Copy No.________

Defence Research and Development Canada
Recherche et développement pour la défense Canada

DEFENCE R&D DÉFENSE

Development of a Magneto-Mechanical Actuator for the Measurement of Strain in Magnetic Shape Memory Alloys

Ken MacKay
Martec Limited

Martec Limited
Suite 400, 1888 Brunswick Street
Halifax, NS
B3J 3J8

Contract Number: W7707-021914/001/HAL (Call Up: W7707-3-2189)

Contract Scientific Authority: Dr. Leon Cheng, (902) 427-2601
Defence Scientist, Emerging Materials Section

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2005-120
May 2005

Canada

This page intentionally left blank.

Development of a Magneto-Mechanical Actuator for the Measurement of Strain in Magnetic Shape Memory Alloys

Ken MacKay
Martec Limited

Martec Limited
1888 Brunswick Street, Suite 400,
Halifax, Nova Scotia
B3J 3J8

Martec Technical Report: TR-05-31

Contract Number: W7707-021914/001/HAL (Call Up: W7707-3-2189)

Contract Scientific Authority: Dr. Leon Cheng, (902) 427-2601
Defence Scientist, Emerging Materials Section

Defence R&D Canada – Atlantic

Contract Report
DRDC Atlantic CR 2005-120
May 2005

Scientific Authority

Leon Cheng

Approved by

Calvin Hyatt

Section Head / Emerging Materials

Approved for release by

Kirk Foster

DRP Chair

Abstract

The Emerging Materials Section at DRDC Atlantic is involved in the development of magnetic shape memory alloys. As part of this research effort on the design, fabrication and characterization of magnetic shape memory alloys, the development of a device to measure the magneto-mechanical behaviour of these materials is required. This requires the re-design of the magneto-mechanical actuator device previously developed at DRDC Atlantic. This report describes the work by Martec Limited to redesign the magneto-mechanical actuator, during September to November 2003. The device measures strain in small (5-30 mm in length) specimens as a function of applied magnetic field, compressive stress and temperature. The design allows for load up to 500 lb to be applied while displacement is monitored using a LVDT. Magnetic fields of up to 1 Tesla can be applied to the specimen. Load is applied using a manual machine screw. The magneto-mechanical actuator was redesigned to correct problems with the existing device and facilitate the addition of new components. This included rearrangement of the load train to eliminate movement of the specimen, other than from specimen deformation, during loading; reducing friction due to misalignment and simplifying the mounting location of sensors, cooling devices, etc. Compressive loads are applied using a series of springs and measured with a load cell, with provisions for future introduction of a mechanical actuator. Strain is measured using the existing LVDT, but the design also include a access for non-contact strain measurement to measure both the longitudinal and transverse strains in the material and to allow the use of irregularly shaped specimens. An improved user interface for the data acquisition system to allow real-time plotting of test variables was developed. The device was demonstrated by obtaining the stress strain behaviour of a brass specimen.

Résumé

Les chercheurs de la Section des nouveaux matériaux de RDDC Atlantique exécutent des travaux d'élaboration d'alliages à mémoire de forme magnétique (alliages MFM). Dans le cadre des projets de recherche comprenant des travaux d'élaboration, de fabrication et de caractérisation d'alliages MFM, il était nécessaire de mettre au point un appareil de mesure du comportement magnéto-mécanique de ces matériaux, entre autres en modifiant le modèle d'actionneur magnéto-mécanique qui avait, à l'origine, été conçu dans les installations de RDDC Atlantique. Le présent rapport contient la description des travaux réalisés par la société Martec Limited, de septembre à novembre 2003, qui avaient pour but de modifier le modèle de l'actionneur magnéto-mécanique. Le dispositif permet de mesurer les déformations subies par des éprouvettes de petite taille (de 5 à 30 mm de longueur), en fonction du champ magnétique appliqué, de la contrainte de compression et de la température. La conception du modèle permet l'application, à l'aide d'une presse à vis manuelle, de charges pouvant atteindre 500 lb, le mouvement résultant étant mesuré par un transmetteur LVDT (transformateur différentiel à variation linéaire). On peut soumettre l'éprouvette à des champs magnétiques pouvant atteindre un tesla (1 T). Les modifications apportées au modèle d'origine de l'actionneur magnéto-mécanique visaient à corriger des problèmes qui lui étaient propres et à faciliter l'ajout de nouveaux constituants. Pour ce faire, on a entre autres modifié la géométrie du dispositif de chargement, afin d'éliminer tout mouvement de l'éprouvette, à l'exception de celui résultant de sa déformation; on a aussi réduit le frottement causé par le mauvais alignement de composantes et simplifié l'emplacement de montage de détecteurs, de dispositifs de refroidissement et d'autres constituants. Les charges de compression sont appliquées à l'aide d'un ensemble de ressorts et mesurées à l'aide d'une cellule de charge; l'agencement actuel permettra éventuellement d'y insérer un actionneur mécanique. Les déformations sont mesurées à l'aide du transmetteur LVDT existant, mais la géométrie du nouveau modèle permet aussi d'y monter un instrument de mesure sans contact des déformations longitudinales et transversales que subit le matériau et d'étudier des éprouvettes de forme irrégulière. On a aussi mis au point une meilleure interface-utilisateur pour le système d'acquisition des données, afin de permettre la visualisation graphique des variables d'essai en temps réel. Le nouveau dispositif a été mis à l'essai avec succès en étudiant le comportement d'une éprouvette de laiton et en obtenant des diagrammes effort-déformation connexes.

This page intentionally left blank.

Executive summary

Introduction

The Emerging Materials Section at DRDC Atlantic is involved in the development of magnetic shape memory alloys. As part of this research effort on the design, fabrication and characterization of magnetic shape memory alloys, the development of a device to measure the magneto-mechanical behaviour of these materials is required. This requires the redesign of the magneto-mechanical actuator device previously developed at DRDC-Atlantic. This report describes the work by Martec Limited to redesign the magneto-mechanical actuator, during September to November 2003.

Results

An apparatus to measure the magneto-mechanical properties of magnetic shape memory alloys was successfully redesigned and fabricated, and its performance demonstrated. Initial testing has shown that the device is capable of determining the stress-strain behaviour of a brass specimen.

Significance

The apparatus intends to allow controlled study of the effect of temperature, magnetic field and load on the performance of magnetic shape memory alloys. This is important in characterizing the performance of the actuator materials being developed at DRDC Atlantic.

Related Work

Details of the final version of this equipment appear in “Landry, G.J., Cheng, L.M 2004. Design of Magneto-Mechanical Actuator and Temperature Chamber for Characterization of Magnetic Shape Memory Alloys. DRDC Atlantic TN 2004-184. Defence Research and Development Canada – Atlantic”.

Mackay, K. 2005. Development of a Magneto-Mechanical Actuator for the Measurement of Strain in Magnetic Shape Memory Alloys. DRDC Atlantic CR 2005-120. Defence R&D Canada – Atlantic.

Sommaire

Introduction

Les chercheurs de la Section des nouveaux matériaux de RDDC Atlantique exécutent des travaux d'élaboration d'alliages à mémoire de forme magnétique (alliages MFM). Dans le cadre des projets de recherche comprenant des travaux d'élaboration, de fabrication et de caractérisation d'alliages MFM, il était nécessaire de mettre au point un appareil de mesure du comportement magnéto-mécanique de ces matériaux, entre autres en modifiant le modèle de l'actionneur magnéto-mécanique qui avait, à l'origine, été conçu dans les installations de RDDC Atlantique. Le présent rapport contient la description des travaux réalisés par la société Martec Limited, de septembre à novembre 2003, qui avaient pour but de modifier le modèle de l'actionneur magnéto-mécanique.

Résultats

Le modèle d'un appareil de mesure des propriétés magnéto-mécaniques d'alliages MFM a été modifié avec succès; une fois construit, le nouveau modèle a été mis à l'essai et les résultats ont démontré sa bonne performance. Les essais initiaux indiquent que le dispositif permet d'étudier le comportement d'une éprouvette de laiton en obtenant des diagrammes effort-déformation connexes.

Importance des résultats

L'appareil permettra de réaliser, dans des conditions déterminées et régulées, des études portant sur les effets de la température, du champ magnétique et de la charge sur la performance des alliages MFM. Des données de ce type sont essentielles pour exécuter la caractérisation de matériaux pour actionneurs élaborés dans les installations de RDDC Atlantique et établir clairement leur performance.

Travaux connexes

Pour plus de détails sur le modèle final de l'appareil susmentionné, le lecteur peut consulter le document suivant : « Landry, G.J. et Cheng, L.M. 2004. Design of Magneto-Mechanical Actuator and Temperature Chamber for Characterization of Magnetic Shape Memory Alloys. RDDC Atlantique TN 2004-184. R & D pour la défense Canada – Atlantique ».

Mackay, K. 2005. Mise au point d'un actionneur magnéto-mécanique pour mesurer les déformations d'alliages à mémoire de forme magnétique. RDDC Atlantique CR 2005-120. R & D pour la défense Canada – Atlantique.

Table of contents

List of figures

This page intentionally left blank.

1. Introduction

One of the research efforts at DRDC Atlantic involves the development of magnetic shape memory alloys to be used as actuator materials. The characterization of the magneto-mechanical properties of magnetic shape memory alloys is to be performed as part of this research effort. In support of these material characterization activities, a device to measure the magneto-mechanical behaviour of these materials was required. Mackay *et al.* [1] developed an actuator device for this purpose. Martec Ltd. was contracted to redesign the apparatus for DRDC Atlantic to correct problems with the existing device and facilitate the addition of new components. This report describes the work by Martec Ltd. from September to November 2003 to redesign the magneto-mechanical actuator.

2. Design of the magneto-mechanical actuator

2.1 Initial device and design requirements

A description of the existing magneto-mechanical actuator can be found in the report by MacKay *et al*. [1] and is shown in Figure 1.

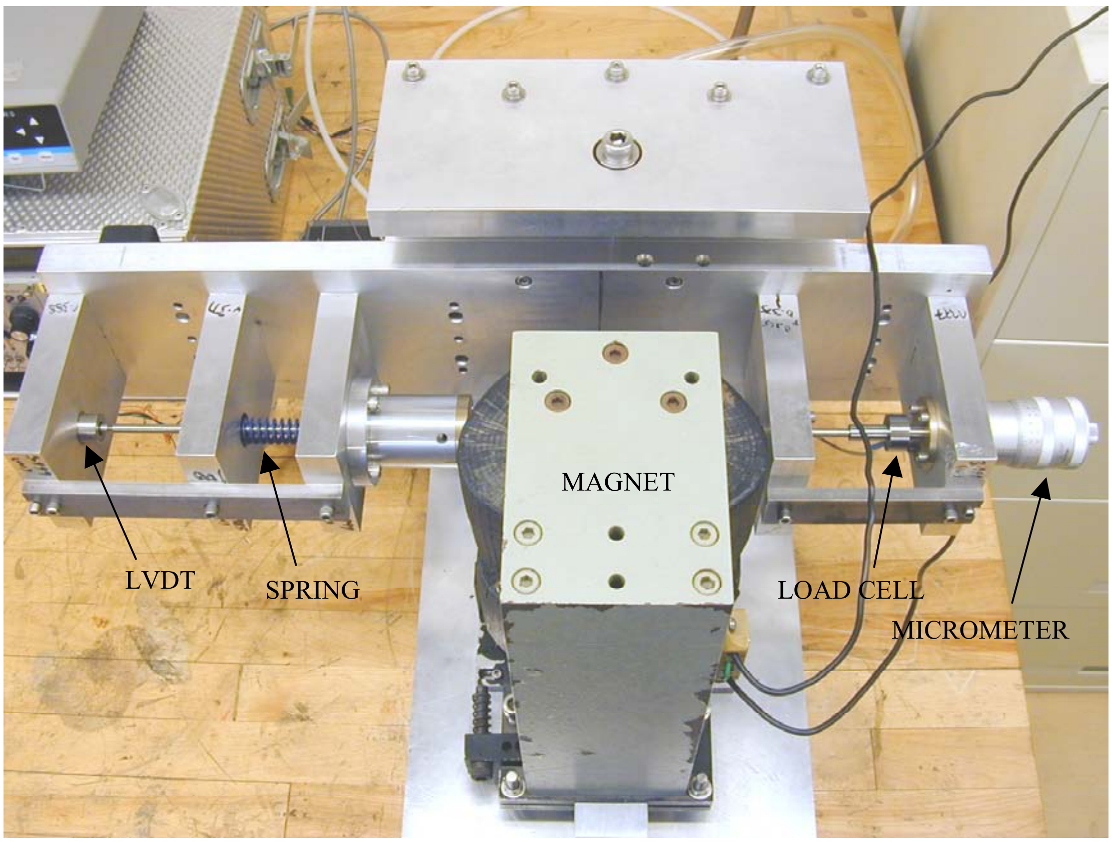


Figure 1. *Photograph of the device developed by MacKay et al [1].*

The loading arrangement of this device consists of a spring-loaded rod on one side of the specimen and a rod driven by a micrometer screw on the other. Applying a load through turning the micrometer screw results in gross displacement of the specimen during loading as the opposing spring is compressed. The initial device determined load by monitoring the displacement of the spring and calculating load based on the spring constant. A later development was the addition of a load cell on the micrometer side of the load train. It was noted during load-cell calibration that significant friction occurs within the device, resulting in hysteresis in loading/unloading cycles. Some friction was attributed to the misalignment of the system and some to the lateral deflection of the spring. An additional problem with the existing device was access to the specimen, as the position of the magnet blocks the view of the specimen. Rearranging the load train components and magnet position would eliminate this displacement and simplify installation of sensors, cooling devices, etc. A second possibility would be to use a gravity/weights based method to apply load to the specimen.

A reliable method to accurately determine strain is critical in characterizing the magneto-mechanical properties of these materials. The existing device required the use of strain gages applied to the specimen. The use of strain gages is limited due to the often irregular specimen shape and small sample sizes. In addition, the strain limit for strain gages is approximately 0.3% using room temperature curing adhesives while the materials were expected to strain several percent. There has also been some question as to the bonded strain gage influencing the materials behaviour. Initial testing has shown that the stain gage signal is not significantly affected by the magnetic field up to 1T provided the proper strain gage alloy is selected, and any other methods must be able to operate in areas of high magnetic field.

The data acquisition for the existing device consisted of a NI-DAQ AT-MIOM10-16X (ISA) data acquisition card and an I/O Connector Board. Strain gage output, load cell output (Omega LCFA-500) and displacement of the spring-loaded rod via an LVDT (Omega LD200-1.25 with LDX-3A power supply) are recorded through this system. Data acquisition was controlled through NI-DAQ DAQWARE software operating in DOS on a desktop computer. This software required setting acquisition channels and parameters for each series of tests.

The objective of this project was to redesign the existing Magneto-Mechanical Actuator to correct the above limitations and to facilitate the addition of new components. This includes:

- Rearrangement of the load train to eliminate movement of the specimen, other than from specimen deformation, during loading. Compressive loads are to be applied using a series of springs and measured with a load cell, with provisions for future introduction of a mechanical actuator (for measurement under variable frequency loads)

- Reduce friction due to misalignment

- Simplify the mounting location of sensors, cooling devices, etc.

- Design a strain measurement system using the existing LVDT (and maybe a second one)

- Develop a graphical user interface for data acquisition and real-time display of test data

The design must also make provisions for the inclusion for non-contact strain measurements in the future to measure both the longitudinal and transverse strains in the material and to allow the use of irregularly shaped specimens.

2.2 Design details

The initial concept for the proposed actuator device is given in Figure 2. Drawings were supplied to the machine shop at DRDC Atlantic who developed detailed drawings. A 3D rendering of the final design is shown in Figure 3 and a photograph of the device is shown in Figure 4. The device was to be fabricated and constructed at DRDC Atlantic using materials supplied by DRDC Atlantic.

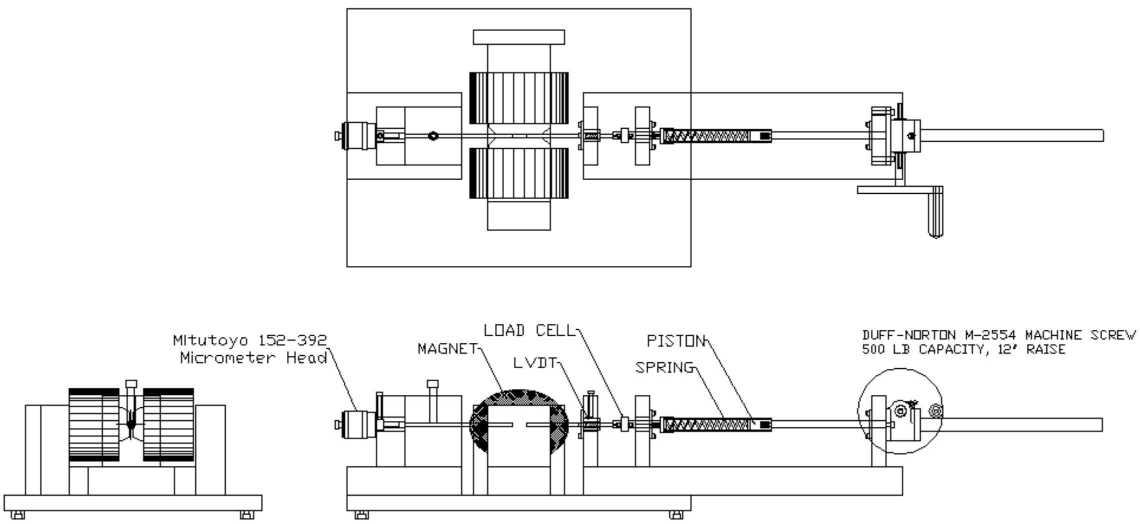


Figure 2. *Sketch of proposed device (top, side and end views).*

As with the previous device the specimen is positioned between the pole pieces of the magnet and loaded between stainless steel rods. The magnet is positioned so that the specimen can be directly observed from above. The rod on the left-hand side of the device is fixed in position using a setscrew. The micrometer is used only to center the specimen between the pole pieces before testing begins. The right-hand rod is driven by a hand-operated machine screw (the machine screw can be fitted with a servo motor for servo control if desired).

The load train contains a spring within a piston/cylinder assembled to provide compliance to the device during actuation of the specimen. The load train contains the Omega LCFA-500 load cell and the Omega LD200-1.25 LVDT to monitor load and displacement. As the left-hand rod is fixed in position, specimen strain and displacement can be directly determined from the LVDT and load cell output.

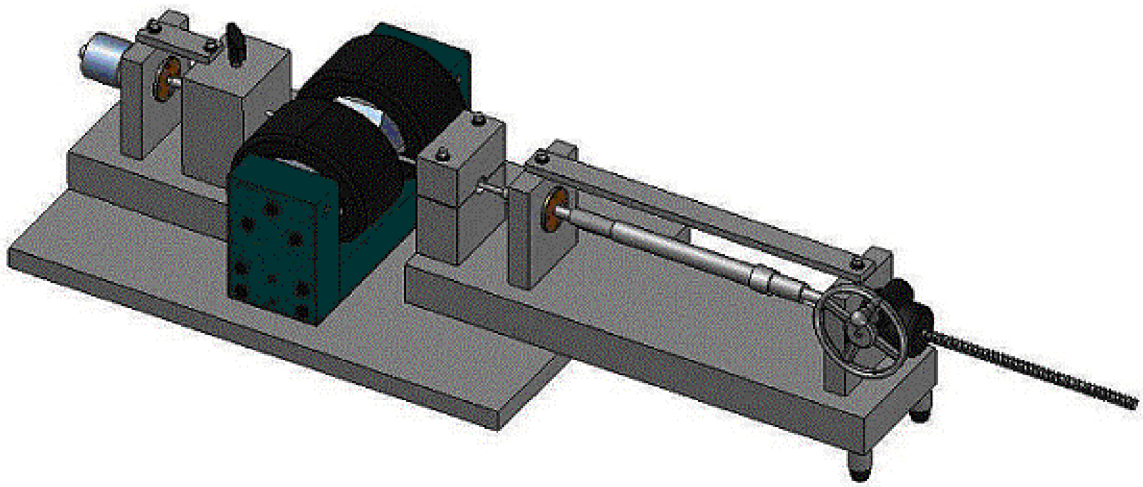


Figure 3. *Final 3D rendering of the actuator device.*

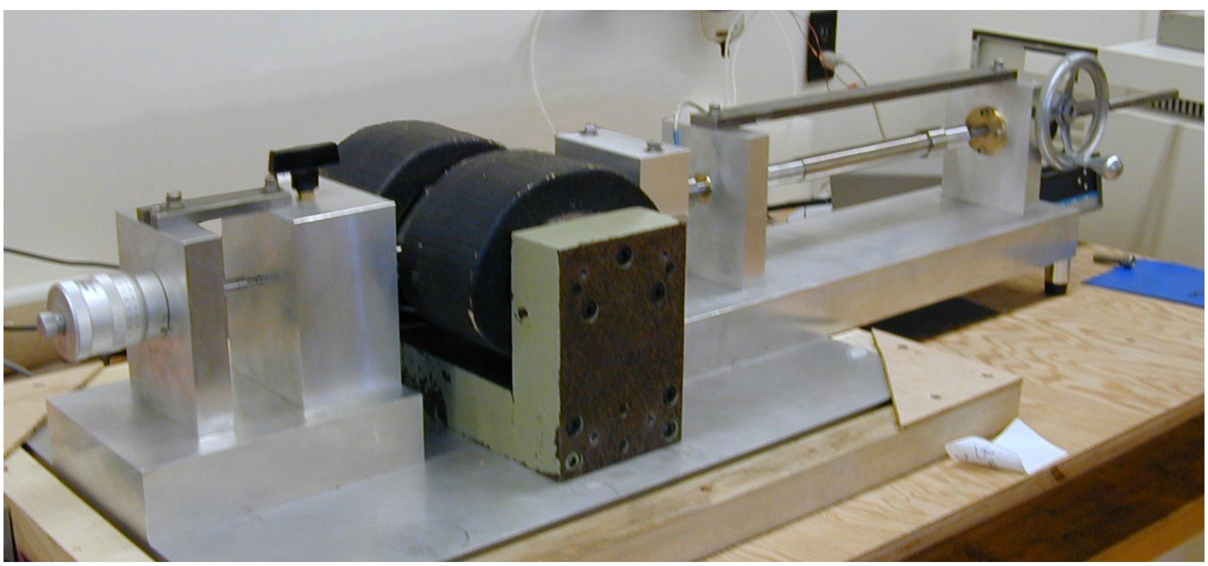


Figure 4. *Photograph of the actuator device.*

2.3 User interface

An improved user interface was developed for the data acquisition system to allow real-time plotting of test variables and is shown in Figure 5. The interface consists of 3 time series charts that display load, displacement and temperature recorded by the system in real time. In addition, there are two real time graphs of Load *vs.* Displacement and Temperature *vs.* Displacement. The “SETTINGS” area in the lower right portion of the screen is used to set device number of the data acquisition card, sampling frequency, the data acquisition channels, calibration multipliers, offsets, and engineering units for the load, displacement and temperature sensors. Default settings are loaded each time the program is started. The program also allows for a moving average data filter to be applied individually to each channel. The number of points to be averaged by the filter is specified in the field below the digital display of for each test variable. The filter is applied to all data stored in memory making it is possible to apply or remove a filter after the data is collected.

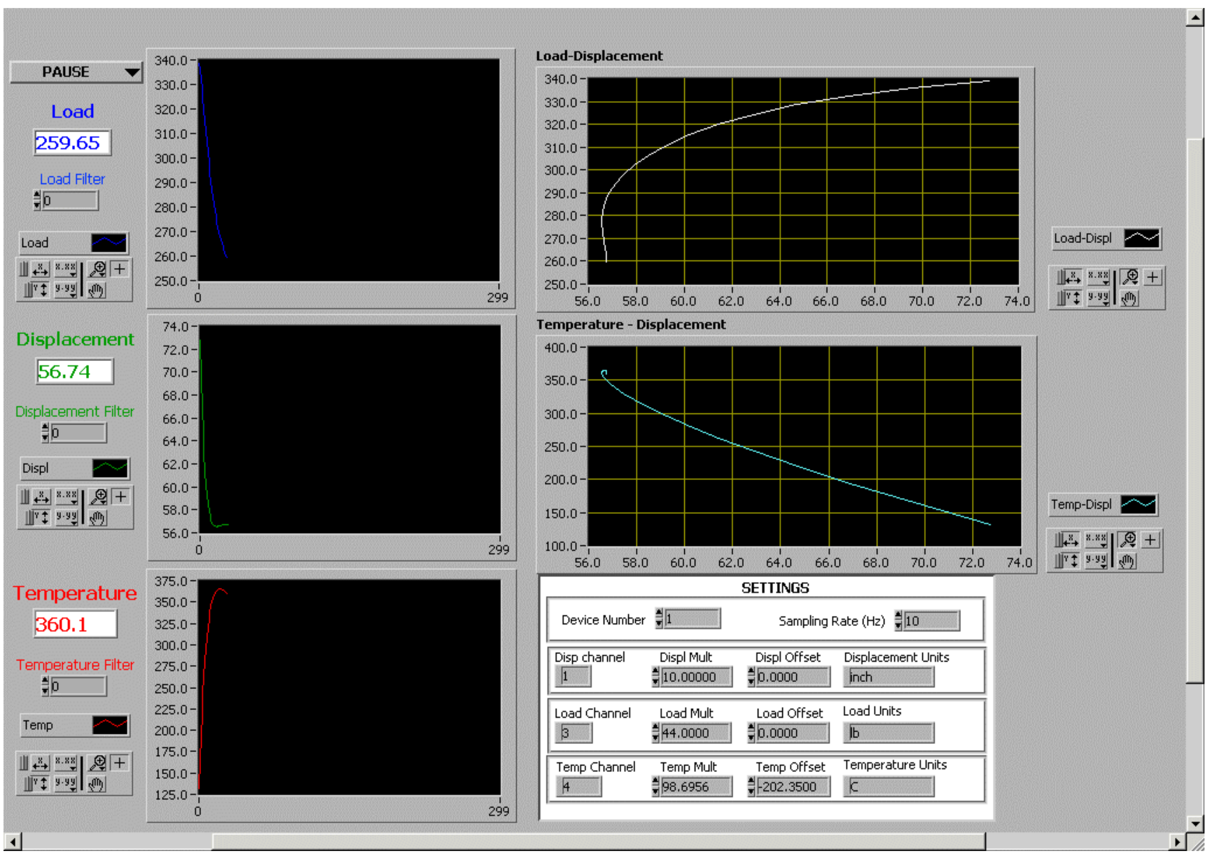


Figure 5. *Data acquisition user interface.*

The program is controlled through menu options located in the upper left of the screen (Figure 6). The menu functions are:

ACQUIRE - resumes/starts data collection. Test data is stored in memory and displayed on screen.

PAUSE - stops collection of data. Collected data remains on screen and in memory.

SAVE Data - collected data in memory is stored in a text file in a format compatible will most spreadsheet and plotting programs. The current filter settings are applied to the saved data. The user is prompted to give a file name for the data file.

ERASE Data - data stored in memory is erased and data plots are cleared. The user is warned that any unsaved data will be lost.

EXIT - closes the program. The user is warned that any unsaved data will be lost.

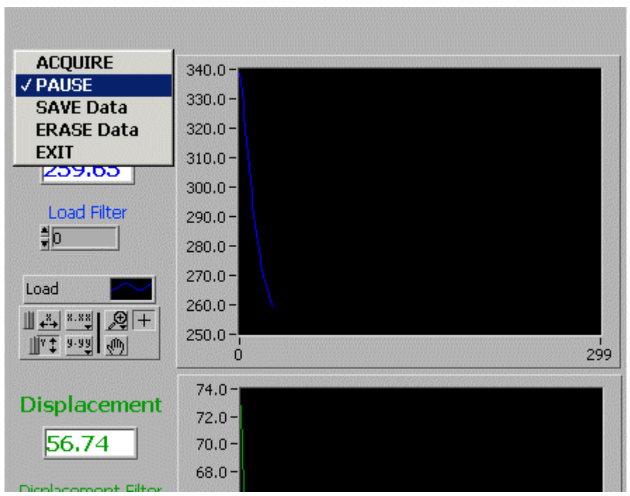


Figure 6. *Menu options for the data acquisition user interface.*

The software was developed using LabView 5.1 and requires the Labview 5.1 Runtime library (available from www.ni.com). The software was installed on a rack mount computer (AMD K6 400 processor) that includes a NI-DAQ AT-MIOM10-16X (ISA) data acquisition card that was used with the previous device. The computer system and data acquisition card were supplied by DRDC Atlantic. The NI-DAQ 6.1.1 driver was used with this board in a Windows NT environment. It should be noted that newer drivers than NI-DAQ 6.1.1 do not support legacy devices such as the AT-MIOM10-16X and the NI-DAQ 6.1.1 drivers are not compatible with the Windows 2000 operating system.

3. Demonstration of the magneto-mechanical actuator

The compliance of the device was determined by performing a loading and unloading cycle without a specimen (direct contact between the rods). A plot of the device compliance is shown in Figure 7. This compliance is due to both the compressive strain in the load rods as well as the compliance of the test frame and end supports.

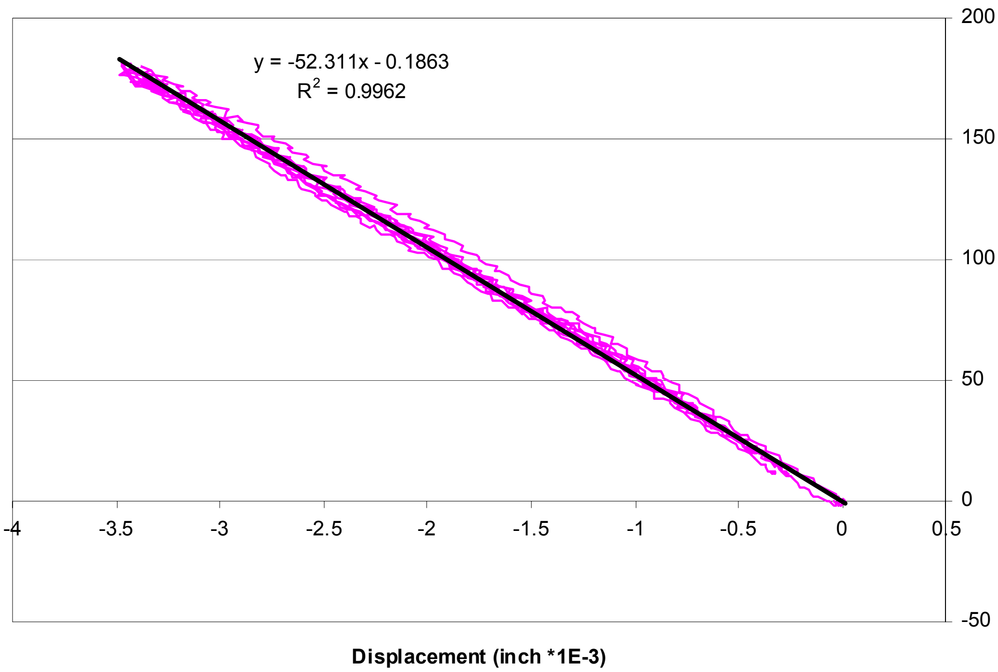
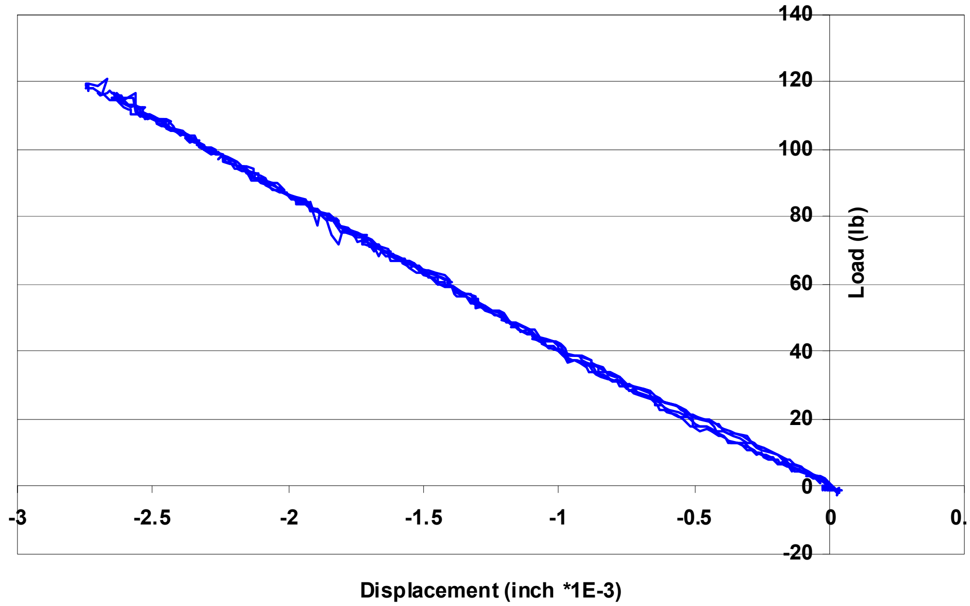


Figure 7. *Actuator compliance.*

Device performance was evaluated using a brass specimen (0.932” × 0.187” × 0.063”). Figure 8 shows the load-displacement curve obtained from the specimen and Figure 9 shows the stress-strain curve. These curves show that some hysteresis still exists in the load train, most likely due to friction between the rod and supports. It should also be noted that the data filters were not applied to this data.



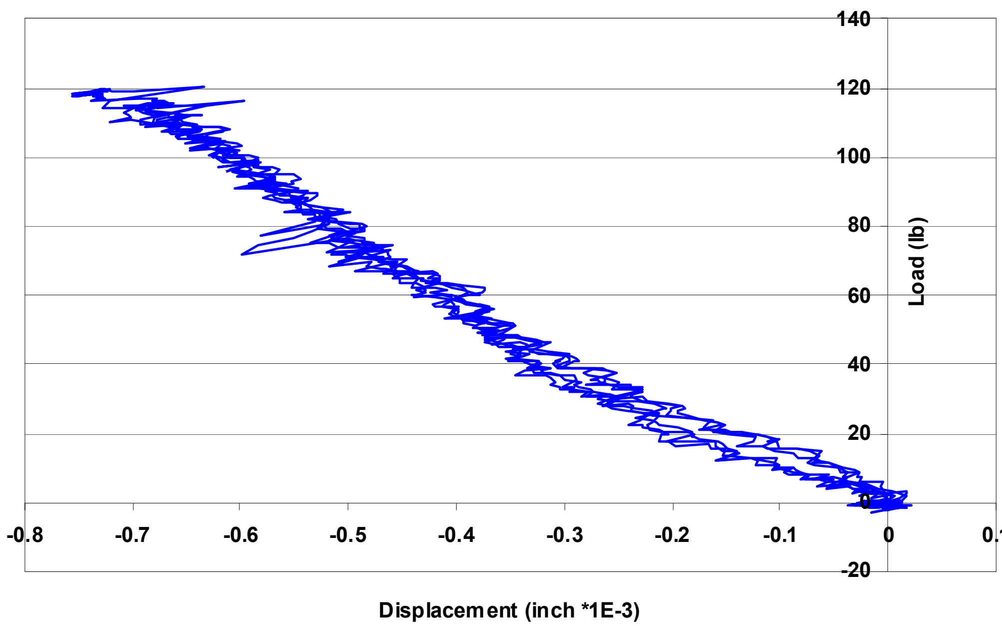


Figure 8. *Brass specimen load-displacement curve, (top) including frame compliance and (bottom) with displacement corrected for frame compliance.*

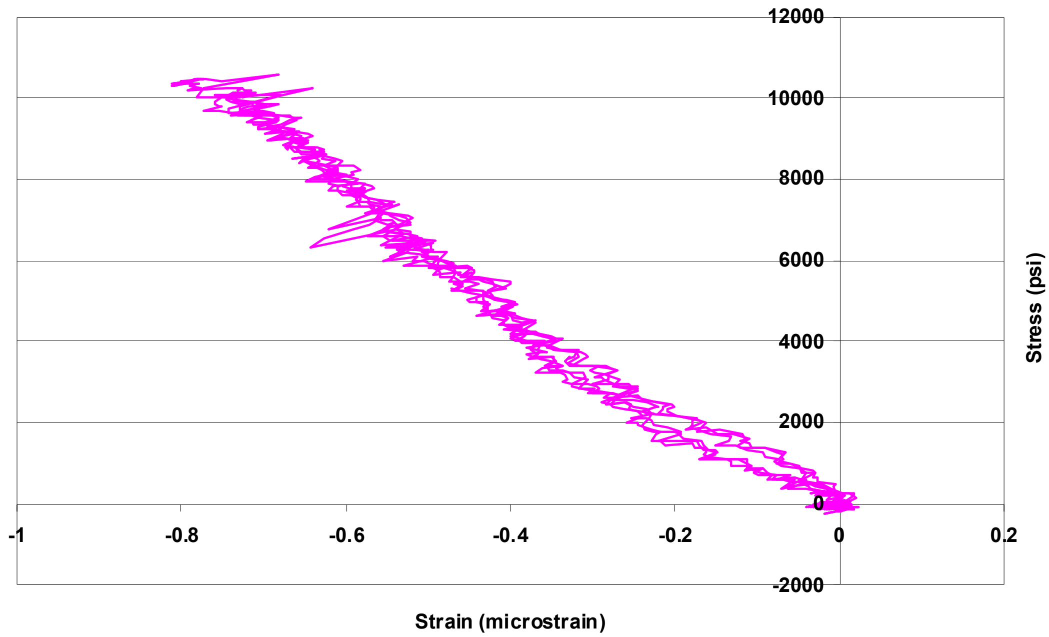


Figure 9. *Brass specimen stress-strain curve (2 cycles).*

4. Conclusions

The magneto-mechanical actuator developed at DRDC Atlantic was redesigned by Martec Ltd. between September and November 2003, and its performance demonstrated. Better access to the specimen facilitates specimen loading and allows for the use of non-contact strain measurement. Strain measurement can be determined from LVDT displacement output once corrected for test frame compliance, and thus eliminates the need to strain gage specimens. An improved graphical user interface was developed to control data acquisition and to provide real-time plotting and display of test parameters.

5. References

1. MacKay, J., Hyatt, C., Morrell, S., Pirge, G., and Matthews, J., "*Experimental Actuator for Assessing Magnetic Shape Memory Actuators and Drive Coils Designs*", DRDC Atlantic TN 2002-128, September 2002.

Distribution list

Dr. Leon Cheng, DRDC Atlantic

Dr. Rosaura Ham-Su, DRDC Atlantic

Dr. Shannon Farrell, DRDC Atlantic

Dr. Calvin Hyatt, DRDC Atlantic

Mr. Ken MacKay
Martec Limited
1888 Brunswick Street, Suite 400
Halifax, NS B3J 3J8

Library 6

DRDKIM 1

This page intentionally left blank.

DOCUMENT CONTROL DATA

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATOR (the name and address of the organization preparing the document. Organizations for whom the document was prepared, e.g. Centre sponsoring a contractor's report, or tasking agency, are entered in section 8.) DRDC Atlantic	2. SECURITY CLASSIFICATION (overall security classification of the document including special warning terms if applicable). UNCLASSIFIED

3. TITLE (the complete document title as indicated on the title page. Its classification should be indicated by the appropriate abbreviation (S,C,R or U) in parentheses after the title).

Development of a Magneto-Mechanical Actuator for the Measurement of Strain in Magnetic Shape Memory Alloys

4. AUTHORS (Last name, first name, middle initial. If military, show rank, e.g. Doe, Maj. John E.)

MacKay, K.

5. DATE OF PUBLICATION (month and year of publication of document) May 2005	6a. NO. OF PAGES (total containing information Include Annexes, Appendices, etc). 15 (approx.)	6b. NO. OF REFS (total cited in document) 1

7. DESCRIPTIVE NOTES (the category of the document, e.g. technical report, technical note or memorandum. If appropriate, enter the type of report, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered).

Contract Report

8. SPONSORING ACTIVITY (the name of the department project office or laboratory sponsoring the research and development. Include address).
Defence R&D Canada – Atlantic
PO Box 1012
Dartmouth, NS, Canada B2Y 3Z7

9a. PROJECT OR GRANT NO. (if appropriate, the applicable research and development project or grant number under which the document was written. Please specify whether project or grant). Project 11gm 13	9b. CONTRACT NO. (if appropriate, the applicable number under which the document was written). W7707-021914/001/HAL
10a ORIGINATOR'S DOCUMENT NUMBER (the official document number by which the document is identified by the originating activity. This number must be unique to this document.) DRDC Atlantic CR 2005-120	10b OTHER DOCUMENT NOs. (Any other numbers which may be assigned this document either by the originator or by the sponsor.)

11. DOCUMENT AVAILABILITY (any limitations on further dissemination of the document, other than those imposed by security classification)
(X) Unlimited distribution
( ) Defence departments and defence contractors; further distribution only as approved
( ) Defence departments and Canadian defence contractors; further distribution only as approved
( ) Government departments and agencies; further distribution only as approved
( ) Defence departments; further distribution only as approved
( ) Other (please specify): Internal Report available with DG/DRDC Atlantic approval

12. DOCUMENT ANNOUNCEMENT (any limitation to the bibliographic announcement of this document. This will normally correspond to the Document Availability (11). However, where further distribution (beyond the audience specified in (11) is possible, a wider announcement audience may be selected).

13. ABSTRACT (a brief and factual summary of the document. It may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall begin with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (S), (C), (R), or (U). It is not necessary to include here abstracts in both official languages unless the text is bilingual).

The Emerging Materials Section at DRDC Atlantic is involved in the development of magnetic shape memory alloys. As part of this research effort on the design, fabrication and characterization of magnetic shape memory alloys, the development of a device to measure the magneto-mechanical behaviour of these materials is required. This requires the re-design of the magneto-mechanical actuator device previously developed at DRDC Atlantic. This report describes the work by Martec Limited to redesign the magneto-mechanical actuator, during September to November 2003. The device measures strain in small (5-30 mm in length) specimens as a function of applied magnetic field, compressive stress and temperature. The design allows for load up to 500 lb to be applied while displacement is monitored using a LVDT. Magnetic fields of up to 1 Tesla can be applied to the specimen. Load is applied using a manual machine screw. The magneto-mechanical actuator was redesigned to correct problems with the existing device and facilitate the addition of new components. This included rearrangement of the load train to eliminate movement of the specimen, other than from specimen deformation, during loading; reducing friction due to misalignment and simplifying the mounting location of sensors, cooling devices, etc. Compressive loads are applied using a series of springs and measured with a load cell, with provisions for future introduction of a mechanical actuator. Strain is measured using the existing LVDT, but the design also include a access for non-contact strain measurement to measure both the longitudinal and transverse strains in the material and to allow the use of irregularly shaped specimens. An improved user interface for the data acquisition system to allow real-time plotting of test variables was developed. The device was demonstrated by obtaining the stress strain behaviour of a brass specimen.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus. e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus-identified. If it not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title).

Magnetic shape memory alloys, actuator, magneto-mechanical

This page intentionally left blank.

Defence R&D Canada

Canada's leader in defence
and National Security
Science and Technology

R & D pour la défense Canada

Chef de file au Canada en matière
de science et de technologie pour
la défense et la sécurité nationale

DEFENCE DÉFENSE

www.drdc-rddc.gc.ca