate the location of the warp to the hot spots and rib marks observed on the fuel element surface. This report briefly describes the equipment used for measuring the angular relationship of fuel element warp to hot spots and rib marks and reports the results of measurements which were made in an attempt to establish these relationships. The measurement of the angular relationship of warp is now incorporated as an integral part of dimensional measurements made at the Metal Examination Facility and will continue to be made to provide additional information on the warp and hot spot mechanisms.

Summary and Conclusions

Equipment for the measurement of the angular relationship of fuel element warp to the tube ribs and to hot spots was tested and proven feasible for routine measurements. Results of the analysis of angular measurement data obtained from irradiated fuel elements showed the following:

- A. The incidence of warp between the ribs is greater than would be expected from a random distribution of warp.
- B. There is no relationship between the point of maximum warp and hot spots.
- C. Fuel elements warped between the ribs show less tendency to exhibit hot spots.
- D. Warp greater than 15 mils increases the probability of a hot spot being exhibited on the adjacent downstream fuel element.

It is proposed that the preferred between the rib orientation of fuel element warp could possibly result from the increased temperatures in the lower half of the process tube. It is also theorized that between the rib warp might raise the adjacent fuel element close to the process tube wall and result in the increased hot spot frequency observed on fuel elements downstream from warped pieces.

Additional data are to be collected and correlations made to determine more precisely:

- A. What effect slug warp has on hot spot formation and frequency.
- B. The relationship of warp angle to fuel element position.

DECLASSIFIEDDiscussion

Dimensional changes undergone by fuel elements during irradiation are measured routinely using a Profilometer at the 105-C Metal Examination Facility. It has long been suspected that a post-irradiation warp of the fuel element might have a preferred orientation with respect to the process tube ribs, and that this warp might contribute to the hot spots observed on fuel elements or possibly the warp has resulted from the non-uniform heating undergone by the fuel element during the formation of hot spots. It can be said with a reasonable degree of assurance that hot spots have resulted from a lack of adequate cooling at points where the fuel element surface lays closer than normal to the tube wall. Evidence to support this statement include: 1) the indication of overheating at the location of the hot spot; 2) the fact that hot spots similar to those observed on fuel elements are frequently observed on the internal surface of process tubes removed from the reactor; 3) very few or no hot spots are observed between the rib marks found on fuel elements; and, 4) intentional cocking or misaligning of the fuel elements¹ actually produces hot spots on fuel elements.

An auxiliary viewer, designed and constructed by Optical Instruments, was incorporated into the existing Profilometer equipment to assist in measuring the angular relationship of the fuel element when rotated to the point of maximum warp with respect to the rib marks and hot spots found on the fuel elements surface. A dial indicator, coupled to the Profilometer chucks, was used to measure the degree of rotation of the fuel element. Repeated tests of the equipment showed that a mark on the surface of the fuel element could be repeatedly repositioned to within two degrees. Figure 1 shows the developed surface of a fuel element which has pronounced rib marks. The developed fuel element surface of Figure 2 shows the relationship of a hot spot to the rib marks. One of the rib marks in this photograph is hardly discernable. Dial indicator readings were used to calculate the warp angle (angle between the center of the rib marks and the point of maximum warp), the hot spot angle (angle between the hot spot and the center of the rib marks) and the warp-hot spot angle (angle between the point of maximum warp and the hot spot).

Two measuring tests were made to determine the reproducibility of angular measurements made with the equipment. In the first test, a tube of 32 fuel elements was measured for warp and angular relationships three times by three different operators. An analysis of these data² showed that the angle measurements were meaningful in 40% of the cases. Since a large amount of the inaccuracies could be a result of inability to locate the rib marks or point of maximum warp on fuel elements with small warp, a second test was made using 32 different fuel elements which had been marked. These data

¹ McCarthy, P. C., and F. W. Van Wormer, "Final Report on Production Test No. 105-634A In-Pile Cocked Slug Tests", HW-55789, June 6, 1958. (Secret)

² Unclassified letter to T. L. Deobald, "Precision of Warp and Angular Measurements", J. L. Jaech, March 18, 1959.

FIGURE 1

Developed Surface of a Fuel Element Showing Pronounced
Rib Marks

FIGURE 2

Developed Surface of Fuel Element Showing Relationship of Hot Spot
to Rib Marks

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showed¹ that the most meaningful data came from fuel elements in positions 8-25 inclusive, (counting from the downstream end of the charge) and with warp greater than 15 to 20 mils.

The warp angle measured on fuel elements from 41 tubes of Production Test Material and from 239 standard fuel elements discharged from C-Reactor on February 18, 1959, are tabulated in Table I. This table shows the number of fuel elements with a warp angle in the four different groups; 0-45°, 46-90°, 91-135° and 136-180°. Also shown is the percentage of fuel elements within each group and the percentage expected for random distribution. Analysis of the data^{2,3} in Table I shows a significantly larger number of fuel elements with a warp angle of between 0 and 45° (convex side of the fuel element lying between the ribs). Although the increased incidence of warp between the ribs is not very large, the distribution does indicate that warp is not completely random and that reactor variables contributed to the location of maximum warp. Sufficient data is not available to permit establishing a relationship between warp angle and fuel element position; however, the data does indicate the possibility that the percentage of elements falling in 0-45° warp angle group increases slightly towards the downstream end of the tube.

TABLE I

Relationship of Warp to Rib Marks

<u>Warp Angle</u>	<u>Expected For Random Distribution</u>	<u>239 - C-Reactor Fuel Elements From 2-16-59 Discharge</u>	<u>41 Tubes of PT Fuel Elements</u>	
			<u>Warp > 10 mils</u>	<u>Positions 8-25 Warp > 15 mils</u>
0°-45°	25%	44 (37%)	238 (33.8%)	77 (39.5%)
46°-90°	25%	33 (28%)	185 (26.3%)	61 (31.3%)
91°-135°	25%	20 (17%)	142 (20.2%)	27 (13.8%)
136°-180°	25%	21 (18%)	139 (19.7%)	30 (15.4%)

The hot spot angle and the warp-hot spot angle for 34 of the 41 tubes of Production Test material are tabulated by position number in Table I of the Appendix. The data includes measurements of fuel elements in positions 8-25 inclusive, with hot spots or with warp greater than 15 mils. Analysis of these data,⁴ with respect to hot spots, revealed the following:

¹ Personal communication with J. L. Jaech.

² Unclassified letter to T. L. Deobald, "Relationship of Warp to Hot Spots and Rib Marks", J. L. Jaech, April 1, 1959.

³ Unclassified letter to T. L. Deobald, "Warp and Hot Spots", J. L. Jaech, May 12, 1959.

⁴ Ibid.

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- A. There is no apparent relationship between the location of the hot spot and the point of maximum warp. The data shows that the hot spots are formed, in most cases, opposite the ribs regardless of where the maximum warp occurs. Also, fuel elements with the highest warp are not necessarily the ones that display hot spots.
- B. Maximum warp positioned between the ribs reduces the probability that a hot spot will be exhibited on that fuel element. This is shown by the data included in Table II. Previous observations have shown that 50 mils warp would not necessarily result in a hot spot and probably can be attributed to the fact that the warp occurred between the ribs.
- C. Appreciable warp on a fuel element increases the probability that a hot spot will occur on the adjacent downstream fuel element. Of the 399 fuel elements with warp less than 15 mils, 86 followed fuel elements with greater than 15 mils warp. Thirty eight, or 44.2%, of these 86 fuel elements exhibited hot spots; this is compared to 53 hot spots (16.9%) on the 313 non-warped fuel elements which were not immediately downstream from a fuel element with greater than 15 mils warp. J. L. Jaech estimates from these data, that elimination of warp greater than 15 mils would reduce the hot spot frequency of slugs in positions 8-25 from 26.3% to 16.9%, or a factor of nearly 2.

TABLE II

Proportion of Warped Fuel Elements Having Hot Spots

<u>Warp Angle</u>	<u>Hot Spot</u>	<u>No Hot Spot</u>	<u>Percent of Fuel Elements Having Hot Spots</u>
0°-45°	13	64	17%
46°-90°	23	38	38%
91°-135°	10	17	37%
136°-180°	19	11	63%

The preferred downward orientation of warp could possibly result from reduced cooling area and higher water temperatures in the lower half of tube. Rib contact reduces the cooling area on the lower half of the fuel element surface by about 7%. N. R. Miller¹ has estimated that water temperatures in the annulus between the ribs in the downstream portions of the charge are increased by a factor as high as 1.3 (ratio of inlet-outlet temperature between the ribs to the inlet-outlet temperature above the ribs) depending on the corrosion index of the tube, the height of the tube ribs and the dimensions of the fuel element. C-Reactor tubes which make up the majority of tubes included in this analysis, are estimated to have the highest ratios. This high between-the-rib water temperature mechanism supports the observation that downward preferred orientation of warp possibly increases at the downstream end of the charge, since it is known that the temperature ratio

¹ Personal communication with N. R. Miller.

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increases towards the downstream end. Additional data will be required to establish or refute this relationship.

The increased frequency of hot spots on fuel elements downstream from adjacent significantly warped fuel elements suggests a mechanism for the formation of hot spots and cocking and could possibly explain other previously unanswered questions regarding the relationship of hot spot frequency to tube exposure and power and to the types of metal. Earlier analysis of fuel element examination data has shown slug warp and hot spot frequency to be a function of tube exposure and tube power. If one envisions a mechanism where a fuel element warps, the maximum occurring between the ribs, and raises the adjacent slug off the ribs and closer to the tube wall to form a hot spot, then the frequency of hot spots would become a function of warp. Figures 3 and 4 depict warped fuel elements raising adjacent fuel elements from the ribs.

FIGURE 3

Warped fuel element cocking adjacent fuel element

FIGURE 4

Warp resulting in misalignment of adjacent fuel element

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P. B. McCarthy noted that while artificially cocking a fuel element during flow testing adjacent elements were raised. It therefore seems feasible that between the ribs warp could raise adjacent pieces in a similar manner. Fifteen mils warp might not move the adjacent fuel element enough to cause a hot spot; however, fuel elements with 15 mils warp very likely were warped considerably more while undergoing irradiation. Undoubtedly many other mechanisms also contribute to the formation of hot spots. The mechanism also suggests a possible explanation for the increased hot spot frequency¹ observed on Blunt-Nose True Line material which were designed to improve alignment and reduce hot spot frequency. The interlocking feature of the BNTL material would increase the probability of warped fuel elements, with the bow downward, lifting the adjacent piece closer to the tube wall. Fuller² found 28 of 35 hot spots on BNTL material were on the downstream end of the slug. This would require that the piece upstream from the warped fuel element be raised. Unfortunately, no warp data are available on this material, hence it could not be determined if the slugs with hot spots did actually occur upstream and adjacent to a significantly warped fuel element.

Measurement of warp angles from additional fuel elements will be made to gain further information on the location of maximum warp and its effect on hot spot frequency and to assist in learning what reactor variables affect fuel element warp.

Acknowledgement

The author gratefully acknowledges the statistical analysis work performed by J. L. Jaech, HLO.

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¹ Fuller, N. E., "Interim Report on PT-IP-196-I Investigation Into the Cause and Occurrences of Hot Spots", HW-57731, October 9, 1958. (Secret)

² Ibid.

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Warp-Hot Spot Angular Relationships

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TABLE I (Continued)

Tube No.	PT No.	Dischg. Date	Position No.	Warp Angle				Hot Spot Angle				Warp-Hot Spot Angle			
				0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°
2168-C	56A	1/4/59	11	16							X				X
2168-C	56A	1/4/59	12			17		X					X		
2168-C	56A	1/4/59	13	29							X				X
2168-C	56A	1/4/59	14				7				X	X			
2168-C	56A	1/4/59	15		16						X		X		
2168-C	56A	1/4/59	16		26						X			X	
2168-C	56A	1/4/59	17		21										
2168-C	56A	1/4/59	18		13						X			X	
2168-C	56A	1/4/59	19	1							X	X			
2168-C	56A	1/4/59	20	17											
2168-C	56A	1/4/59	21		9						X		X		
2168-C	56A	1/4/59	22				23								
2168-C	56A	1/4/59	23				10				X	X			
2168-C	56A	1/4/59	24	38											
2170-C	56A	1/4/59	14			19									
2170-C	56A	1/4/59	18		12				X			X			
2170-C	56A	1/4/59	21	19											
2170-C	56A	1/4/59	22			13					X		X		
2183-C	56A	2/2/59	8				15				X	X			
2183-C	56A	2/2/59	9	62											
2183-C	56A	2/2/59	10		23						X			X	
2183-C	56A	2/2/59	11			34					X		X		
2183-C	56A	2/2/59	12	11							X			X	
2183-C	56A	2/2/59		50							X			X	
2183-C	56A	2/2/59	14		19										
2183-C	56A	2/2/59	17	21											
2183-C	56A	2/2/59	18		9						X		X		
2183-C	56A	2/2/59	19	35											
2183-C	56A	2/2/59	20			5					X		X		
2183-C	56A	2/2/59	21		33										
2183-C	56A	2/2/59	22		27						X			X	
2183-C	56A	2/2/59	23	31				X				X			
2183-C	56A	2/2/59	24			12					X	X			
2183-C	56A	2/2/59	25			11					X	X			
2269-C	56A	1/4/59	8		28										
2269-C	56A	1/4/59	9	26					X				X		
2269-C	56A	1/4/59	10	32											
2269-C	56A	1/4/59	11		6.5						X	X			
2269-C	56A	1/4/59	13		61.0						X				X
2269-C	56A	1/4/59	14				5				X		X		
2269-C	56A	1/4/59	15	15							X				X
2269-C	56A	1/4/59	17		25										
2269-C	56A	1/4/59	18				4.5				X	X			
2269-C	56A	1/4/59	19		28										
2269-C	56A	1/4/59	20	21.0											
2269-C	56A	1/4/59	21			35					X	X			

TABLE I (Continued)

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TABLE I (Continued)

Tube No.	PT No.	Dischg. Date	Position No.	Warp Angle				Hot Spot Angle				Warp-Hot Spot Angle			
				0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°
2171-D 95A		11/17/58	12				8	X							X
2171-D 95A		11/17/58	13		8						X		X		
2171-D 95A		11/17/58	14		22										
2171-D 95A		11/17/58	15	2							X				X
2171-D 95A		11/17/58	25	19											
2189-D 95A		12/14/58	11		3				X			X			
2189-D 95A		12/14/58	17	7							X				X
2189-D 95A		12/14/58	19		19										
2189-D 95A		12/14/58	21	5							X			X	
2461-D 95A		12/14/58	15		15										
2461-D 95A		12/14/59	16	17							X				X
2461-D 95A		12/14/58	17		14						X			X	
2461-D 95A		12/14/58	18				6				X	X			
2461-D 95A		12/14/58	20		14						X			X	
4070-D 95A		12/14/58	14		3				X						X
4070-D 95A		12/14/58	17		7						X			X	
4070-D 95A		12/14/58	19			12					X		X		
4070-D 95A		12/14/58	21		19										
4070-D 95A		12/14/58	23		11						X				X
3476-C 132D		11/18/58	8				4				X	X			
3476-C 132D		11/18/58	9	18											
3476-C 132D		11/18/58	10				3	X							X
3476-C 132D		11/18/58	11				12				X	X			
3476-C 132D		11/18/58	12			42									
3476-C 132D		11/18/58	13			23									
3476-C 132D		11/18/58	15	26											
3476-C 132D		11/18/58	21		31										
3476-C 132D		11/18/58	22	29											
3476-C 132D		11/18/58	23		33			X				X			
3476-C 132D		11/18/58	24				29				X	X			
3476-C 132D		11/18/58	25	21											
3988-C 132D		11/18/58	8		39										
3988-C 132D		11/18/58	9				28				X	X			
3988-C 132D		11/18/58	12	10					X					X	
3988-C 132D		11/18/58	13		20										
3988-C 132D		11/18/58	14		23										
3988-C 132D		11/18/58	15				21				X	X			
3988-C 132D		11/18/58	16		24										
3988-C 132D		11/18/58	17			35									
3988-C 132D		11/18/58	18				20				X	X			
3988-C 132D		11/18/58	20				38								
3988-C 132D		11/18/58	21		38				X			X			
3988-C 132D		11/18/58	22		35										
3988-C 132D		11/18/58	24				32								
3681-C 141A		12/27/58	10	12							X				X
3681-C 141A		12/27/58	11	12				X				X			

TABLE I (Continued)

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TABLE I (Continued)

Tube No.	PT No.	Dischg. Date	Position No.	Warp Angle				Hot Spot Angle				Warp-Hot Spot Angle			
				0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°
2785-C	168A	12/27/58	14				24								
2785-C	168A	12/27/58	15		27										
2785-C	168A	12/27/58	16	17											
2785-C	168A	12/27/58	17				14			X		X			
2785-C	168A	12/27/58	18		23						X				X
2785-C	168A	12/27/58	19				2				X	X			
2785-C	168A	12/27/58	23				19								
2785-C	168A	12/27/58	24	20											
2785-C	168A	12/27/58	25		2						X			X	
2788-C	168A	12/27/58	11		13						X				X
2788-C	168A	12/27/58	12	23						X				X	
2788-C	168A	12/27/58	13		11					X		X			
2788-C	168A	12/27/58	16			8				X					X
3792-C	168A	1/5/59	9				3				X	X			
3792-C	168A	1/5/59	10				2				X	X			
3792-C	168A	1/5/59	14	21											
3792-C	168A	1/5/59	15			10					X		X		
3792-C	168A	1/5/59	21				7				X	X			
3792-C	168A	1/5/59	22		3						X			X	
3283-C	168A	12/27/58	8	22											
3283-C	168A	12/27/58	15				5				X	X			
3283-C	168A	12/27/58	19				4.5			X				X	
3283-C	168A	12/27/58	21		22						X		X		
3283-C	168A	12/27/58	22			17									
2275-KW	178A	1/19/59	10	22											
2275-KW	178A	1/19/59	12	16											
2275-KW	178A	1/19/59	15		10						X		X		
2275-KW	178A	1/19/59	20	18											
2275-KW	178A	1/19/59	27			16									
1481-C	179A	3/4/59	9		16										
1481-C	179A	3/4/59	10				24								
1481-C	179A	3/4/59	11	21											
1481-C	179A	3/4/59	12	15											
1481-C	179A	3/4/59	13	3							X				X
1481-C	179A	3/4/59	14	18											
1481-C	179A	3/4/59	17	19											
1481-C	179A	3/4/59	21	17											
1488-C	179A	3/4/59	12	24											
1488-C	179A	3/4/59	13			6					X	X			
1488-C	179A	3/4/59	15	19											
1488-C	179A	3/4/59	16	16							X				X
1488-C	179A	3/4/59	19		16										
1488-C	179A	3/4/59	20	19											
1488-C	179A	3/4/59	21			7					X	X			
2387-C	179A	3/4/59	16			10					X		X		
2387-C	179A	3/4/59	20			8					X	X			

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TABLE I (Continued)

Tube No.	PT No.	Dischg. Date	Position No.	Warp Angle				Hot Spot Angle				Warp-Hot Spot Angle			
				0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°	0° 45°	46° 90°	91° 135°	136° 180°
2688-C	179A	3/4/59	8				19								
2688-C	179A	3/4/59	9	17											
2688-C	179A	3/4/59	10	15											
2688-C	179A	3/4/59	12	19											
2688-C	179A	3/4/59	13	24											
2688-C	179A	3/4/59	16				19								
2688-C	179A	3/4/59	19	21											
2688-C	179A	3/4/59	20	7											
2790-C	179A	3/4/59	8			14				X					X
2790-C	179A	3/4/59	9	19											
2790-C	179A	3/4/59	12	18											
2790-C	179A	3/4/59	13		15						X			X	
2790-C	179A	3/4/59	14	15											
2790-C	179A	3/4/59	15	16											
2790-C	179A	3/4/59	16			5					X		X		
2790-C	179A	3/4/59	17	15											
2781-C	179A	3/4/59	8	20											

Total

101 86 45 61

DATE

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8/3 /94

END