Report no. changed (Mar 2006): M-130-UU

SACLANTCEN SPECIAL REPORT
serial no.: M-130

*SACLANT UNDERSEA RESEARCH CENTRE SPECIAL REPORT*

# AN AUTOMATED INSTRUMENT FOR TESTING AND MONITORING OCEANOGRAPHIC MOORING CABLES AND ROPES

*L. Gualdesi, F. De Strobel, D.E. Di Massa*

September 1997

Report no. changed (Mar 2006): M-130-UU



SACLANT Undersea Research Centre
Viale San Bartolomeo 400
19138 San Bartolomeo (SP), Italy

tel: +39-187-540.111
fax: +39-187-524.600

e-mail: library@saclantc.nato.int

**NORTH ATLANTIC TREATY ORGANIZATION**

# An automated instrument for testing and monitoring oceanographic mooring cables and ropes

Gualdesi, L., de Strobel, F.,
Di Massa, D.E.

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Jan L. Spoelstra
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**An automated instrument for testing and monitoring oceanographic mooring cables and ropes**

Gualdesi, L., de Strobel, F., Di Massa, D.E.

**Executive Summary:** Underwater acoustic experiments at the NATO SACLANT Undersea Research Centre, La Spezia, Italy (SACLANTCEN), are largely dependent on moored and towed instrumentation. Every year up to 500 cable terminations are made and tested in compliance with safety standards to evaluate breaking strength and fatigue effects and life-cycle analysis of fiber ropes.

Elongation and breaking strength can be determined for rope samples (maximum length 10 meters) subjected to up to 300 kN of tensile force. A computerized acquisition system records the details of safety control tests and the associated analysis. The machine also performs tension to tension cycling and "strumming" effect simulations on cable terminations, thus reproducing in air the two basic forcing functions on mooring lines at sea: wave action and current action.

Aramid fiber ropes with advanced characteristics are being evaluated and the apparatus is being applied to the development of a new type of rope with high modulus fibers.

An improved, rapid splicing technique has been developed for reliable cable terminations for long term moorings deployed during Atlantic-Ionian-Stream (AIS) 95 and Otranto Gap Experiment (OGEX2) oceanographic experiments in the Sicilian Channel and the Adriatic Sea.

## Contents

**ABSTRACT - Underwater acoustic experiments at the NATO SACLANT Undersea Research Centre, La Spezia, Italy (SACLANTCEN) are largely dependent on moored and towed instrumentation. Every year up to 500 cable terminations are made and tested in compliance with safety standards to evaluate breaking strength and fatigue effects and life-cycle analysis of fiberropes..**

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**Aramid fiber ropes with advanced characteristics are being evaluated and the apparatus is being applied to the development of a new type of rope with high modulus fibers.**

**An improved, rapid splicing technique has been developed for reliable cable terminations forlong term moorings. This technique has been successfully applied to the moorings deployed duringAtlantic-Ionian-Stream (AIS) 95 and Otranto Gap Experiment (OGEX2) oceanographic experiments in the Sicilian Channel and theAdriatic Sea.**

## I. BACKGROUND

As a result of large scale operations during the period 1986 - 1992 in the Greenland Iceland Norway Sea (GIN Sea), the acquisition of a tensile testing instrument was considered essential for cable evaluation in long term oceanographic mooring design.

Systematic tests and simulation were described in [1].

## II. THE LINE TESTING MACHINE

The apparatus consists of a twin parallel beam steel structure 14 m long within which the cable is positioned. (Fig. 1) Hydraulic power provides the energy to a piston from which the specimen under test is connected to a load cell to measure the corresponding stress force. [2].

In order to accommodate two different elongation spans for cable testing, two arrangements are provided. A 2 m stroke piston on one side of the steel frame allows testing of nylon cable which requires this degree of elongation. For standard testing of steel wires, a 0.5 m stroke piston is installed on the other side of the frame.

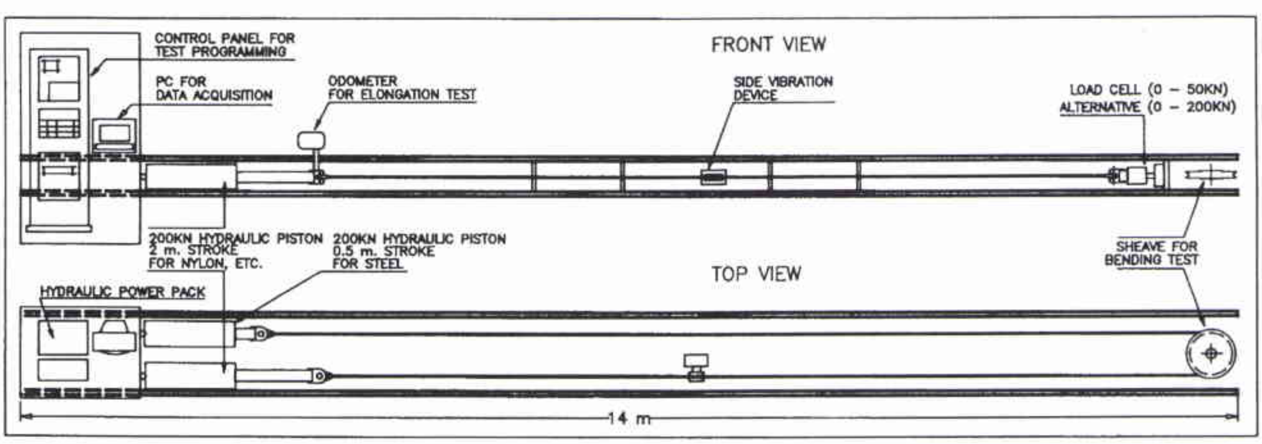


Fig. 1. Line testing machine.

While both pistons are able to provide a potential testing pull of 300 kN, due to the size range of cable normally employed at SACLANTCEN, two load cells are available: a 50 kN cell for weaker cables and a 200 kN cell for stronger cables (Fig. 2).

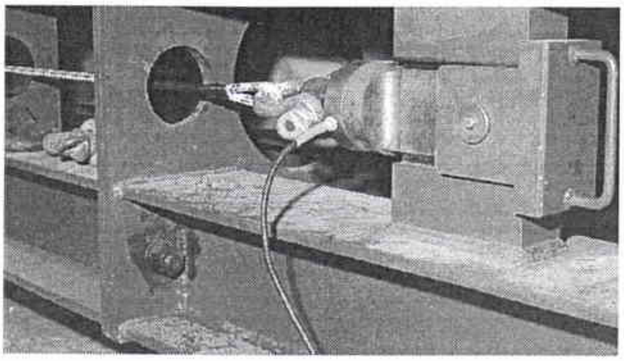

Fig. 2. The 200 kN load cell

The position of the load cell can be changed to accommodate cable lengths up to ten meters. The hydraulic piston is moved by either preprogramming the system or using the manual control buttons on the electronics panel. An odometer reads the piston position and measures the elongation.

The line testing machine is connected to a computer by an RS232 port on the electronics panel. There is a dedicated data capture program written in DB4 to receive data from the machine. During a typical test, the machine is pre-programmed to achieve a certain load in a certain time period, thus determining load rates. It is also possible to predetermine a number of stressing cycles of desired duration and loading.

The cell provides the force feedback and the odometer records the elongation with respect to a determined reference length. A data record of time, force, and elongation is recorded every 0.5 seconds. At the end of the test, the full data set can be saved in a named file. The name consists of the year, month, day, test number of that day, and the file appendix. It is possible to view all or some of the data immediately, depending on the file size, in numerical form or as a graph of force *versus* elongation. (Fig. 3)

At midspan of the loaded cable a side vibration device is fitted which can reproduce cable 'strumming' stress at different frequencies. Electric and pneumatic devices are available to perform this test which is recorded as time and tensile load, while the vibration frequency is read *via* the pick-up of a portable analyzer (Fig. 4).

Cyclic tension over sheave tests can also be performed. A sheave arrangement is provided at the end of the bench to reel the cable which is tensioned and moved by either piston as required by the cable type (Fig.5). For jacket abrasion testing it is possible to fit a sharp edge or a sand paper surface to cause controlled damage to the cable.

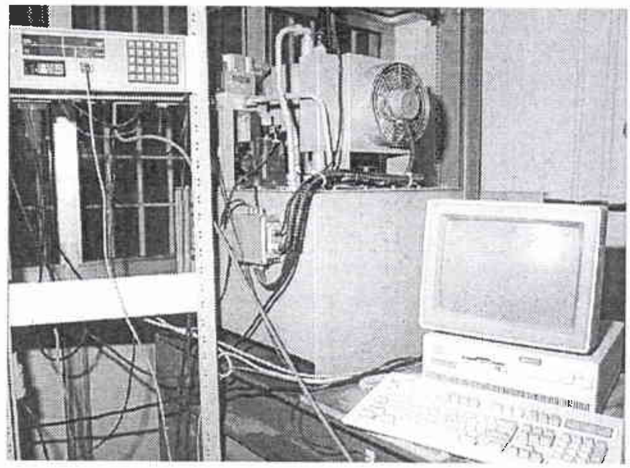

Fig. 3. Hydraulic power pack, control panel and PC for data acquisition.

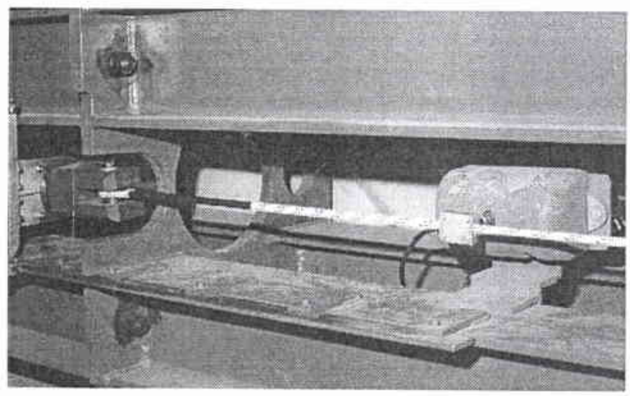

Fig. 4. Side vibration device.

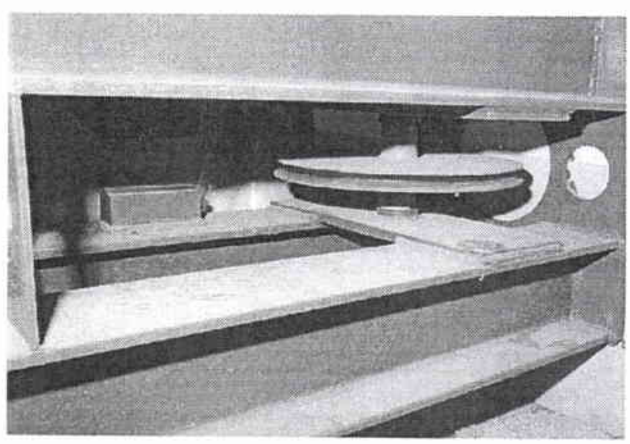

Fig. 5. Sheave arrangement for bending test.

## III - TESTS AND STANDARDS

Different test methods must be applied to synthetic fiber ropes for different applications as there is no international standard for synthetic cable properties and characteristics [3].

Some of the potential test specification differences to consider are: the cable termination type, the length of unspliced rope between splices, the reference load, the rate of loading, and whether or not the rope was pre-cycled before a breaking test. For breaking tests, cables can be terminated either by grasping the cable with a mechanical structure or by making a splice or a knot.

Liu and Furman [4] present a detailed analysis for a variety of conventional and unconventional termination methods for fiber ropes.

Given that the type of splice used is critical, SACLANTCEN adopted a splicing technique which proved to be reliable during arctic expeditions in which hundreds of Kevlar slings were used for long term oceanographic moorings in severe conditions.

The same splicing technique was used for moorings deployed during AIS 95 and OGEX2 oceanographic experiments in the Strait of Sicily and the Adriatic Sea. It may also be noted that all oceanographic mooring losses during the above mentioned campaigns may be attributed to fishing activity as opposed to mooring failures.

A characteristic of the splice is that it does not affect the nominal cable breaking strength, because the sample is frequently broken in the clear rope between the splices (Fig.6). The splicing technique is of the tuck-up type with some modifications by a skilled operator to preserve yarn integrity and to retain the jacket working in the loop as protection to the fiber (Fig.7).

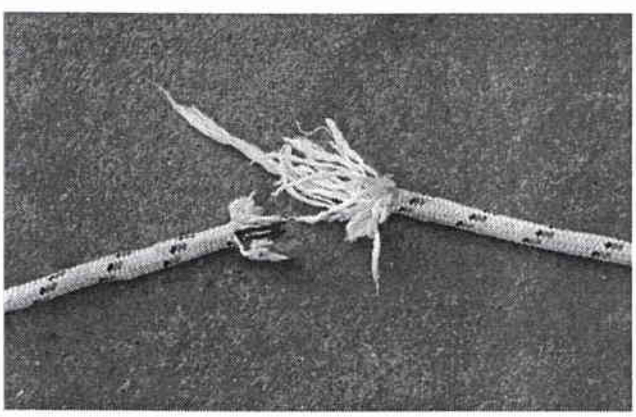

Fig. 6. Rope sample broken between splices

The splicing operator needs to have a special training and qualification, but this produces a fast technique with standard reliability. This feature in particular gives flexibility to oceanographic missions, when operational needs can frequently lead to last minute requirements.

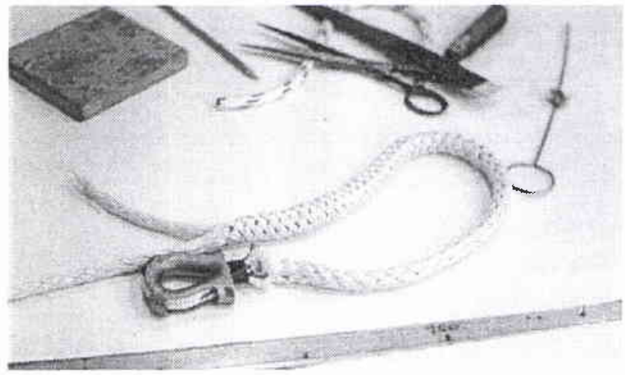

Fig. 7. SACLANTCEN splicing technique on Aramid rope

Another critical issue is whether or not the specimen was pre-cycled before the breaking test. A pre-cycled rope will usually give a higher breaking strength as the pre-cycling at low loads aids in fiber alignment and even distribution of force among the fibers. A pre-cycled rope breaking test is more representative of the strength of a used rope as very rarely are new ropes subjected immediately to high loads.

Comparisons between the residual strength of a rope sling with spliced ends and a knotted one have been performed for a variety of knots.

For oceanographic application, SACLANTCEN developed a towed oscillating system [5], the design of which is based on a 3.17 mm diameter high modulus steel wire, which had to be intensively tested against failure for 'strumming'.

The in water 'strumming' frequency, at one cable end, was measured during an actual tow of the vehicle and reproduced in air on the cable termination connected to the machine.

The specimen was subject to side vibration, as previously described, for 20 days, which represents the standard duration of this tow body system experiment. The subsequent breaking test showed a residual strength similar to the nominal one, demonstrating that the damper adopted improves the termination life-time according to operational requirements.

## V. ARAMID AND POLYETHYLENE COMPARISON

High density polyethylene fibers with high strength and low elongation mechanical properties, recently introduced on the rope market compare well with the more widely available Aramid family fibers.

Two characteristics of polyethylene fibers were considered of specific interest for SACLANTCEN oceanographic applications: abrasion resistance which eliminates the need for a protective jacket and positive buoyancy.

The comparison carried out on Dupont Kevlar rope (Aramid Kevlar9) and DSM Dyneema rope (Polyethylene Dyneema7) for oceanographic moorings is intended to determine whether the standard 9.5 mmAramid rope with polyester jacket can be replaced with a bare Dyneema Cable while maintaining associated strength and elongation characteristics. The consequent reduction in rope diameter would be largely beneficial for the rope's cross-sectional area exposed to drag forces.

A buoyant rope is also appreciated by seamen during mooring recovery because it is easier to capture by grapnels.

Conclusions must be extrapolated in term of specific strength referred to as fiber linear weight and not in terms of rope diameter reduction, but after the results of this test a more specific investigation is programmed.

*A. Dry Breaking Tests*

The test standard chosen for the breaking strength tests was the 1995 ASTM Standard [6]. The procedure requires that the specimen first be cycled ten times to 20% of the predicted breaking strength and then relaxed to zero load for 30 minutes before the actual breaking test.

Tests carried-out on dry Kevlar9 samples (9.5 mm jacketed diameter), manufactured with a linear Kevlar weight of 43 gr/m, gave an average strength of 44.9 kN.

Similar tests carried-out on dry Dyneema7 samples (7 mm bare diameter) manufactured with a linear polyethylene weight of 26 gr/m gave an average strength of 34.6 kN.

It is evident that, since the contribution of the jacket to the total strength is negligible, the advantage of using bare Dyneema is demonstrated by a positive result in exposed diameter of 50%, while the negative difference in strength is only 30%.

If the ropes are pre-cycled, the breaking strength comparison is reduced to 15%.

In spite of some system failures, the results are clear, given that the specific stress of Kevlar is 2.03 Newton/tex (23 gram-force/denier) and that of Dyneema 2.82 N/tex (32 gf/den) and that the diameter comparison is made between stretched bare Dyneema (6 mm) and jacketed Kevlar (9.5 mm). This inconsistency is unavoidable as Kevlar may only be used in jacketed form.

*B. Cycling and Breaking Tests*

Tension-to-tension cycling tests were performed on samples of Kevlar9 and Dyneema7.

Cycles were approximately 12,300 across 12 days, after which the sample was broken. The machine oscillated between 1.4 and 12.3 kN.

The typical elongation difference between minimum and maximum loading was 22 mm or 0.52% of the original length. This represents the elastic strain of the sample.

After cycling, Kevlar9 was broken at 45.8 kN while the residual breaking strength of Dyneema7 was found to be 39.8 kN, which is significantly higher than the 34.6 kN average (27% higher) of the breaking tests. Here again it appears that cycling at these load levels increases the breaking strength considerably.

*C. Elongation Tests*

Elongation tests were carried out on one sample each of Kevlar9 and Dyneema7 to evaluate the plastic and elastic strain properties. A 3 m Kevlar 9 cable was cycled 60 times to 34.3 kN which is 80% of the predicted breaking strength.

The values for the stable hysteresis loop are reached within the first ten cycles.

A 2.10 m Dyneema7 cable was commanded to cycle 60 times to 27.7 kN which is approximately 80% of the average breaking strength.

Comparing the results from the two elongation tests, it appears that the plastic strain of Dyneema7 is more than 2.5 times greater than Kevlar9, but that the elastic strain is comparable.

D. Absorption Tests

Two Dyneema 8 mm diameter cables were soaked in oil for approximately one month before being subjected to breaking tests. One cable was soaked in array oil[1] and the other in isopar h oil. Isopar h is the lighter of the two. Table 1 shows the results of these three absorption tests. The weight per meter of the Dyneema8 samples increased 134% with array oil and 89.8% with Isopar h oil

TABLE I
SUMMARY OF ABSORPTION TESTS

| Sample | Fluid | Dry Weight | Linear Dry Weight | Wet Weight | Linear Wet Weight | Soak Time |
|---|---|---|---|---|---|---|
| | | (g) | (g x m) | (g) | (g x m) | (days) |
| Dyneema 8 | Array oil | 109.4 | 32.2 | 256.0 | 75.3 | 31 |
| Dyneema 8 | Isopar h | 116.5 | 32.2 | 221.2 | 61.1 | 30 |

[1] Towed array oil is used to provide buoyancy and acoustic continuity

Both cables were subjected to the ASTM Standard Breaking Test and associated pre-cycling. From these tests it appears that the oil has little effect on both the breaking strength (42.5 kN) and the percent elongations for Dyneema8. The termination did not show any slippage due to oil imbibation.

The above results demonstrate the potential of this rope for use as strength member of a towed array.

E. Knot Tests

A practical test was carried out to compare the breaking strength of knotted fiber ropes.

A knot selection for both materials is given in Table 2

TABLE II

RESULT OF KNOT TERMINATION BREAKING STRENGTH TESTS

| Bowline | Fisherman | Anchor | |
|---|---|---|---|
| | (kN) | (kN) | (kN) |
| Kevlar Strength | 18.4 | 29.6 | 10.7 |
| Dyneema Strength | 11.5 | 18.1 | 10.2 |

## V. CONCLUSIONS

The SACLANT line testing machine has proved useful for standard breaking tests and is easily adapted for cables of various diameters and lengths.

The splicing technique adopted has been supported by intensive testing with reliable results.

The intention is now to capitalize on this achievement by adopting new polyethylene ropes after similar testing procedures.

All Dyneema tests were performed on cables with a diameter of 7 or 8 mm. Breaking tests showed that Dyneema 7 has an average strength of 34.6 kN.

Cycling to moderate load levels considerably increases the breaking strength for both Dyneema and Kevlar. Dyneema 8 is relatively insensitive to extended immersion in oils.

The elongation tests on the Dyneema 7 sample showed that the elastic strain remains nearly constant through moderate cycling and is comparable to that of the Kevlar, whereas the plastic strain of Dyneema is more than 2.5 times that of Kevlar.

Dyneema has proved promising for oceanographic use, as it has properties similar to Kevlar which are well-suited to ocean-related applications.

AKNOWLEDGMENT

The authors express appreciation to B.Miaschi, M.Tavernelli and A.Brogini for their contributions to this work.

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Report no. changed (Mar 2006): M-130-UU

# Document Data Sheet

NATO UNCLASSIFIED

| Security Classification | | Project No. |
|---|---|---|
| NATO UNCLASSIFIED | | ETD |
| **Document Serial No.** | **Date of Issue** | **Total Pages** |
| M-130 | September 1997 | 9 pp. |

*Author(s)*

Gualdesi, L., de Strobel, F., Di Massa, D.E.

*Title*

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Originally published in OCEANS 96 MTS/IEEE Conference Proceedings.
The Coastal Ocean - Prospects for the 21st Century. 23-26 September 1996,
Fort Lauderdale, Florida. ISBN 0-7803-3520-1.

*Keywords*

*Issuing Organization*

North Atlantic Treaty Organization
SACLANT Undersea Research Centre
Viale San Bartolomeo 400, 19138 La Spezia,
Italy

*[From N. America: SACLANTCEN
(New York) APO AE 09613]*

Tel: +39 (0)187 540 111
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