SSC-293

LEVEL II

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UNDERWATER NONDESTRUCTIVE TESTING OF SHIP HULL WELDS

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1979

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SR-1243

September 1979

The Ship Structure Committee has sponsored a state-of-the-art study of underwater nondestructive inspection techniques to determine whether or not additional research is necessary to provide adequate methods for inspection of large vessels and mobile drilling units while afloat and of offshore platforms below the waterline.

This report documents the results of this survey.

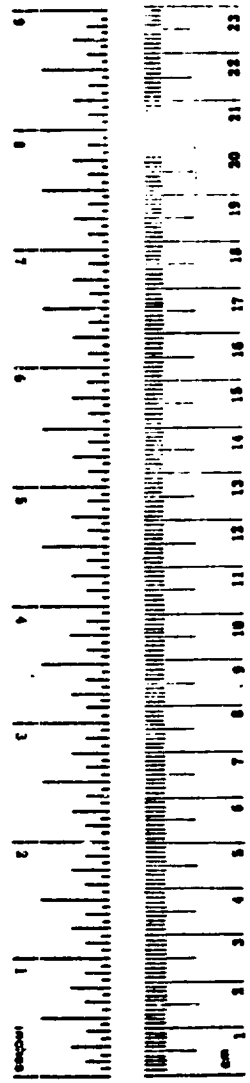
Henry H. Bell
Rear Admiral, U.S. Coast Guard
Chairman, Ship Structure Committee

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

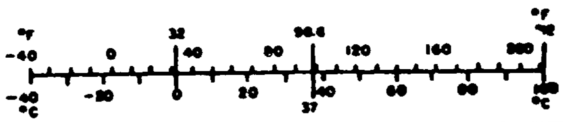
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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Techniques are presented whereby nondestructive testing of hull ~~butt~~ welds can be accomplished underwater. Radiography, ultrasonic inspection, and magnetic particle testing are discussed including the modifications necessary for underwater applications. In all cases, trained divers are required.

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INTRODUCTION

At present, steel ships are nondestructively inspected at the time of fabrication and thereafter only in drydock. The expense of drydocking a modern vessel is such that this is done only at the time of scheduled hull maintenance or if structural damage has been incurred. Until recently, there were no other options. However, in a related industry, offshore drilling, nondestructive testing is being done onsite, including that portion of the structure positioned underwater. Considering the lost operating time and sizable expense involved in drydocking a modern steel vessel, it may be desirable to do underwater nondestructive testing on some occasions to provide assurance of hull integrity. In addition, as underwater welding techniques are inproved and further developed, it is conceivable that hull repairs may be done underwater, thus obviating the need for dry-docking. Such repairs might not be acceptable to underwriting associations or code bodies unless proof of adequate weld quality can be verified by nondestructive testing.

The Ship Structure Committee has recognized the advancement in technology and has requested the Naval Surface Weapons Center to prepare a state-of-the-art report on Underwater Nondestructive Testing.

OBJECTIVE AND SCOPE

The objective of this task is to provide the maritime industry with nondestructive testing (NDT) techniques suitable for the underwater inspection of steel welds. This is to be done within the framework of existing methods of nondestructive testing.

In addition, to a state-of-the-art survey, the methods of NDT which are suited to underwater work will be analyzed in regard to technical capabilities and limitations and the modifications desirable or necessary for their application to underwater weld inspection.

NONDESTRUCTIVE TESTING OF HULL WELDS

Traditionally, steel hull welds are nondestructively tested with one of five methods of nondestructive testing: visual, magnetic particle, radiography, ultrasonics and liquid penetrant. With the exception of liquid penetrant, all of these methods have been adapted to underwater steel weld inspection. The advantages and disadvantages of each method as applied to underwater hull weld inspection are presented in Table I.

TABLE 1

PRESENT NDT TECHNIQUES: ADVANTAGES AND LIMITATIONS IN UNDERWATER APPLICATIONS

METHOD	DEFECTS	ADVANTAGES	LIMITATIONS
Visual	Surface cracks, Impact damage.	Easy to interpret. Findings can be photographed or transmitted to topside by television and video recorded.	Limited to surface defects. Surface must be cleaned for detailed observation.
Magnetic Particle	Surface cracks, laps, seams, and some near-surface flaws.	Indications can be photographed or televised topside for evaluation and video recording.	Requires thorough cleaning. Weather dependent in splash zone. Limited to surface and near surface defects. Present equipment limited to diver use. Cumbersome to perform underwater.
Ultra-sonics	Cracks, Inclusions, Lack of fusion and incomplete penetrameter in welds.	Especially sensitive to cracks. Can be used to evaluate subsurface integrity. Equipment is lightweight. Results can be transmitted topside and video recorded.	Thorough cleaning required. Operator skill is required. Surface roughness can affect test. Present equipment limited to diver use.
Radio-graphy	Internal defects such as shrinks, inclusions, porosity, lack of fusion and incomplete penetration in welds.	Provides a permanent record. Standards have been established and are accepted by codes and industry.	Potential health hazard. Water should be displaced between source and subject. Requires access to both sides. With available isotopes, it is difficult to obtain 2% sensitivity.

DIVING EQUIPMENT

Underwater NDT requires a diver. Because the hulls are not very deep, the diver can use scuba equipment. This system has the diver carrying his own air supply and gives maximum freedom of movement. Alternatively and preferably, the diver can be supplied breathing media (air or mixed gas) from the surface by a flexible hose. Although the umbilical cord of this latter system inhibits freedom of movement somewhat, the umbilical cord is necessary for other reasons: First, voice communication is very valuable. Second, in most cases, video transmission topside is worthwhile. Third, the diver needs electricity for a number of reasons, ranging from lights to power equipment. Considering these requirements, the surface-supplied system seems preferable. It can be used to depths of 50 meters using air and to 90 meters with breathing gas.[1] These depths exceed any depth of hull immersion in commercial shipping.

The diver may have a dry suit and a heavy helmet or a face sealing mask and a wet suit which can be filled with warm water. The heavy helmet seems to be advantageous in that it readily accomodates voice communication equipment, and a source of light can be mounted on the side of the helmet to illuminate the work area which frees the divers hands for other tasks. A television transmitter can also be mounted on the helmet which permits topside personnel to view the work and the work area.

The diver equipment described above represents the current state of the art and is commercially available.

UNDERWATER CLEANING

With the exception of radiography, every method of NDT now in use for underwater work requires that the surface to be inspected be cleaned to bare metal as illustrated in Figure 1. Mostly, this means removing marine organisms such as barnacles, but scale, loose paint and rust must also be removed. This requirement often is more time consuming and difficult then the inspection itself.

The cleaning can be done by hand with a scraper or brush, but manual methods are not practical for jobs larger than two or three linear feet of weld. For the bigger jobs, power tools are available of which water jetting is most often used. The system consists of a surface pump and a high-pressure hose. At the work site, the diver manipulates the jet with gun-like controls. Pressures on the order of 15,000 pounds/square inch are possible. To keep the diver from being pushed off site, the nozzle also has a lesser pressure flow in the opposite direction - thus counterbalancing the force of reaction. Cleaning rates of two - three square feet per minute are claimed possible by skilled and experienced operators.

FIGURE 1 AN EXAMPLE OF A STEEL WELD AND ADJACENT AREA CLEANED OF MARINE GROWTH TO BARE METAL

Note: The water jet is very dangerous and if inadvertently directed toward the diver can inflict physical damage as severe as limb amputation.

Other power tools for underwater cleaning include hydraulic grinders and needle guns. In regard to the needle gun, it should be noted that this tool delivers impact blows to the work area and, therefore, to a degree peens the metal. This makes suspect the possibility of concealing defects otherwise open to the surface. This has caused one insurer (Lloyds Register) to state a preference that the weld and heat-affected zone not be cleaned with a needle gun.[2]

ENVIRONMENTAL LIMITATIONS

The diver may be hampered in his work by murky water. This condition can be improved by flooding the work area with clean water pumped from topside.

Extreme cold may severely limit the diver's stay time. As mentioned before, diving suits are available which can accomodate an injection of warm water.

Turbulent water is the most severe limitation likely to be imposed on the diver. This is especially true near the water line where wave action is most pronounced. Solutions would have to be determined on a per case basis, but scaffolding lowered from topside may be useful.

NONDESTRUCTIVE TESTING METHODS

Visual Inspection. Visual inspection requires water clarity and adequate illumination. Previously discussed, equipment and techniques can be used to achieve this. Because the face plate of the diver acts as a lens with slight magnification, which is usually helpful in visual inspection, it does require that measurements be made against a standard (Rule) rather than be estimated.

If the nature of the inspection is surveillance, visual inspection should also be done prior to cleaning as there is sometimes a perceptible color change in the marine growth immediately over a crack.[3] The detection of such a condition prior to other NDT would be very meaningful in further planning or work. After cleaning, the weld should again be visually inspected in-as-much as cracks found this way can reduce the need for more sophisticated NDT or enable an improved scope of inspection.

Using visual inspection on new welds, the diver can measure a weld profile using commercially available gauges, Figure 2, while undercut can be measured with a depth gauge.

Underwater photography is a well established art and can be used to provide a record and for more extensive evaluation topside.

Magnetic Particle Inspection. Magnetic particle testing (MT) can be applied to ferromagnetic materials such as ordinary carbon steels. Of the sophisticated methods of NDT, magnetic particle testing is the most widely used for the inspection of offshore drilling rigs and is readily adaptable to underwater hull weld inspection.

The test consists of three basic operations:

1. Establishing a suitable magnetic field in the object, where the magnetism must be in the correct direction, and the field strength must be sufficiently strong.

2. Applying magnetic particles to the surface of the object in the magnetized area.

3. Examining locations where the particles accumulate.

The method uses a pair of electrical prods positioned alongside the weld as shown in Figure 3. It is recommended that the prods be used in conjunction with lead shoes or other low melting point materials to suppress arcing and thus prevent burn marks on the steel surface. The electrical current required for proper magnetization underwater is the same as that used when working in dry air, Table 2.[4]

Alternating current yokes and permanent magnets can also be used to induce the magnetic field but the surface should be ground smooth for good contact.

Assuming the weld area has been cleaned of marine growth and the diver has adequate visibility (Underwater lighting), ordinary magnetic particles in a slurry in a squeezable container can be used to complete the inspection. The suspension is directed at the inspection area and the results obtained are essentially the same as when done topside using dust.

Superior results are obtained by using fluorescent particles and illuminating the work area with ultraviolet light. Cracks are readily detected, Figure 4. The ultraviolet lamps for use in this type work have been designed with adequate electrical insulation and resistance to hydrostatic pressure and are commercially available.

If a record of the magnetic particle inspection is desired, the diver's equipment can include a television transmitter and video recording can be done topside. Alternatively, photographs can be taken.

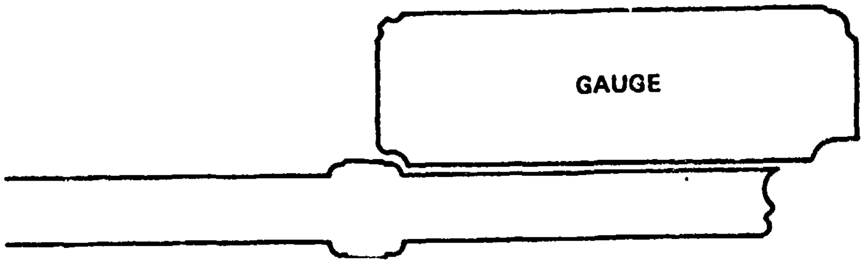


FIGURE 2 - A GAUGE FOR MEASURING WELD REINFORCEMENT

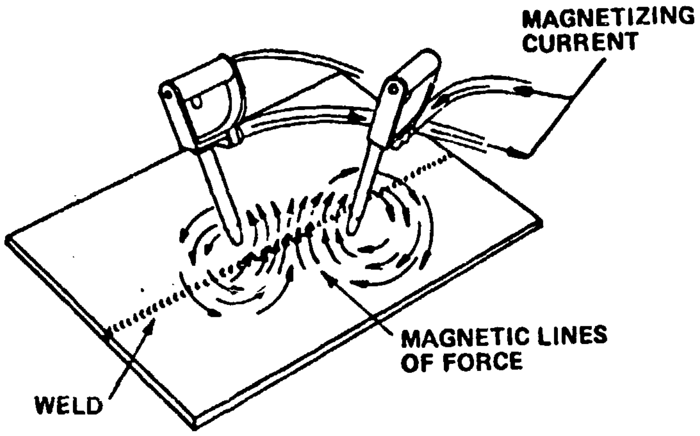


FIGURE 3 - RECOMMENDED POSITIONING OF ELECTRICAL PRODS WHEN INSPECTING BUTT WELDS

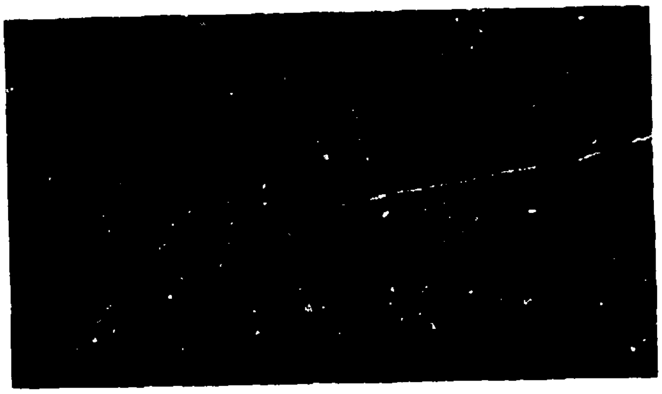


FIGURE 4 - AN EXAMPLE OF CRACK DETECTION USING FLUORESCENT MAGNETIC PARTICLE INSPECTION

TABLE 2 ELECTRICAL CURRENT REQUIREMENTS FOR MAGNETIC PARTICLE INSPECTION

PROD SPACING (INCHES)	AMPERES SECTION THICKNESS	
	UNDER 1/4"	3/4" AND OVER (AMPERES)
3	300–400	375–500
4	400–500	500–625
5	500–625	625–775
6	600–750	750–900
7	700–875	875–1100
8	800–1000	1000–1200
9	900–1100	1100–1300
10	1000–1200	1200–1400
11	1100–1300	1300–1500
12	1200–1400	1400–1600

Radiographic Inspection. Radiography requires that the film cassette and radiation source be positioned on opposite sides of the hull. The film cassette can be placed on the outside of the hull with the source of radiation inside, or this arrangement can be reversed. There are advantages using the first arrangement and, if possible, hull radiography should be done this way. However, if a physical obstruction prevents placement of the radiation source inside the hull but there is room to position a cassette, then radiography can still be done using the other arrangement.

Radiography of steel welds of ordinary hull thicknesses is usually done with positive pressure cassettes containing lead intensifying screens. For the film cassette outside the hull, there is a need for watertight integrity and a polyethylene envelope will suffice.[5] The cassette package can be firmly fixed in place using permanent magnets with attached springs.

Because the water behind the cassette is a back-scattering media, a sheet of lead, approximately 1/8" thick, should be fixed behind the cassette to minimize film fogging. If the package is too heavy for underwater work, neutral buoyancy can be achieved by placing a low-density material, such as styrofoam sheet, behind the lead and within the watertight envelope, Figure 5. Simple experiments should enable a close approximation to neutral buoyancy. Alternatively, the cassette package can be attached to a rope supported from topside and maneuvered into position by the diver using voice communication to coordinate the work.

Aligning the film cassette and the radiation source is difficult to accomplish by coordinate measurements. Pinging is reported to be of considerable help in locating the approximate position[6], but precise positioning can be done with ultrasonic transducers. For this, an ultrasonic probe is fixed in position at the desired location within the hull and the ultrasonic instrument is set to receive with the entire range displayed. The diver then manipulates a second probe of the same frequency, but powered separately. When the two probes are aligned, a signal will be received on the oscilloscope and, using voice communication, the diver is instructed to mark that location.

The thickness of the hull at the weld site can be determined precisely using an ultrasonic thickness gauge. This information, in conjunction with radiographic technique curves, affords the radiographer a means for correct exposure to obtain the desired film density.

Should circumstances dictate that the source be placed outside the hull, neutral buoyancy becomes more important. The underwater source of radiation will be an isotope rather than an x-ray machine as no commercial x-ray equipment has been modified to this purpose whereas this has been done with isotopes.[7] The isotope is invariably encased in lead of substantial thickness. In addition, rigid structure must be used to maintain the source to object distance, Figure 6. This structure can be either conical or pyramidal in shape. If made watertight, either air or water can be allowed to fill the space. Whichever system is used,

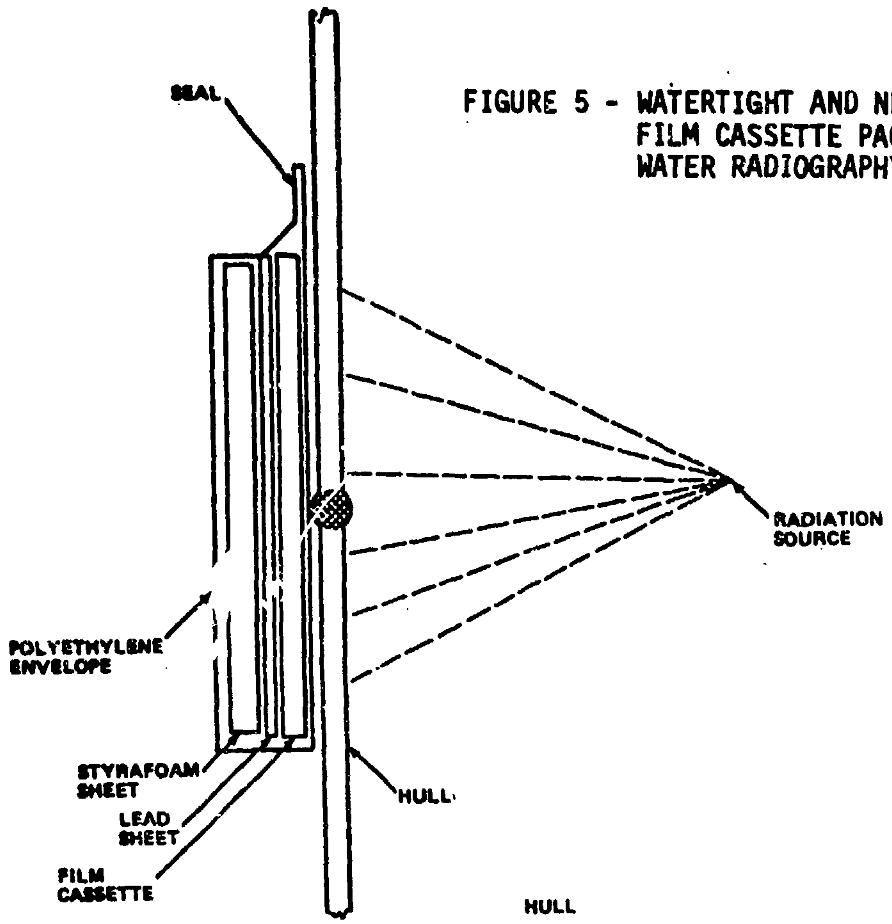


FIGURE 5 - WATERTIGHT AND NEUTRAL BUOYANCY FILM CASSETTE PACKAGE FOR UNDERWATER RADIOGRAPHY

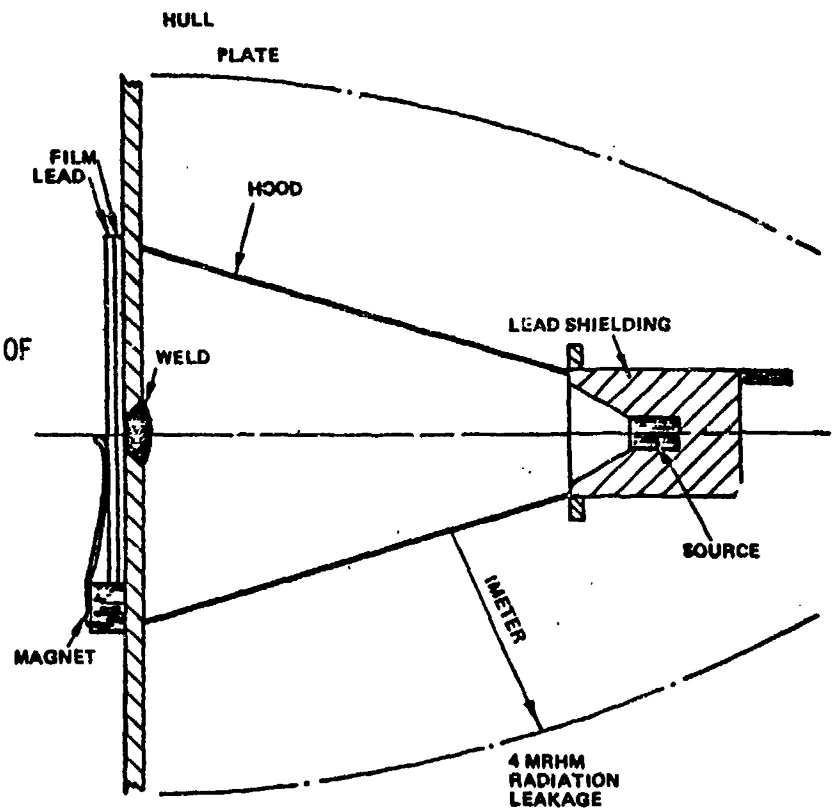


FIGURE 6 - SCHEMATIC ARRANGEMENT OF THE ISOTYPE HOLDER FOR UNDERWATER RADIOGRAPHY

consideration must be given to the diver's limitation to manipulate the structure into position, even if assisted by ropes maneuvered from topside.

Once the source is properly positioned, permanent magnets can be used to grip flanges and fix the structure in place. As before, the correct exposure time can be calculated, but it is difficult to control in-as-much as it depends upon the diver's prompt action in regard to cutting off the source or, having the cassette moved from the field of continuing radiation.

Where the radiation source is inside the hull, an x-ray machine is preferable to an isotope because it affords the radiographer a means of selecting a kilovoltage suited to the object thickness whereas isotopes operate at specific energies and only Co^{60} and Ir^{192} are commonly available. If an x-ray machine is used, the selection of kilovoltage for a specific thickness should not exceed that shown in Figure 7. Also shown in this figure are the ordinary thickness range of Co^{60} and Ir^{192} and their possible extension beyond this range with marginal radiographic sensitivity.

If the radiation source is outside the hull and the film cassette inside and the water is displaced, then the exposure time is unchanged. If, however, the water is not displaced and the radiation must penetrate the water before reaching the weld, then the exposure time will be lengthened and the radiographic sensitivity will be degraded. The extent of these effects were determined experimentally using x-rays of 250 KVP and 2 MeV which approximate the isotopes Ir^{192} and Co^{60}. This was done by making radiographs of steel plates of various thicknesses with and without columns of water between the source and the plate.

From measurements of the film densities, radiographic technique curves were constructed for steel and specific water columns, Figures 8 and 9 and also for water and specific thicknesses of steel, Figures 10 and 11. These curves enable a determination of the half-value-layer of water for each energy, e.g., for 250 KVP this is 2.4" and for 2 MeV this is 5.2".

The extent of degradation was determined by placing an array of penetrameters on top of the steel plates and then calculating the sensitivity according to the smallest visible penetrameter holes using the equation:

$S_1 \times N_1 = S_2 \times N_2$ where:

S_1 = equivalent penetrameter sensitivity

N_1 = 2

S_2 = contrast sensitivity

N_2 = ratio of minimum detectable hole diameters to penetrameter thickness.

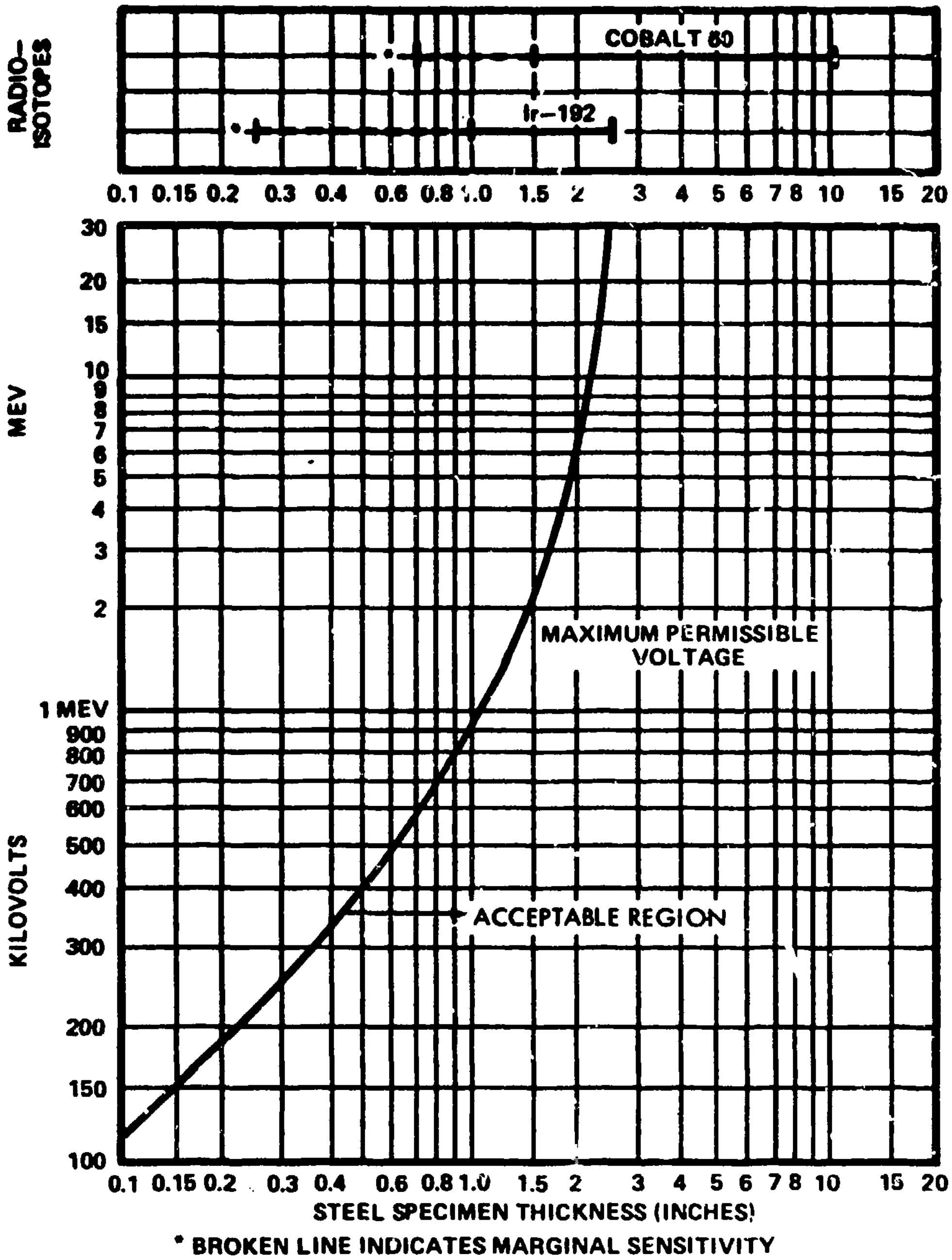


FIGURE 7 MAXIMUM VOLTAGE OR RADIOACTIVE ENERGY FOR MINIMUM STEEL THICKNESS

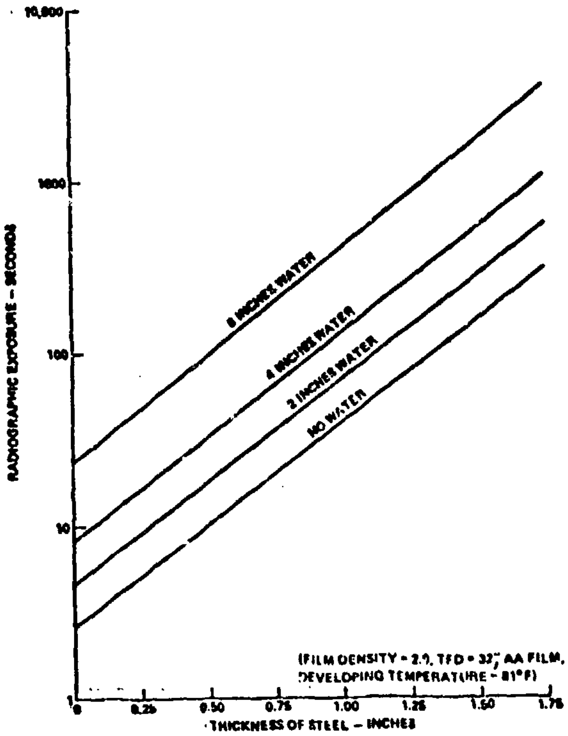


FIG. 8 - RADIOGRAPHIC TECHNIQUE CURVES FOR STEEL AT 250 KVP WITH VARIOUS THICKNESSES OF WATER INTERPOSED BETWEEN THE SOURCE AND OBJECT

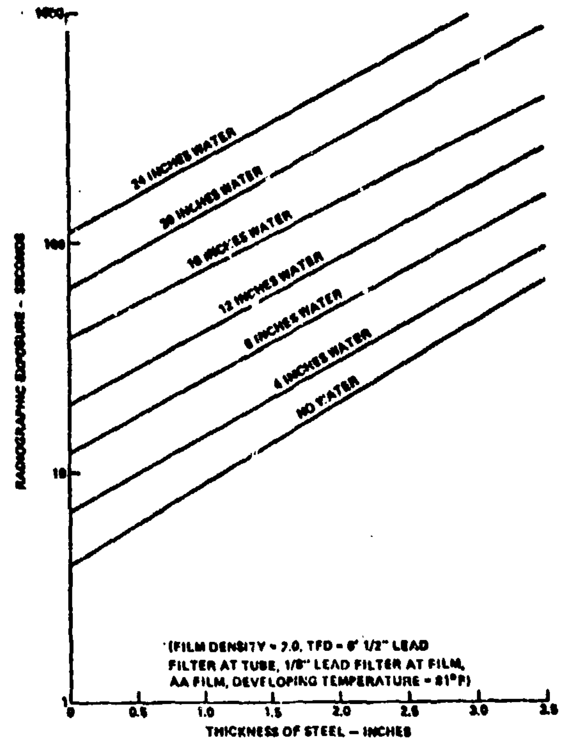


FIG. 9 - RADIOGRAPHIC TECHNIQUE CURVES FOR STEEL AT 2 MeV WITH VARIOUS THICKNESSES OF WATER INTERPOSED BETWEEN THE SOURCE AND OBJECT

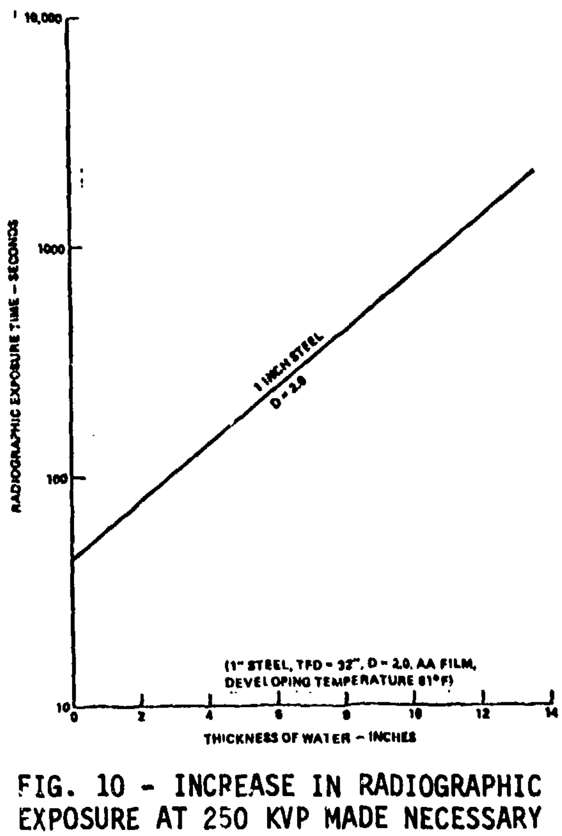


FIG. 10 - INCREASE IN RADIOGRAPHIC EXPOSURE AT 250 KVP MADE NECESSARY BY INTERPOSING WATER BETWEEN THE SOURCE AND OBJECT

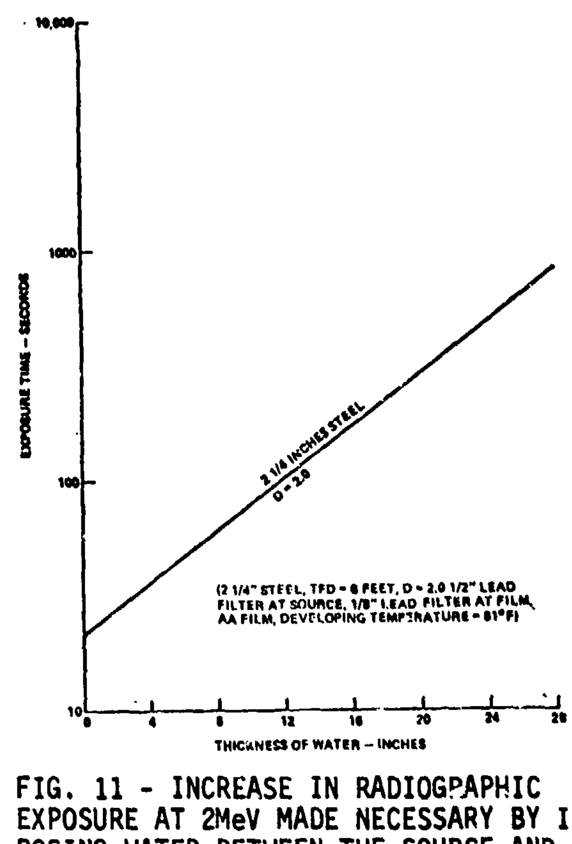


FIG. 11 - INCREASE IN RADIOGRAPHIC EXPOSURE AT 2MeV MADE NECESSARY BY INTERPOSING WATER BETWEEN THE SOURCE AND OBJECT

The results of this determination presented in Figures 12 and 13 show a progressive degradation of radiographic sensitivity with increased thicknesses of water between the source and object.

Ultrasonic Inspection. The adaption of ultrasonic inspection to underwater work is simple in principle. The water serves as a couplant; and except for the transducer being made watertight[8], the technique is the same as that topside, Figure 14. Battery-powered ultrasonic inspection equipment is commercially available; and if made watertight, can be carried by an inspector-diver. The technique is restricted to work near the surface unless the equipment housing is designed to withstand hydrostatic pressure.

A more practical approach is for the instrument to remain topside while the probe is taken below by the diver. Through voice communication the diver can be instructed regarding the position and manipulation of the probe. A television transmitter attached to the side of the diver's helmet with transmission topside permits the ultrasonic technician to see the probe movements as well as scope presentation and comprises a reasonable ultrasonic inspection by remote control.

Before doing ultrasonic inspection, the area of probe manipulation must be cleaned of marine growth-to bare metal.

When ultrasonic inspection is done in air, cracks have an air interface with a reflection coefficient of almost 100%. In water, assuming the cracks come to the surface of the plate and water enters, the acoustic impedance mismatch is changed and some of the ultrasonic energy is transmitted into the water. According to theory, the reflectivity coefficient is reduced to 88%[9]. Laboratory experiments confirm this approximate reduction. This difference is not considered cause for concern, because even small cracks are very efficient reflectors of ultrasound readily found by ultrasonic inspection.

The use of a very long cable increases the capacitance load on the instrument pulser and necessitates a higher gain setting on the instrument to achieve the same sensitivity level used in ultrasonic inspection topside with shorter cables. In addition, instrument calibration should be performed in a salt-water bath. However, the ends of the drilled holes in the test block, Figure 15, should be sealed (epoxy cement is suggested) to maintain the air-steel reflectivity coefficient upon which the present weld inspection sensitivity level is based.

A word of caution: Present procedure for inspecting butt welds with ultrasonics assumes a flat surface (250 RMS or better) adjacent to the weld. Corrosion pits may be sufficiently numerous such that beam directivity is weakened by scatter of the sound waves at the interfaces of the pits. The scatter may be severe to the point where an expected signal is not obtained even though the test is otherwise done correctly. There are no quantitative data available in this regard.

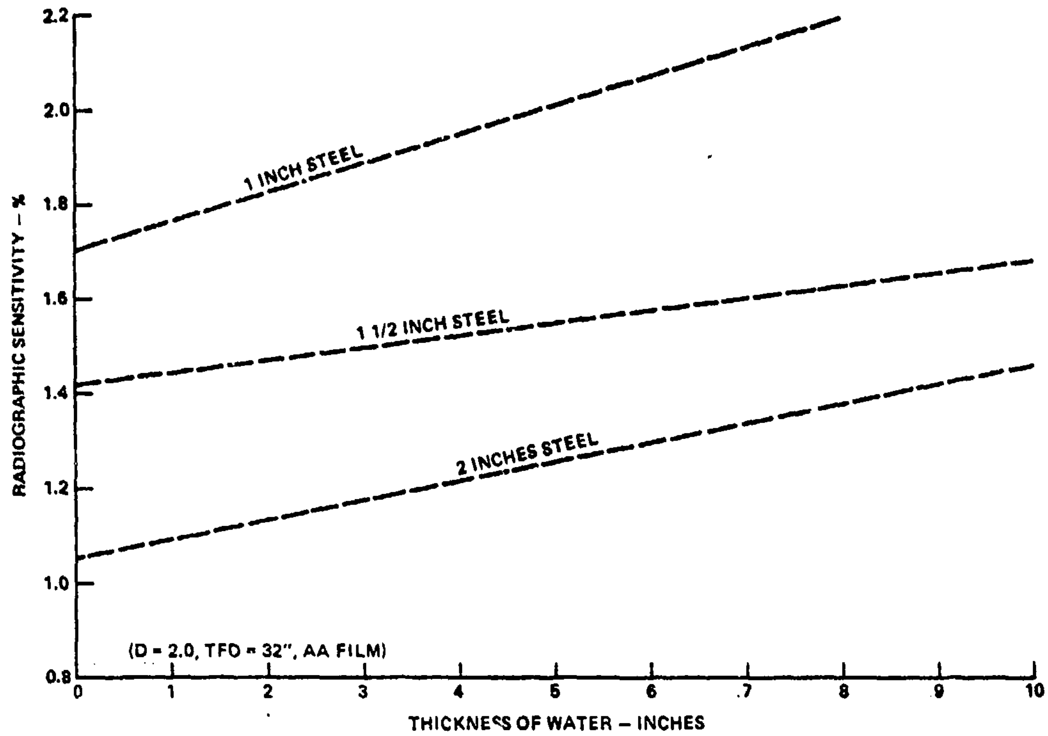


FIGURE 12 - DEGRADATION OF RADIOGRAPHIC SENSITIVITY FOR STEEL AT 250 KVP DUE TO INTERPOSITION OF WATER BETWEEN THE SOURCE AND OBJECT

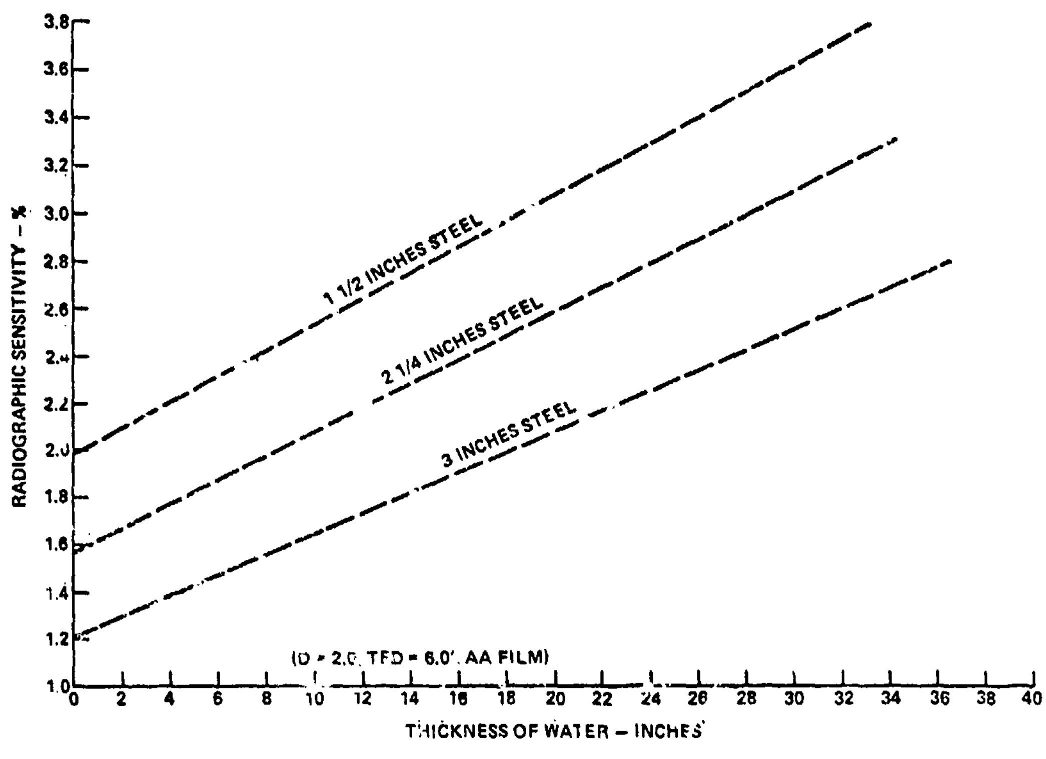


FIGURE 13 - DEGRADATION OF RADIOGRAPHIC SENSITIVITY FOR STEEL AT 2MeV DUE TO INTERPOSITION OF WATER BETWEEN THE SOURCE AND OBJECT

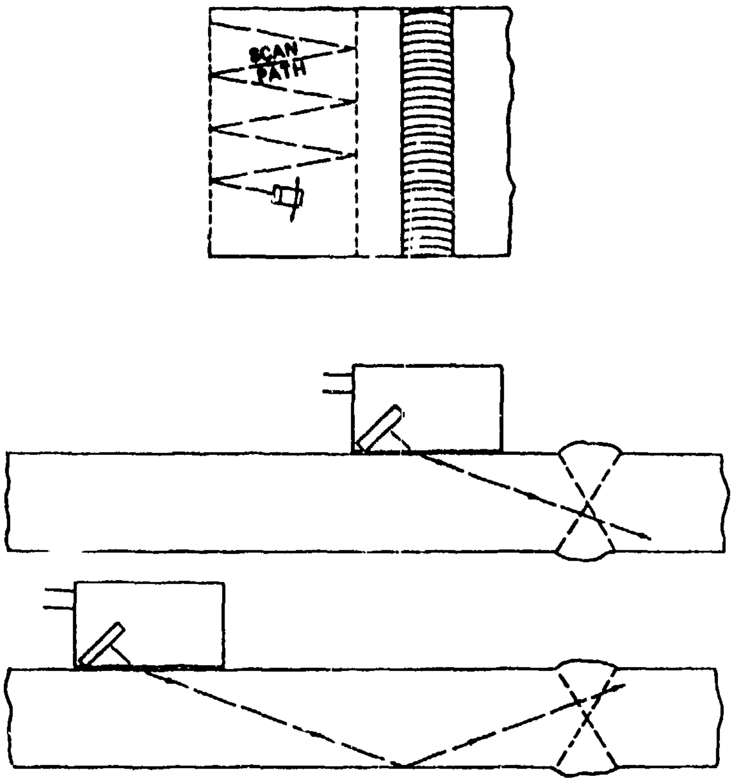
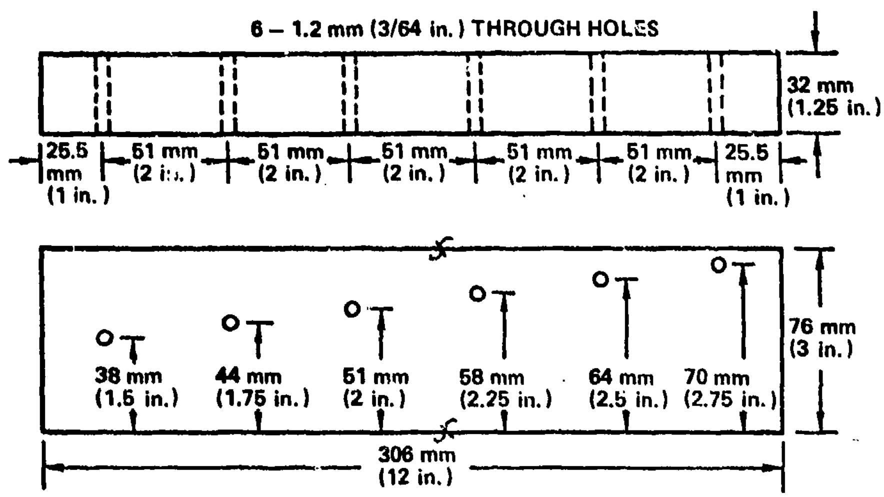


FIGURE 14 - POSITIONING AND MANIPULATION OF THE PROBE FOR ULTRASONIC SHEAR WAVE INSPECTION OF BUTT WELDS



MATERIAL – LOW CARBON STEEL
– SURFACE FINISH 6.3 x 10^{-6} RMS MICROMETERS (250 RMS MICROINCHES)

FIGURE 15 - TYPICAL TEST BLOCK FOR CALIBRATION OF THE ULTRASONIC INSTRUMENT

Commercially available video-tape recorders can record the ultrasonic oscilloscope presentation as well as an accompanying voice description. The video recorder can also record the diver's field of view as transmitted from the camera mounted on his helmet. These can be combined on one tape with playback on a split screen.

ADDITIONAL METHODS OF NONDESTRUCTIVE TESTING

Acoustical Holography. Acoustical holography is analogous to optical holography with the exception that the object is on focus in a plane. The system uses a matrix of ultrasonic transducers, focused to inspect each point of the weld volume[10], and act both to send and receive. The returning signal is received separately at several transducers where signal amplitude, time and phase are monitored in conjunction with an electronic gate. Then, the phased signals corresponding to the gate time are electronically processed to obtain a focused acoustic hologram.

As developed for underwater weld inspection, the diver positions a probe, Figure 16, adjacent to the weld and the data are transmitted to electronic equipment elsewhere (A lockout submersible at present, but could also be topside for hull weld inspection). There, the data are processed into an image on a plane; and by combining this with a reference plane, it can be viewed as an oblique projection similar to three-dimensional viewing. The base of the probe contains a television presentation of the constructed image which helps the diver to manipulate the probe for best position.

The system appears capable of detecting cracks but has not been fully evaluated. While acoustical holography may be of considerable use in surveillance work, especially in murky water, it seems unlikely that it could be used as a primary inspection tool for evaluating welds.

Magnetographic Method. The magnetographic method uses magnetic tape instead of a powder or slurry of particles.[11]

The tape is placed on top of the weld by a diver and then a magnetic field is induced in the work piece. Leakage flux at discontinuit sites are detected and recorded on the tapes. Evaluation is done topside with electronic processing to produce either an oscilloscope display or a strip chart. The tape can be stored as a permanent record. This method has not gained widespread recognition and is not generally used.

A Harness of Ultrasonic Transducers. Currents or wave action, particularly near the surface may make it difficult or impossible for the diver to stay in a position which would make it difficult or impossible for him to do either ultrasonic or magnetic particle inspection. Recognizing the difficulties caused by turbulence, a British Corporation (BIX) has developed an ultrasonic inspection device consisting of a linear array of ultrasonic shear wave transducers which is incorporated into a flexible and magnetic pack.

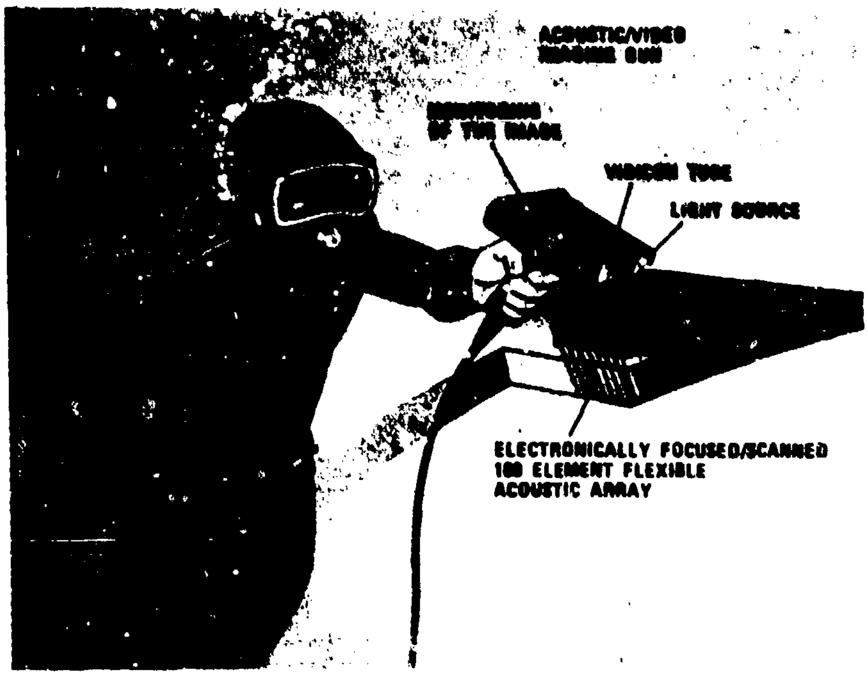


FIGURE 16 DIVER USING ACOUSTICAL HOLOGRAPHY PROBE

The diver places this device atop the weld, slides it into proper position and magnets fix the pack firmly against the work surface. Topside, signals obtained from all transducers are displayed simultaneously on an oscilloscope. If no signals are obtained, the weld is evaluated as free of cracks. If a signal is obtained, then the transducers are separately turned on and off to establish the location and length of crack. The diver then moves the pack into a new position.

While this system provides reasonable assurance of crack detection, no provision is made for to-and-fro motion of the transducers and it, therefore, cannot be considered a suitable tool for primary weld inspection.

Television from Topside to Diver. A patented diver's helmet contains a television receiver and a system of moveable optical prisms which enables visual information from topside to be transmitted to the diver.[12] This can be blueprints of the work area or the ultrasonic oscilloscope presentation. For the person manipulating the probe, it is very helpfu to see the oscilloscope screen and, in most cases, will result in better ultrasonic inspection.

COST CONSIDERATIONS

The cost of performing nondestructive testing underwater is difficult to determine because of the many considerations involved; such as cleaning of marine growth, depth and temperature of water, visibility, tidal currents, and the type of inspection. The experience of those working on offshore platforms in the North Sea may not be typical of what can be expected for ship hull inspection in harbor, but little else is available for purposes of comparison. Det Norske Veritas reports that an inspection vessel with eight crew members, sixteen cleaning divers and sixteen inspection divers can test two one-meter welds per day.[13]

Although these figures undoubtedly represent a situation of extreme difficulty, nonetheless, they suggest a very high cost for underwater inspection.

After inspection, areas cleaned to bare metal will require a restoration of the protective coating. Epoxy paints can be applied underwater by brush rolling[14] and other means, but the additional expense of doing this must be considered a part of the cost of inspection.

CONCLUSIONS

With the exception of liquid penetrant, the ordinary methods of nondestructive testing (visual, magnetic particle, ultrasonics and radiography) used topside to inspect steel butt welds can be extended to underwater applications.

Performing NDT underwater will be expensive - far more so then the cost of such work topside - but, as has been demonstrated in the related industry of offshore drilling, it can be done.

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