THE 150 kV cp MICROFOCUS X-RAY UNIT

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Le but de la présente note est de définir le stade de développement du matériel de radiographie de 150 kV à microfocalisation et anodetige, dont le pouvoir de résolution radiographique est très élevé. Cette méthode a été utilisée avec succès sur des soudures entre les tubes et les plaques support d'échangeurs et de générateurs de vapeur en Europe et aux Etats-Unis. D'autres champs d'application comprennent l'examen de turbo-réacteurs (aviation) et turbo-moteurs (marine).

INTRODUCTION

In this paper the microfocus X-ray technique calls for the small, intense electron source of a triode electron gun to be imaged on a small tungsten target at the end of a long thin rod. This long thin rod actually is an electron lens system, which images the electron source onto the target. Dynamic focusing and centering of the electron beam is provided to assure a minimum X-ray source size of about 0.05 mm with good centering for a circumferential beam intensity variation of less than 10%. Dynamic centering also compensates for a stray magnetic field, which would otherwise tend to decenter the X-ray source.

Microfocus lens systems having an outer diameter of 9 mm with a useful length of about 1 m have been constructed. Electrical design considerations include the resistive heating of the magnetic lenses, which are a function of the required magnetic field and the available space for the lens and the deflector windings.
Appropriate design trade-offs have been made to minimize the lens dimensions while at the same time meeting the lens heat dissipation by the use of oil cooling.

To facilitate exchanging X-ray targets and/or the lens structure, the accelerator and lens system undergoes continuous vacuum pumping by means of an oil diffusion pump. Pump down is rapid, permitting quick and easy exchange of the lens and X-ray target. Depending on the choice of the X-ray target, a forward and reverse throw or a true radial beam throw is obtained. By using a canted target, directional beam characteristics can be obtained as well.

While the total power for the tungsten X-ray target is limited to about 15 W, the beam current is in the microampere range. However typical exposure times are still quite short due to the inverse square law gain of a short film-focal-distance. Typical exposures through 10 mm of steel with a 25 mm FFD will require about 90 seconds on Kodak M film and yield a radiographic sensitivity of better than 1%.

Compared with small-size radioactive sources, such as ^{60}Co, ^{192}Ir and ^{170}Tm, the microfocus X-ray source gives a better radiograph because of its:

- improved sharpness due to the smaller radiation source size,
- improved image contrast by the wider energy distribution of X-rays.

An additional advantage is the higher radiation output in the microfocus X-ray unit, which results in a shorter exposure time.

With the microfocus X-ray unit a radiographic sensitivity of better than 1% of the test object thickness has been routinely demonstrated. A comparative radiographic sensitivity study of microfocus X-ray and isotopic techniques for boreside radiography of tube-to-tubesheet welds has been reported by B.E. Foster and R.W. McClung (1).

The successful application of the microfocus X-ray unit for tube-to-tubesheet weld inspection is shown by its capability for a more accurate setting of the automatic welding parameters, therefore reducing the possibility of weld defects during production.

PRINCIPLE OF OPERATION

By means of a double magnetic lens system, the electron source of about 30 μm diameter is imaged on an X-ray target.
Unlike conventional X-ray tubes, in this system the electron gun technique of operation is much the same as in electron microscopy. This has the advantage of giving a smaller and brighter electron source and producing a much smaller focal spot at a considerable distance from the filament.

For imaging the electron source on the X-ray target, the electron beam is temporarily scanned over the X-ray target.
The X-ray target is insulated from electrical ground and is used as a current collector. The dynamic focusing indication is obtained by monitoring the target current signal with a oscilloscope while scanning the electron beam across the X-ray target. This method is relatively simple and allows dynamic X-ray beam centering and electron beam focusing while the rod anode is in place and ready for an actual exposure.

The most serious lens defects influencing the X-ray spot size are astigmatism and defocusing. The contribution of spherical aberration is small. The astigmatism depends upon the lens construction. The defocusing and astigmatism effect can be reduced by the use of a smaller lens aperture at the expense of the available electron beam current.

The effective penetration depth of accelerated electrons in high atomic number target materials (such as Ta and W) for X-ray generation is about 5 microns (80 kV) to 15 microns (150 kV).
When using a perpendicular incident electron beam, the total electron beam current is about twice the measured target current due to electron backscattering. As the fraction of electrons backscattered depends upon the electron-beam angle of incidence, a tungsten target in the shape of a cone with a flat top is ideal for focusing indication. This target type can be used for a panoramic orthogonal X-ray beam with an emergent beam angle of about 60^{o}. It is well to remember that in a conventional X-ray tube with a grounded target (anode) structure the total emission current is measured, while with the microfocus X-ray unit only the absorbed electron beam current

of the insulated target is measured.

THE INSTRUMENT

The 150 kV instrument is continuously evacuated by an oil diffusion pump. The X-ray beam originates at the target near the end of the lens system, giving access into small diameter deep holes for panoramic radiography. The 150 kV microfocus X-ray unit consists of a high tension generator and an accelerator system containing the electron gun with lens attached an automacic vacuum system and an operator's control console.

The high tension generator is of voltage multiplying design with an output of 150 kV cp and 0.25 mA. The high tension setting is continuously variable up to 150 kV cp. The emission current is adjustable by means of a grid bias or Wehnelt resistor setting. There are two versions, one a cable version with the high tension generator connected to the accelerator system by means of a flexible high tension cable with quick disconnects and safety interlocks, the other an integral version with the accelerator tube mounted inside the high tension generator tank. As an example please note figure 1 and 2. Special configurations of the lens system and the X-ray beam pattern are possible to meet customer requirements. To be mentioned in this respect are the high definition lens and the 3 mm outer diameter target system.

Remote control of X-ray spot size by focusing and centering of the electron beam is obtained from the 19" control console, enabling reliable operation with in-situ focus inspection. The setting of operating parameters such as kV, beam current, exposure time and the pre-adjustment of the electron beam focusing and centering is made via the operator's control console.
Vacuum controls and monitoring equipment, safety interlock circuitry and a radiation warning system is provided as standard.

Electronic examination and optimizing the X-ray focal spot for minimum size and proper centering while in place is extremely important for optimum results. Any slight defocusing or decentering caused by external magnetic influences or mechanical droop of the lens structure can be readily detected and corrected in-situ, thus assuring a well centered and minimal X-ray spot size for every exposure.

THE RADIOGRAPHIC RESOLUTION

The radiographic resolution of the microfocus X-ray unit is measured by means of a wire image quality indicator.
Guaranteed resolution value at 80 kV is the imaging of a 0.050 mm diameter steel wire through a 3.0 mm thick wall of a steel test cylinder having an inner diameter of 25 mm.
At 150 kV this becomes a 0.100 mm diameter steel wire images through a 10 mm thick steel wall for the same inner diameter of 25 mm. For these sensitivity tests, the microfocus X-ray spot is positioned on the center axis of the steel test cylinder, with the steel wires of the image quality indicator positioned at the inside. The X-ray film is positioned around the outer surface of the test cylinder.

The equipment radiographic resolution is better illustrated by a specific customer requirement on a $2\frac{1}{4}$ Cr - 1 Mo steel test cylinder, with an ID of 10.2 mm (0.404 in.) and an OD of 16.0 mm (0.632 in.). In this test three sets of steel wires are positioned longitudinally on the source side of the test cylinder at 120 degrees intervals. Each set of steel wires consists of a 0.025, 0.050, 0.075 and 0.100 mm diameter steel wire. Typical radiographic results of this test procedure will show that all of the 0.100, 0.075 and 0.050 mm wires are imaged. Typical results, although not guaranteed, render the 0.025 mm wire visible to trained X-ray film readers.

For the radiographic film interpretation, one has to keep in mind the projection of the penetrameter wires owing to the film-focal distance and the relatively thick object which results in varying degrees of objects defect enlargement. Magnification is useful for flaw size and porosity measurement because of the extreme sharpness of the resultant radiographs. The recommended fine grain films are Eastman Kodak M or R and Agfa-Gevaert D_4 or D_2, or equal. Radiographic data with a special thin plaque-type penetrameter with 1T, 2T and 4T holes for the investigation of porosity sensitivity are given as well by B.E. Foster and R.W. McClung (1).

BENEFITS

This practical high resolution technique allows close monitoring of welding parameters, therefore resulting in an optimized welding process with a lower defect rate and an improved reliability for the weld. The microfocus X-ray unit can be readily adjusted for the desired radiographic sensitivity by adjusting the focal spot size and/or target selection.

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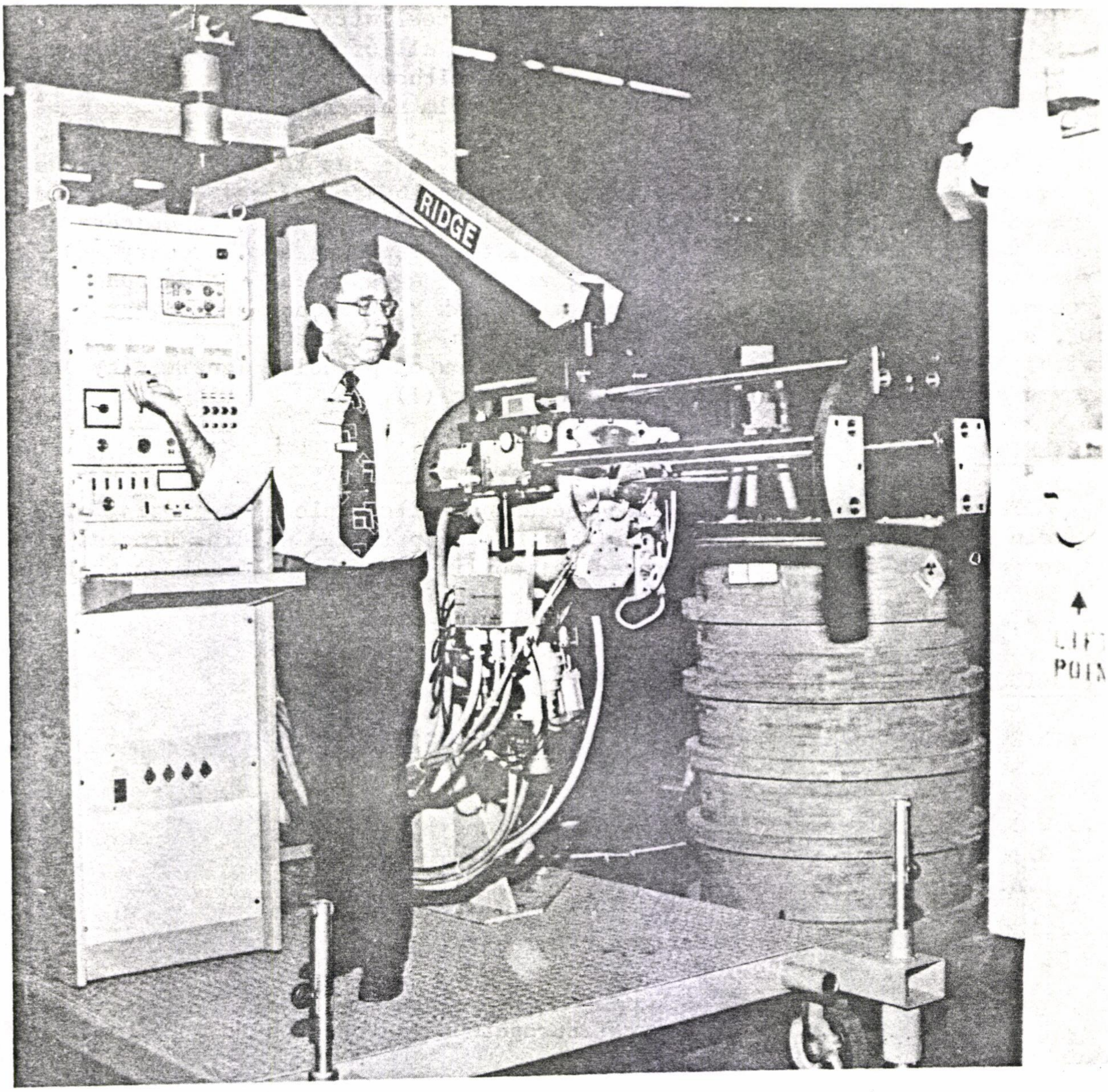

FIGURE 1

Partly shown of the 150 kV microfocus X-ray unit in cable version are the 19" controle console and the accelerator tank with lens system mounted in the mechanical positioner. The X-ray source is positioned at the end of the lens system with a useful length of 450 mm and an overall outer diameter of 9 mm. The installation in 1977 of four of these 150 kV microfocus X-ray units in cable version at the Energy Systems Group of Rockwell International, Los Angelos, California has been provided by Ridge Instrument Co., Tucker, Georgia, USA.

The operator shown is Mr. B.E. Foster, first user in the United States of this kind of equipment at the Oak Ridge National Laboratories, Oak Ridge, Tenessee, USA and who greatly supported the introduction of this equipment at ESG.

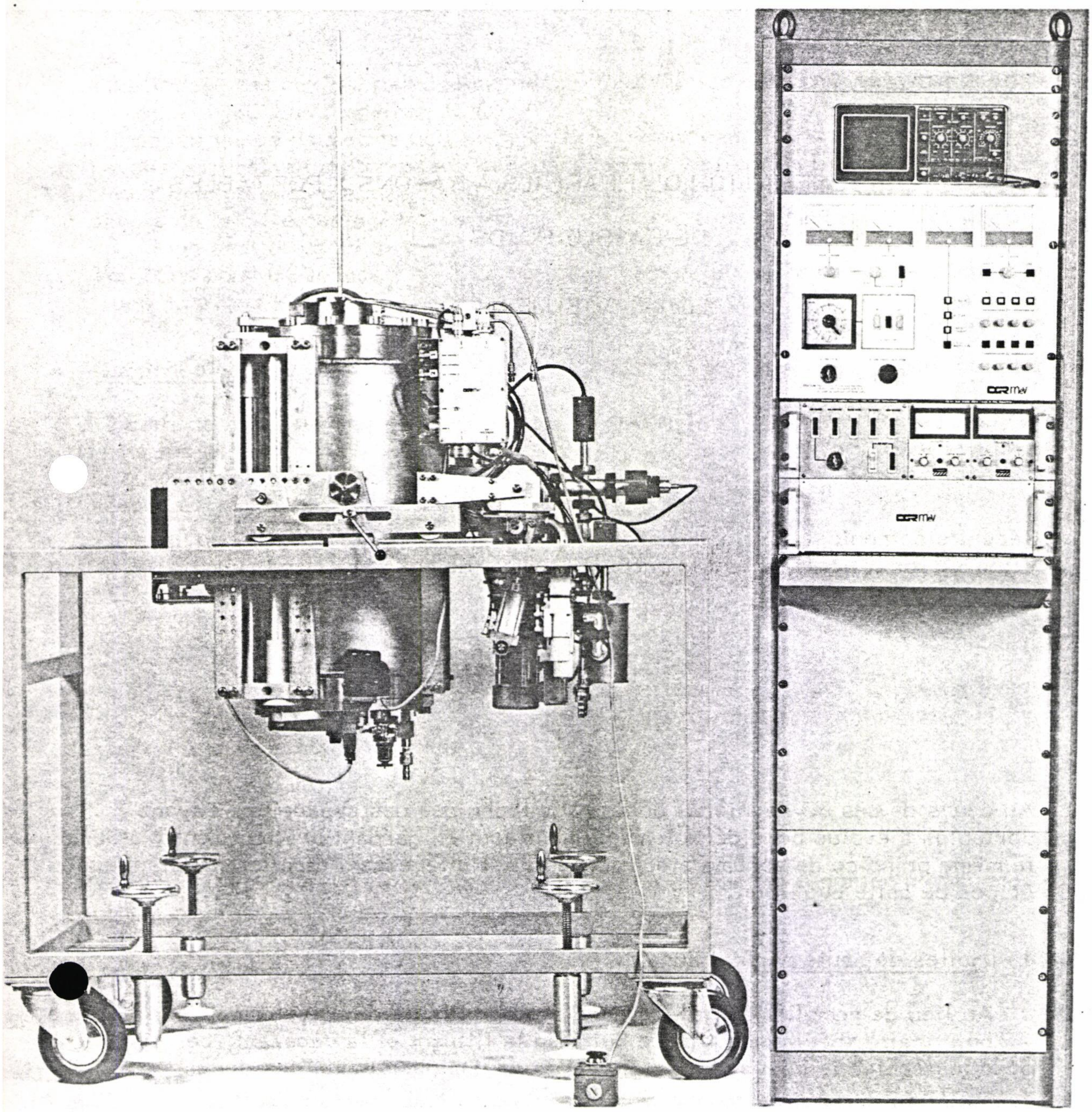

FIGURE 2

Partly shown of the 150 kV microfocus X-ray unit in the integral version are the 19" controle console and the generator and accelerator tank with lens system mounted in a framework for transportation. The X-ray source is positioned at the end of the 450 mm effective length and 9 mm outer diameter lens system (top left side picture).
The installation in 1978 at Turbomeca SA, Bizanos (France) has been provided by CGR-MeV, Buc (France).