SYNTHESIS REPORT

Contract n^{0} : BRE 2 - 319

Project n^{0} : BE - 5907

Title : NDT METHODS FOR FLAW DETECTION DURING WELDING

Project co-ordinator : MITSUI BABCOCK ENERGY LTD
(Dr B W O Shepherd)

Partners : Nordon & Cie
Isotopen Technik Dr Sauerwein GmbH
University of Surrey
Institut de Soudure

Reference period : from 1/6/93 to 31/09/97

Starting date : 1/6/93 Duration : 52 Months

Date of issue of this report : 30/11/97

Project funded by the European Community under the Industrial & Materials Technologies Programme (Brite-EuRam III)

CONTENTS

1. SUMMARY

1.1 Keywords

- **Ultrasonic Testing**
- **Radioscopic Testing**
- **Signal Processing**
- **Welding**
- **On-line Inspection**

1.2 Abstract

The basic approach to manufacturing or repair inspection of welds has hardly changed in the last 30 years. The normal practice has continued to be to inspect the weld only after welding is complete. Thus by the time a defect is detected considerable time and money has been spent on completing the welding of a rejectable component. A large number of additional weld runs have generally been deposited over the defect, increasing cost of a possible repair and decreasing the quality of the component since the repair will be larger. The opportunity to use process control to reduce the number of defects has also been lost.

There would be major cost and programme advantages for a wide range of industries if non-destructive testing (NDT) was performed during welding as an on-line operation.

Only recently have technological advances meant that it should now be possible to perform NDT during welding, with all the associated economic and programme advantages.

This project has exploited recent developments in real time radioscopy, ultrasonics and signal processing by adapting them for on-line flaw detection during welding

The problems of unfavourable weld geometry, hostile environment and need for automated defect recognition have been overcome. Final demonstration trials were performed in a factory environment.

2. THE CONSORTIUM

2.1 Partner Organisations

Organisation:	Mitsui Babcock Energy Limited
Department:	Technology Centre
Contact:	Dr. Barrie Shepherd
Address:	High Street **RENFREW PA4 8UW** UK
Tel:	+44 141 886 2201
Fax:	+44 141 885 3370
e-mail:	bshepherd@mitsuibabcock.co.uk

Organisation:	Nordon & Cie
Department:	Direction Technique
Contact:	Mr. Henri Godinot
Address:	78, Av. du Xxeme Corps **54001 NANCY** FRANCE
Tel:	00 33 3 83 39 54 00 (49 Dir)
Fax:	00 33 3 83 39 55 00

Organisation:	Sauerwein System-Technique GmbH
Contact:	Dr. Wolfgang Nuding
Address:	Bergische Strasse 16 Postfach 1354 **D-42781 HAAN** GERMANY
Tel:	00 49 21 29 551 0 (13 Dir)
Fax:	00 49 21 29 551 77
e-mail:	sauerwein.st@t-online.de

Organisation:	University of Surrey
Department:	Dept. Mechanical Engineering
Contact:	Mr. Gary Bonser
Address:	Guildford, **SURREY GU2 5XY** UK
Tel:	01483 259681
Fax:	01483 306039
e-mail:	gbonser@surrey.ac.uk

Organisation:	Institut de Soudure
Contact:	Dr Didier Flottè
Address:	Z.I. Les Jonquiéres **57365 ENNERY** FRANCE
Tel:	00 33 3 87 73 02 11
Fax:	00 33 3 87 73 02 87

2.2 Description of the Consortium

The project consortium consists of an ideal mix of organisations with different but complimentary backgrounds from three EC countries. Its structure was geared not only to maximise the probability of success through technical excellence but to allow full exploitation and dissemination of the results.

A brief profile of each of the partner organisations is given below.

Mitsui Babcock Energy Limited is a high-technology company whose core business is centred around steam-raising plant and associated technologies. The company has a wide range of skills and capabilities, with one of the world's most modern heavy engineering manufacturing facilities. The company is highly active in research and development since it recognises that the exploitation of new technology can help it to compete in world markets by combining high product quality with competitive price and programme.

MBEL Technology Centre has built up expertise in a number of areas associated with the main company business, including materials and combustion technology, mechanical engineering, chemical and mechanical testing. Non-destructive testing is an important field, not only for application to company products, both during manufacture and in-service, but also because high-quality inspection services are provided directly to third-party clients.

MBEL were the primary proposer and were responsible for the overall project management. They were responsible for the development of the ultrasonic techniques. They performed the final ultrasonic tests at Nordon's premises.

Nordon & Cie is a European leader in the design and manufacture of piping systems and specially welded vessels. Nordon has participated in the construction of every French nuclear power station. They have a sound international reputation in the fields of petrochemical and paper industries. Nordon manufactured the deliberately defective testpieces that were used for the development of the inspection techniques. They also provided welding facilities for the final demonstration trials.

Sauerwein System-Technik GmbH, formerly part of Isotopen-Technik Dr Sauerwein GmbH has been designing, manufacturing and marketing conventional and advanced radioscopy and tomography systems of outstanding performance to industry and research institutes since 1981. Industrial inspection systems using advanced techniques and high quality equipment in radioscopy and computerised tomography (CT) are most important for the future of the company . For this reason the company is continuously working on further developments in these fields and to participate in development projects involving new inspection technology. Within the present project Sauerwein has performed the radioscopic inspections and the adaptation of the system to the conditions in a welding environment.

Sauerwein were involved in the adaptation of radioscopic equipment for inspection during welding. They also worked closely with the University of Surrey on developing signal processing and evaluation software and incorporation into hardware. They, with the help of the Institut de Soudure performed the final radioscopic tests at Nordon.

The **University of Surrey** has been active in the field of robotics and manufacturing automation since 1976 and has extensive experience of image processing techniques, machine vision and real-time image processing systems. The University were responsible for the design and development of a fully automated signal processing system for the on-line identification of flaws using ultrasonic and radioscopic sensor data.

The **Institut de Soudure** is a major training centre, a leading laboratory and a very active organisation in the field of technical assistance and services. The objectives of the Institut de Soudure are focussed on the study, improvement and advancement of all welding processes and NDT methods applied to welding structures. It is very active in the fields of consultancy and spread of knowledge. They were involved in all project tasks either by undertaking practical work or through involvement in technical evaluation. Their main practical involvement was in assisting Nordon in the manufacture of the initial testpieces, performing initial NDT on these testpieces, assisting Sauerwein and MBEL during the final trials and performing final metallography.

3. TECHNICAL ACHIEVEMENTS

3.1 Manufacture of Initial Test Specimens

Test specimens have been manufactured which contain deliberate defects. These specimens were completed to different levels of weld completion, i.e. 25%, 50% and 75%, to represent various stages during the welding process. Two welding techniques were used, submerged arc (SAW) and tungsten inert gas (TIG). A set of specimens was manufactured for each technique.

Conventional NDT techniques were applied to the test specimens to provide some early assurance that the intended defects were in fact present, and at the intended locations.

3.2 Ultrasonic Inspection System Development

For ultrasonic inspection during welding to be effective, two major problems had to be overcome.

The first problem was that an incomplete weld is an unfavourable geometry for ultrasonic inspection. The specimens described above have been used to develop and optimise an ultrasonic configuration which largely overcomes this problem. Extensive trials have been performed using the optimised set-up and it has been demonstrated that all deliberate defects in the testpieces are detectable, regardless of the stage of weld completion, for both the 25mm thick TIG specimens, and the 80mm thick SAW specimens. The approach adopted should also be applicable to intermediate thicknesses, to thickness slightly below and above this thickness range, and to other weld processes.

The second problem was that ultrasonic inspection at elevated temperature was required, both because of heat input due to the welding process and because components are sometimes subject to pre-heat during welding.

A special high temperature rig has been designed and manufactured. The rig allows the temperature of the specimens to be raised and held at a specified value. The rig has been used to carry-out elevated temperature scanning of the test specimens using special high temperature ultrasonic probes. The data has been compared with that obtained at ambient temperatures. The detectability of the defects at elevated temperatures is similar to that at ambient temperature.

The technique has been developed further to allow it to be used for final demonstration trials involving scanning on a test piece during welding. A novel coupling system has been developed and demonstrated to prevent coupling entering the weld during welding.

The major problems associated with performing ultrasonic inspection during welding have therefore been overcome. The system developed can perform inspection at temperatures (local to the probes) up to 250^{o}C.

3.3 Radioscopic Inspection System Development

Various radioscopic inspection methods have been evaluated and compared using the specimens described above. Sauerwein have adapted their radioscopic system GAMMASCOPE to the environment of an industrial workshop for large steel components. The image detector has been protected against heat irradiation by means of a cooler with compressed air. To prevent a loss of image quality by magnetic fields, caused by the high electric current required for the weld process, a mu-metal shielding have been integrated into the cooler.

In the final test in the workshop of partner NORDON the inspection system has been tested during the welding process. Several welds with defects have been produced by TIG and SAW welding. The inspection was performed after each layer. Even with some loss of image quality the results are acceptable for weld inspection.

The results were directly transferred to the partner University of Surrey, who also attended the final tests with their evaluation system. Immediately after welding they made an automated evaluation of the radioscopic images.

The inspection during the weld process is of great economic importance, since the radiographic examination after completion of the weld and a subsequent heating and repair wastes production time and energy. Filmless inspection saves also the chemical treatment of films and reduces the pollution of the environment caused by disposal of the photochemical liquids. Production plants with a high consumption of films will save the cost of the investment by replacing the films by electronic means.

3.4 Signal Processing Systems Development

Two sets of signal processing software for the flaw identification during welding of incomplete geometries have been developed within this project. They have been demonstrated and evaluated for both 80mm thick mild steel submerged arc and 25mm thick steel tungsten inert gas welding on double vee and vee butt weld geometries respectively:

(a) The automated radioscopy software

For development and demonstration purposes the software has been implemented on a Datacube MaxTD real-time image processing system. It accepts 512x512 by 8 bit grey scale images formed by a radioscopy system and evaluates the image for flaws within the weld region. The core of the software uses standard image processing filters for signal pre-processing, and a novel standard variation operator for image segmentation. Methods using an Artificial Neural Network have also been investigated, but have not proven as successful for this class of weld joint. The software is written in Visual C++ and is capable of being ported to a number of real time radioscopy manufacturers equipment. When executing in software the algorithms take approximately 30 seconds to analyse a 100mm length of weld. A hard copy output of the size (area in pixels) and location of all defects is produced.

(b) The automated ultrasonic Time of Flight Diffraction software

This software has been ported to a 200Mhz Pentium PC for demonstration purposes. The novel software accepts variable sized TOFD scans, having been tested up to 1000x512 by 8 bit scans, produced by standard commercially available TOFD equipment and evaluates the scan for flaws within the weld region. Again the core of the software uses standard image processing filters for signal pre-processing, and a novel standard variation operator for image segmentation. Methods using an Artificial Neural Network have also been investigated, but have not proven as successful due to the variable signal to noise ratio present in the scans due to the effect of high temperature on the probes and couplant. The software is written in Visual C++ and is capable of being ported to a number of PC based TOFD scan equipment. When executing in software the algorithms take approximately 20 seconds to analyse a 700mm length of weld. A hard copy output of the size (area in pixels) and location of all defects is produced.

3.5 Final Demonstration Trials

Final demonstration trials of the techniques, equipment and software developed have been performed in a factory environment (the premises of Nordon).

Two welding stations were set up, one for TIG welding and one for SAW welding. The ultrasonic, radioscopic and signal processing systems were integrated into these stations. A photograph showing the integrated TIG welding/ultrasonic inspection system is appended.

On-line flaw detection during welding trials were performed using the ultrasonic and radioscopic systems, with the automated defect detection software used to identify defects in close to real-time.

The radioscopic system requires the imaging system to be stationary with respect to the weld for a few seconds during each exposure. Radioscopy was therefore performed at discrete intervals during welding.

The ultrasonic system allows the probes to follow a few centimetres behind the welding head so that defects can be detected almost immediately.

During the trials the testpieces were removed at intervals to allow additional deliberate defects to be produced.

The final demonstration trials yielded very good results. The “on-line” radioscopy combined with automated defect recognition resuled in 87% of defects out of a total of 158 to be detected, compared to conventional inspection (UT plus radiography) after weld completion. The on-line ultrasonic inspection combined with automated defect recognition resulted in 79% of defects out of a total of 174 to be detected, compared to conventional inspection (UT plus radiography) after weld completion.

These results demonstrate that significant reductions in repair costs can be achieved using the technology developed in this project.

4. EXPLOITATION

Mitsui Babcock Energy Limited has identified two routes by which it can exploit the technology developed in this project:

- as an end user, ie using the technology to perform NDT during welding on its own manufacturing and construction contracts;

- supplying NDT during welding (and technical spin-off) consultancy, equipment and services to external clients.

Sauerwein wants to benefit from the results of the project by sales of radioscopic equipment. They will publish the results in NDT journals and present them at NDT conferences and exhibitions. Also a direct advertising by explaining the method and its advantages to their customers is planned. The software for automated defect recognition and classification can be integrated into Sauerwein's inspection systems.

The University of Surrey's exploitation objective is to licence the developed software to third party companies who currently supply either radiographic, radioscopic or ultrasonic TOFD systems. A suitable financial agreement is expected in lieu of the release of the software and for any associated integration services.

The University of Surrey also plans to further research and develop the software for new applications such as food and roadway inspection. Suitable funding programmes will be approached to jointly fund this work in collaboration with suitable partners.

All exploitation will be used to increase the profile of the University of Surrey as both a research centre and educational establishment, at both a national and European level.

Institut de Soudure will act as a link to make potential end users aware of the system developed during the programme and arrange contacts between partners and manufacturers of NDT equipment to interest them in selling systems or any component parts (e.g. : image processing system or ultrasonic signal processing system for automatic flaw identification, radioscopy system for elevated temperatures).

The knowledge acquired during this project will also improve the quality of technical consultancy provided by the Institut de Soudure.

The system for automatic flaw identification interests the Institut de Soudure because it can be incorporated as a part of their own developments as :

- adaptation of radioscopic system with image processing to automatic control of welds in hyperbaric environment

- robot for radioscopic inspection of onshore pipe welds.

The technique of ultrasonic signal processing for automatic identification is of particular interest for Institut de Soudure and can be employed in its expertise work.

5. REFERENCES

Lawson, S.W., and Parker, G.A., "Intelligent segmentation of industrial radiographic images using neural networks", Proc of SPIE, Machine Vision Applications, Architectures, and Systems Integration III, Vol 2347, Boston, MA, USA, 31st Oct. - 2nd Nov., pp245-255, 1994;

Press release on the project was printed in the November 1994 issue of "Insight" (The British Journal of Non-Destructive Testing);

Shepherd B.W.O., "NDT Methods For Flaw Detection During Welding", British Institute of Non-Destructive Testing 1996 Annual Conference, Erskine, Glasgow, 17-19 Sep 1996;

Farley J.M., "NDT Methods For Flaw Detection During Welding", 14th World Conference on Non-Destructive Testing at New Delhi, India, December 1996;