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A SPECIALIZED X-RAY GENERATOR FOR RADIOGRAPHING
CIRCUMFERENTIAL WELDS IN SMALL DIAMETER TUBES*

By

Neville B. Edenborough, Frank J. Sattler
and Gerold H. Tenney

University of California
Los Alamos Scientific Laboratory
Los Alamos, New Mexico

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ABSTRACT

Heat exchangers in many reactors contain circumferential welds which, owing to the overall geometry, cannot be radiographed satisfactorily with commercially available sources of radiation. The Nondestructive Testing (NDT) Group of the Los Alamos Scientific Laboratory encountered this problem especially in connection with the development of the Ultra High Temperature Reactor Experiment (UHTREX) and of the Core Test Facility.

On the basis of preliminary investigations, money was appropriated by the AEC's Division of Reactor Development for the design and construction of an insertion X-ray generator based on specifications established by the Los Alamos Scientific Laboratory's NDT Group.

This paper describes the characteristics and performance of the X-ray generator. It has a 9-in.-long, 3/8-in.-diameter anode extension that produces a 360° reflected X-ray beam. This generator can be operated up to 75 kV and at an intensity of 50 microamperes. Radiographs reveal 4-mil-diameter voids in a 125-mil-thick specimen. In the field, this unit was used to radiograph welds in 0.1-in.-thick, 1.5-in.-O.D. stainless steel tubes.

It is hoped that the American equipment manufacturing industry will make this specialized X-ray generator available to the general technical public in the near future.

Introduction

In 1958, a proposal was submitted by the Nondestructive Testing Group (GMX-1) of the Los Alamos Scientific Laboratory to the Division of Reactor Development, USAEC, through the Nondestructive Testing Steering Committee (now the Nondestructive Testing Working Group) to develop an insertion X-ray generator designed specifically for radiography of small diameter (at least 1/2-in. I.D.) tube-to-header welds in heat exchangers.

The necessity for such a device became apparent with the development of the crevice-free tube-to-header weld. This was the first tube-to-header weld which could be radiographically inspected. Since it was developed primarily for nuclear reactors, especially sodium heat-transfer systems, its failure could lead to radioactive contamination as well as other industrial hazards brought about by the coolant material.

The criteria of the X-ray generator under consideration called for the possibility of inserting it at least 8 in. into 1/2-in.-I.D. (or larger) tubing. In addition, it should emit X-rays perpendicular to the axis at a 360° angle. The X-ray energies should range from 50 to 100 pkV and have a target current of at least 5 microamperes and a focal spot of 0.25 mm in maximum projected dimension.

This proposal was accepted by the Division of Reactor Development, and a contract was given to Resitron Laboratories of Santa Monica, California, by the Los Alamos Scientific Laboratory under the supervision of its Nondestructive Testing Group.

This paper covers the technical evaluation of this instrument performed at Los Alamos and also describes briefly its practical application.

DESCRIPTION

The prototype insertion X-ray tube is shown in Figure 1. The total length is 29-3/4 in., and the diameter at the barrel is 3-1/2 in. The projecting target extension is stainless steel, 3/8-in. O.D. and 16-3/8 in. long. However, only 9-1/8 in. are available for insertion owing to the focusing coil. The internal configuration is shown in Figure 2.

The operation of the generator is similar to that of most standard X-ray generators. Electrons are emitted from the filament and are collimated by a 0.005-in.-thick stainless-steel disc with a 0.021-in.-diam hole in the center. The electrons are accelerated through the field between the filament and the anode, and the majority of the electrons should travel through the stainless-steel tube to strike the target. As the electrons leave the filament and are accelerated while traveling within the target extension, they are focused by the magnetic field of a surrounding coil. This converging electron beam is aimed at a small X-ray emitting spot on the 0.04mm-thick tantalum target. From this 0.25mm-diam focal spot a reflected X-ray beam is emitted radially, almost parallel to the plane of the target; and a transmitted beam is emitted in a cone perpendicular to the plane of the target.

The transformer and controls are of standard design, utilizing a voltage doubling Greinacher circuit. The voltage is varied by an adjustable transformer controlling the primary voltage of the high-voltage transformer. The focusing coil is fed by an adjustable, constant-current power supply.

The complete insertion X-ray generator system is shown in Figure 3. The complete unit is portable: the heaviest item is the transformer, which weighs approximately 100 lb.

Description of Experiments

Various experiments were performed in order to obtain the following information:

1. Maximum permissible target currents.
2. Radiographic resolution and sensitivity capabilities using mild- and stainless-steel tubing as specimens.
3. Development of radiographic techniques for such tubing.
4. The performance of the generator under field conditions.

The maximum permissible current was determined by the temperature limitations of the various components of the X-ray tube.

The generator was enclosed in a lead-lined container to give personnel protection and to reduce the air flow. The stainless-steel target extension was enclosed by, but not in contact with, a 1/2-in.-O.D. pipe so that air flow in this region would be severely reduced.

Two chromel-alumel thermocouples were placed on the stainless-steel target extension, one on the brazed joint at the base of the extension and one 1/2 in. from its tip. The thermocouple at the tip of the tube measured the heat developed around the glass plug sealing the extension.

The temperature of the focal spot was measured optically using a micropyrometer; the reflection of the focal spot was observed in a mirror. Literature research indicated the following temperature limitations:

1. The brazed joint should withstand temperatures up to 570°C,
2. The glass plug, 350°C, and
3. The tantalum target, 1100°C.

These limiting values were the guides for determining the maximum permissible currents to be used at several different energies.

Resolution capabilities were examined and studied through the use of test samples as shown in Figure 4. They consist of small diameter tubes into which holes varying from 0.003 to 0.030 in. in diameter and depth had been drilled. These specimens were radiographed with Kodak Industrial X-Ray Film, Type AA or M, Ready Pack, wrapped around the outside, the X-ray tube being properly centered within the specimen. The cut-a-way portions of the specimens were taped in place during the radiography.

The general operation of the unit proved to be quite simple. One adjustment that requires some unusual procedures is focusing to the smallest possible emitting surface. One method used was to observe the focal spot illumination through the micropyrometer and mirror setup, while another was to observe the resolution of a small discontinuity on a fluoroscopic screen. In either case, the focusing coil current was varied until an optimum in the observed phenomenon was obtained. Probably the latter method is more nearly applicable to field operation owing to the availability of equipment.

Some difficulty was experienced in the placement of the X-ray tube. Since the reflected X-ray beam is very narrow, approximately 0.3 in. at 1/2-in. target-to-film distance, it is difficult to align the proper portion of the specimen within this beam.

The generator was rated at 30 to 100 kV; however, during this experimentation, it was impossible to focus the beam above 70 kV. When a new power supply was installed in the focusing coil circuit, it was possible to focus at higher energies. Above 80 kV, arcing occurred somewhere within the transformer section of the generator assembly.

Experience soon indicated that the focusing system supplied with the generator was inadequate: the current through the focusing coil drifted as the components in the circuit warmed up. This condition was remedied to a certain extent by the construction of a new power supply which incorporated a milliammeter, allowing current adjustment to maintain a constant focus. This power supply has since been replaced by a constant-current power supply. During the course of this evaluation, it was determined that a specific current is needed for focusing at each particular energy. Figure 5 shows a plot of focusing coil current versus X-ray generator voltage for one particular coil placement.

Results of Experiments

The results of the maximum current determination are shown in Figure 6. As can be seen, the maximum allowable current varies with energy from 200 microamperes at 30 kV to 70 microamperes at 70 kV. Owing to arcing within the generator assembly and focusing difficulties with the equipment on hand at that time, no experiments were performed above 70 kV. Since that time, the focusing difficulties have been corrected.

The determining factor for maximum allowable current was found to be the target temperature at the focal spot. The temperatures at the other critical points rose to a safe value and stabilized. The stabilization remained steady for the length of the test exposures which took up to 17 min. It is felt that the values of maximum allowable currents shown in Figure 6 may be considered as continuous-duty ratings.

Photographic copies of the radiographs of the stainless-steel test pipes are shown in Figure 7. The radiographs were made with the insertion X-ray generator coaxial to the pipe using the exposure factors shown in Table I. Figure 7A is a photographic copy of a radiograph of a 1/2-in.-O.D., 0.035-in.-wall-thickness test pipe, which contained test holes 0.003, 0.004, 0.010, 0.020 and 0.030 in. in diameter and depth. Figure 7B is a copy of a radiograph of a 1.0-in.-O.D., 0.065-in.-wall-thickness test pipe, with test holes the same as those in the 1/2-in. pipe. The photographic copy of the radiograph of a 2.0-in.-O.D., 0.125-in.-wall-thickness test pipe is shown in Figure 7C. The test holes were the same as those in the previous pipe samples (Figures 7A and 7B) except that the 0.003-in. hole was not included. Although the photographs do not show the 0.004-in. hole, in all cases it was clearly resolved in each of the three radiographs. Equal radiographic resolution was obtained using the mild-steel test pipes.

Table I*

Figure	Pipe O.D. (in.)	Pipe Wall Thickness (in.)	Film Type	Exposure Microampere Minutes	Film Density
7A	0.5	0.035	M	115	2.48
7B	1	0.065	M	400	2.18
7C	2	0.125	AA	800	2.56

*All radiographs were made at 70 kV.

All films were processed for 6 min in General Electric Supermix Developer at 68°F.

M and AA in column 4 represent Kodak Industrial X-Ray Film, Types M and AA, Ready Pack, respectively.

Field Evaluation

The field evaluation of this unit consisted of radiographing the tube-to-header welds in the main heat exchanger of the UHTREX (Ultra High Temperature Reactor Experiment under construction by K Division of the Los Alamos Scientific Laboratory) cooling system during its fabrication at the Baldwin-Lima-Hamilton Corporation plant in Eddystone, Pennsylvania. This heat exchanger contains 96 stainless-steel tubes, 1.50 in. in outside diameter with a nominal wall thickness of 0.072 in. The welds connecting these tubes to the header are approximately 0.1 in. thick, since the header stubs are of greater thickness than the tubing. Figure 8 shows the jig for positioning the tube head above the header for this radiographic inspection. The target was centered in each successive tube using a phenolic insertion guide as shown in Figure 9. The exposure factors used for this radiography were:

1. 75 kV
2. Kodak Industrial X-Ray Film, Type AA, Ready Pack
3. 68 microampere minutes
4. Standard manual processing - The technique used was such that the one "T" hole in a MIL STD. 271-C, size 0.25 steel penetrometer was easily resolved.

To further illustrate this radiographic setup, Figure 10 shows the anode extension in a header nipple, and Figure 11 shows a setup with the X-ray film wrapped around the outside of the weld. The total time required for radiographing an individual weld was about 5 min. Most of it was consumed in placing the film on the weld. The location of the generator target within the weld proved quite simple with the positioning devices provided. Owing to the configuration of the welds, the target was actually centered about 3/8 in. below the weld center line.

During the radiographic procedures described above, it was ascertained by field survey that work on other heat exchangers in the immediate vicinity (6 ft away) did not have to be interrupted even during actual radiography. The transmitted X-ray beam was confined within the tubing of the heat exchanger, and that small portion of the reflected beam which escaped from the immediate setup was absorbed in the mass of the header.

Figure 12 is a photographic reproduction of some of these production radiographs. In this Figure, Weld No. 345 shows a high-density inclusion that was found to be a stainless steel wire (from a wire brush used to clean the prepared joint) that had been fused into the weld. In this same Figure, Welds No. 325 and 342 show porosity ranging in size from 0.010 to 0.030 in. They represent typical production radiographs in this operation.

Conclusion

The prototype insertion X-ray generator surpasses the original expectations. The energy range and output are adequate for most of the contemplated materials and configurations. A radiographic resolution of 0.004 in. was observed on a fairly wide range of sizes of stainless- and mild-steel tubes.

The insertion X-ray generator has these distinct advantages over other available sources of radiation.

1. The small focal spot and the long wave-length radiation beam produce excellent radiographs on welds in small diameter, thin-walled tubing.
2. Very fine grain industrial X-ray films need not be used.

3. Exposure time is short.

4. Radiation hazard is easily controlled.

Acknowledgements

The Baldwin-Lima-Hamilton Corporation gave permission to use the photographs of the radiographic setup on the UHTREX heat exchanger which were taken in their plant.

It is especially gratifying to acknowledge the contribution of Mr. Jules Simmons, as Chief of the Fuels and Materials Development Branch, Division of Reactor Development, within the AEC, through his approval of this project and his encouragement of those members of the Los Alamos Scientific Laboratory who contributed to its realization. Mr. D. B. Hall, K Division Leader of the Los Alamos Scientific Laboratory, supported this undertaking locally. Mr. Douglas Venable, GMX-11 Group Leader, acted very effectively as consultant on the tube design and manufacture. The former GMX-1 Alternate Group Leader, Mr. J. W. Dutli, took part in conceiving the idea of the insertion X-ray generator and its implementation until his termination from this laboratory. The interest and work of Mr. Dana E. Elliott, who authored the AEC report on this subject, also constituted valuable guidelines.

References

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- (2) Metals Handbook, T. Lyman, Editor, American Society for Metals, Vol. 1, pp. 1222 - 1224, 1961.
- (3) An Insertion X-Ray Generator and Its Application, Dana E. Elliott, Los Alamos Scientific Laboratory, Los Alamos, New Mexico, July 1965.

Figure 1. Prototype Insertion X-Ray Tube

Figure 2. Cross Section of Prototype Insertion X-Ray Tube

Figure 3. Complete Insertion X-Ray Generator System

Figure 4. Three Sectioned Resolution Test Samples with the following dimensions:

<u>Sample</u>	<u>Tube Size (Inches)</u>		<u>Hole Sizes in Inches</u>
	<u>OD</u>	<u>Wall</u>	
Top	1.0	0.065	0.003, 0.004, 0.010, 0.020 and 0.030
Center	2.0	0.125	0.004, 0.005, 0.010, 0.020 and 0.030
Bottom	0.5	0.035	0.003, 0.004, 0.010, 0.020 and 0.030

Figure 5. Focus Coil Current Versus X-Ray Generator Voltage

Figure 6. Maximum Permissible Tube Current Versus X-Ray Generator Voltage

Figure 7. Photographic Copies of Resolution Test Radiographs (Stainless-Steel Test Pipes)

Figure 8. Radiographic Setup for UHTREX Heat Exchanger Weld Radiography

Figure 9. Phenolic Insertion Guide

Figure 10. Target Extension Position in Header

Figure 11. Film Position in X-Ray Setup

Figure 12. Photographic Copies of UHTREX Heat Exchanger Weld Radiographs

FIGURE 1

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FIGURE 3

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FIGURE 4

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FIGURE 5

FIGURE 6

A

B

C

FIGURE 7

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FIGURE 8

CMX-1 GT SITE

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FIGURE 9

GMX-1 GT SITE
ORDER NO. 10551

FIGURE 10

GMX-1 GT SITE
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FIGURE 11

GMX-1 GT SITE
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FIGURE 12

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