COOP-CT-2005-018236

ChainTest

Autonomous Robotic System for the Inspection of Mooring Chains that Tether Offshore Oil and Gas Structures to the Ocean Floor.

Horizontal Research Activities Involving SMEs

Co-operative Research

Final Publishable Activity Report

Period covered: from 15 Sept. 2006 to 14 March 2008

Date of preparation: April 2008

Start date of project: 15 Sept. 2005

Duration: 2.5 years

Project co-ordinator: Dr. Stephen Williams

Project co-ordinator organisation: TWI Ltd

Revision 1.0

1. PROJECT EXECUTION

1.1 PROJECT OBJECTIVES

The objective of ChainTest was to overcome the limitations of current inspection working practices on chains used in the mooring systems for floating offshore oil and gas production platforms obviating the need for human inspectors, and thereby increasing inspection reliability. The aim was therefore to develop an autonomous vehicle capable of moving along the chain, above and below water, carrying out inspection tasks while the chain is in-situ, eliminating the need to bring the chain on board. The main components of the system include:

- The development of a cleaning system to remove sufficient marine growth and rust scale from the surfaces of the chain for inspection.
- Developing a vision system that can measure chain link dimensions and conduct visual inspection.
- Developing novel non-destructive techniques, sensors and systems that will detect fatigue cracks and corrosion with the minimum of surface preparation and probe scanning and on surfaces hidden between chain links. The system will use Alternating Current Field Measurement (ACFM) to find surface breaking cracks at the weld, and ultrasonic testing for cracks originating at the inter-grip region.
- Crawling vehicle

1.2. PROJECT PARTNERS

Type	Name	Country
RTD	TWI	UK
SME	Miltech	Greece
SME	TSC Inspection Systems	UK
SME	Bytest	Italy
SME	Interlab IEC	Spain
SME	NES Limited	UK
OTH	Vicinay Cadenas	Spain
OTH	Petrobras	Brazil
RTD	Zenon	Greece
RTD	NDT Consultants	UK

1.3. WORK PERFORMED

In the first year the system specification and requirements document were completed. This was an on-going document to be updated throughout the project duration. The proofs of concept for the functional units were also completed in year 1 and the design and build of the devices by which the functional units are deployed on the chain by the crawler. The design of the robotic crawler, was also started during this period.

In year 2 there were a number of changes/improvements to the specifications of the system and these have been incorporated in the final version of the System Specification and Requirements document. These included:

(1) a change in the design of the crawling vehicle from motorised movement along the chain to winch controlled movement along the chain; The design and manufacture of the crawling vehicle was completed according to the new specification of a winch pulled system. Being winch assisted, a control system for the crawler was not required.

(2) a change in the deign of the deployment mechanism for the cleaning gun from a pan-tilt mechanism to a robot arm;

(3) a change in the design of the slider mechanism from a telescopic friction based mechanism to a pincer design that does not depend on friction for motion;

(4) a change in the deployment mechanism for the ultrasonic technique used to detect cracks at the link inter-grip area (this was needed because the UT technique was also changed).

5) Change in ultrasonic inspection technique.
Further work was required in technique development as development of the guided ultrasonic wave technique to 20% cross-section loss sensitivity seemed unlikely in the given timeframe. Therefore, new techniques were investigated. These were resonance and phased array ultrasonic inspection. The resonance technique demonstrated the potential to detect 20% cross-section loss in the mooring chains used in the ChainTest project. However, the method had to be validated for underwater use as the conclusions drawn in air were not necessarily valid for underwater. It was deemed unlikely that a satisfactory conclusion to the validity of this technique could be achieved within the project timescale. Longer cables however made it feasible to connect phased array ultrasonic probes to the UT flaw detector electronics making this a viable technique for demonstration purposes.

6) A change was made to the configuration of the optical system so that only one camera was needed instead of two.

Year 2 of the project also saw:

- Completion of the control software for the slider and robot arm

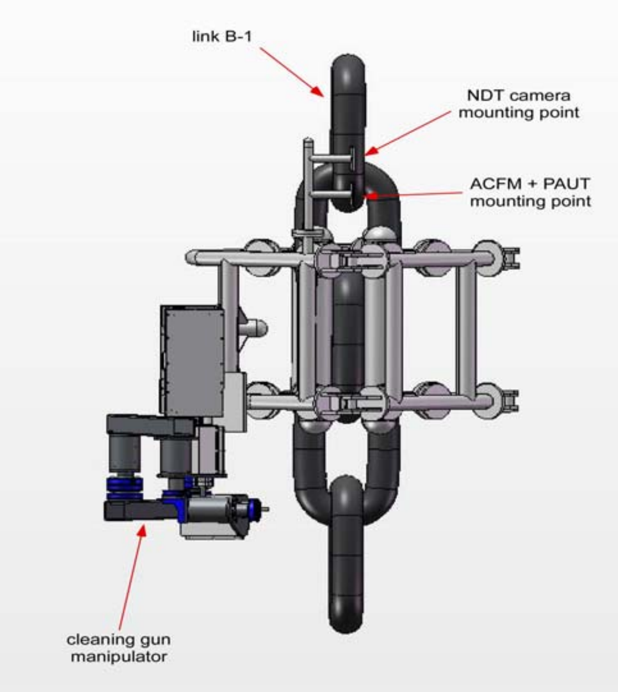
- Completion of the MMI with all hardware components and software.

- Integration of the cleaning system and the robot arm and the integration of the ACFM and PAUT probes to the slider being demonstrated and tested before the final integration of both robot arm and slider mechanism onto the crawler.

- The laboratory trials of the integrated system were abandoned due to time constraints and to ensure that the field trials could take place. Field trials were conducted at an indoor seawater facility at Brest in France.

1.4. RESULTS

The diagram below illustrates the system developed.



With respect to the objectives of the project the results achieved were as shown

- **The development of a cleaning system**

The cleaning techniques were satisfactorily demonstrated in year 1.

- **Developing a vision system**

In year 1 the optical inspection system demonstrated sufficient precision for the measurement of chain dimensions in air under laboratory conditions. In year 2 it was tested underwater to allow the necessary adjustments to the layout of the cameras and lighting sources and to ensure that precision remained adequate.

The cameras for the video guidance and visual inspection system were procured and integrated onto the vehicle. The cameras procured were suitable for underwater use (IP68) and therefore suitable for all applications of the prototype.

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- **Developing novel non-destructive techniques**,

A 2MHz linear phased array probe was designed and manufactured. The probe was curved along the passive axis direction (55.5mm radius);
The probe was successfully trialled on chain links to detect and size the representative slot defects, showing sensitivity that was better than that required in this application (20%) cross-section loss cracks at the inter-grip region. This technique was successfully validated for this application and the probe was successfully deployed on the prototype robotic system for in-situ scanning of off-shore mooring chains.

The capabilities of the ACFM inspection were demonstrated adequately in year 1. The new slider design was successfully demonstrated scanning the ACFM and PAUT probe around the weld area with the holders for these probes shown to effectively deploy the probes.

- **Crawling Vehicle**

The crawling vehicle design proposed by Zenon in year 1 was changed at the beginning of year 2. The fundamental change was that the vehicle would no longer be a self-powered unit driven by motorised wheels. Instead the vehicle produced was a frame that was moved up the chain by means of an independently controlled winch coupled to it by a cable. The crawler was to move down the chain by means of gravity under self-weight. The reason for the change in design was that the motorised design relied exclusively on friction to control movement up and down the chain and given the surface condition of in-service chain, friction could not be relied upon as a means of controlling the movement. All interfaces between the crawler and the deployment means for NDT and cleaning were also redesigned.

- **Instrumentation and Man-Machine Interface**

NDT Consultants made an early start to this task by collaborating with TWI on a plan on the top-level operation of the man-machine interface, which has now been accepted by all partners. This allowed control to be passed sequentially to each functional unit (cleaning or NDT), which will see each operate independently. Data fusion was not attempted. NDT Consultants were also responsible for programming the operation of the crawler and Zenon supplied a library of functions for this task. Late delivery of the manipulator resulted in incomplete integration.

The man-machine interface has been implemented on a single computer, which interfaces directly with each functional unit. NDT Consultants requested and received details from all partners of the hardware interface requirements. These were incorporated into the specification of the host computer and integrated into the host computer except for the robot and optical system.

1.4.5 SUMMARY OF ACHIEVEMENTS

Description	Percentage Completion
Development of ACFM techniques for weld crack detection	100
Development of inspection technique for detecting inter-grip cracks	100
Robot arm mechanical design	100
Robot arm control system	100
Tool and probe holders	100
Cleaning system	100
Robotic crawling vehicle mechanical design	100
Robotic crawling vehicle build	100
Software for System instrumentation and mm-interface	100
Hardware for System instrumentation and mm-interface	100
Integration of NDT, visual inspection and cleaning systems with robot scanner	100
Integration of robot scanner with robot vehicle	100
Integration of control and mechanical systems	100
Performance trials	80

2. DISSEMINATION AND USE

The results of the ChainTest project have been and will continue to be disseminated through a variety of conferences, publications and other media. The table below summarises this process.

Planned/Actual Dates	Type	Type of Audience	Countries Addressed	Size of Audience	Partner Responsible/ Involved
June 2006	Project website www.chaintest.com	Operators Maintenance contractors	Worldwide	5,000	TWI
June 2006	Article in TWI's JoinIT Publication	TWI Industrial Members	Worldwide	3500	TWI
June 2006	Article in TWI's Connect Publication	TWI Industrial Members	Worldwide	3500	TWI
June 2007	Industry focus group (FPSO Operators)	Mooring designers and specialists	Worldwide	50+	TSC
September 2007	Intl Offshore conference	Operators	Worldwide	300+	TWI
October 2007	AIPND national conference	NDT involved technicians from Italian Industry	Italy	200+	Bytest

The consortium has not yet fully agreed upon details of publications that will complete dissemination of the results whilst at the same time safeguarding the legitimate business interests of the partners. This will be completed within the next few months with the aim of supporting and publicising the exploitation of the project results in 2008/9.

The consortium anticipates that there will be several key exploitable deliverables in the period following completion of the project. These deliverables are listed in the table below.

Exploitable Knowledge	Exploitable Products or Measures	Sectors	Timetable for Commercial Use	Patents or other IPR Protection	Owner and Other Partners Involved
ChainTest system.	ChainTest system.	Oil and Gas	2011	None as yet - system requires further development	All partners
Chain Cleaning System.		Oil and Gas	2008	None at present	NES
Phased Array UT system for detecting cracks and corrosion away from weld	UT system for detection of sub-critical cracks in chain links	Oil and Gas	2008	Pre-existing patents	All partners
ACFM system for detecting cracking at welds		Oil and Gas	2008	Pre-existing patents	TSC
Vision system for determining chain wear	Undersea acquisition equipment and specialised image processing software for underwater measurements.	Oil and Gas	2009	None as yet – Preliminary study needed to assess the possibility and pertinence of a Spanish or European patent.	Interlab
Amphibious robot vehicle	Amphibious robot vehicle	Underwater	-	None now planned due to failure to complete robot vehicle within project	Miltech
Chain Inspection strategies and procedures		Oil and Gas	2008		Bytest