LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-TR-739112

Laser Shot Peening System Final Report CRADA No. TC-1369-96

B. C. Stuart, F. Harris

September 28, 2017

Disclaimer

This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Laser Shot Peening System

Final Report
CRADA No. TC-1369-96
Date Technical Work Ended: February 28, 2004

Date: October 6, 2005 Revision: 4

A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL) and Metal Improvement Company, Inc. (MIC).

The Regents of the University of California
Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550
Brent C. Stuart, L-470
Tel: (925) 424-5782
Fax: (925) 423-6195

Metal Improvement Company, Inc.
10 Forest Avenue
Paramus, NJ 07652
Fritz Harris
Laser Peening Division
Livermore, CA
Tel: (925) 960-1090
Fax: (925) 960-1093

B. Project Scope

This CRADA project was established with a primary goal to develop a laser shot peening system which could operate at production throughput rates and produce the desired depth and intensity of induced shots. The first objective was to understand all parameters required for acceptable peening, including pulse energy, pulse temporal format, pulse spatial format, sample configuration and tamping mechanism. The next objective was to demonstrate the technique on representative samples and then on representative parts. The final objective was to implement the technology into a meaningful industrial peen.

The original project consisted of four phases and a total of six tasks, with the following major deliverables:

Deliverables:

Phase I: Concept Feasibility
Systematically work the laser system parameters to optimize performance (LLNL)
Laser shot peen appropriate samples (LLNL)
Test samples and sample analysis (MIC)

Phase II: Concept Demonstration
Laser shot peen appropriate component parts (LLNL)
Provide component samples and complete component analysis (MIC)

Phase III: Prototype Development
Prototype system design and cost estimates (LLNL)
Construct prototype system (LLNL)
Laser shot peen component parts (LLNL)
Provide system requirements and cost (MIC)
Provide component samples and complete component analysis (MIC)

Phase IV: Process Commercialization
Support selection of production system manufacturer (LLNL)
Provide laser technology transfer to production system manufacturer and provide technology transfer of process to MIC (LLNL)
Support selection of production system manufacturer (MIC)
Support LLNL in technology transfer to production system manufacturer (MIC)

The estimated duration of this project was three (3) to five (5) years.

As the tasks under each phase of the project were successfully completed, Amendments One through Fifteen to the CRADA were executed to increase the funds-in amount to continue work on the remaining tasks, and extended the duration of the CRADA for an additional eighteen months. Amendment Twelve to the CRADA extended the term of the project, modified the original Task 5 under Phase III and Task 6 under Phase IV, and resulted in the following modified deliverables:

Deliverables:

Phase III. Prototype Development

Deliverables for Task 5.

Final short report on research and development results and outstanding issues. (LLNL)
LLNL to provide research and development results related to laser peening of a variety of parts to meet required residual stress and fatigue testing results. LLNL to treat required number of test parts. (LLNL)

LLNL to define and develop software code and indexing and alignment techniques and hardware as part of its research needed to implement accurate performance of robot for fan blade peening. LLNL to test upgraded code and alignment of hardware. (LLNL)

Final short report on meeting conclusions and outstanding research and development issues. (MIC)

Final report on long duration operation experience of a laser peening system. Report to be shared with DOE Yucca Mountain Project providing realistic evaluation data in support of YMP's license application process. (MIC)

MIC to provide robotic hardware and test results on peening processing. MIC will verify acceptable performance of part peening technology. (MIC)

MIC to provide robotic hardware and evaluate LLNL research results. (MIC)

MIC to verify performance of robot programming for fan blade and disc peening. (MIC)

Phase IV. Process Commercialization
Deliverables for Task 6.

LLNL will recommend improvements to enhance performance and reliability of the laser peening prototype system at MIC. (LLNL)

MIC to define additional research and development needed for the existing prototype production laser system and for future systems. (MIC)

MIC will rigorously test system performance and reliability for the purpose of improving the prototype production laser system. (MIC)

MIC will report on performance progress to enable improvements for their laser system and share knowledge with LLNL in the upgrade of possible government laser systems. (MIC)

C. Technical Accomplishments

All of the task and deliverables for this project were successfully completed. The overriding accomplishments were a very successful technology transfer that has resulted in a new business that is proving to be highly beneficial to the US economy, the U.S. military, and to the safety of air travel. A laser peening technology was developed and brought to a level of maturity and was turned into an industrial production process. Uniqueness of the process is recognized by the filing and awarding of over ten (10) US and foreign patents. The industrial partner is now capable of building the laser and peening systems and has built and is operating facilities in the US and the UK. The developments associated with the peening have been internationally recognized by four (4) R&D 100 Awards for significant new inventions.

D. Expected Economic Impact

The economic impact of laser peening has already surpassed $3.5B and is growing rapidly. During the 18 months since the industrial partner put the technology into production, over 16000 components valued at over $350M have been peened. The safety and reliability of over $25B in commercial aircraft has been positively impacted. Amounts in excess of this will be added to the totals each year as more facilities come on line. Over 40 permanent jobs have been created in the US (Livermore, CA) and additional jobs in the UK. Expected spin back in value to the US Military (F-22 fighter, F-16 fighter and others) and US government (for programs such as Yucca Mountain Nuclear Waste Disposal) will amount to many billions.

D.1 Specific Benefits

Benefits to DOE:

The most significant advantage of this project for DOE will be application of the laser peening technology to eliminate stress corrosion cracking on canisters for the Yucca Mountain Nuclear Waste Disposal Program. Estimated savings over thermal annealing are at the $1B level. Laser peenforming, a related technology also developed under the CRADA, has the potential to save an additional $2B. Stronger materials and new forms of materials for NNSA applications are also being developed.

There is a broad potential use for this technology including the treatment of aircraft and industrial components. This laser technology was developed as part of the Laser Programs Directorate. The improvements and enhancements of LLNL's current high power glass solid state laser technology and newer advances in the custom designed solid state lasers will benefit the DOE/DP critical technologies of high power laser system development which are crucial to the NIF project.

Benefits to Industry:

Benefits of longer lasting more reliable components are and will abound for industry. Aircraft engines are already more safe and reliable. Three engine models are already having components peened and two more are imminently on the way. Many more will follow. Aerospace, automotive, oil industry and medical applications are becoming numerous. Value created is already measured at over $3.5B and will increase that the rate of up to $10B per year.

E. Partner Contribution

MIC funded all activities, provided essentially all robotics hardware, provided engineering and technician support and connected the technology to users with problems. The partner invested an additional $15M in setting up production plants. A substantial list of inventions and patents were generated during the course of this work. MIC did not disclose any sole subject invention. Most of the subject inventions arising from the CRADA involved joint MIC and LLNL inventors, and are listed below.

F. Documents/Reference List

Reports

LLNL made technical presentations of work done under the CRADA at the request of MIC. These presentations described the work involved in the CRADA.

Presentation at Seventh Joint DoD/FAA/NASA Conference on Aging Aircraft, New Orleans, LA
"Life Extension by Laser Peening in High-Strength Aluminum Structure"; Mike Hill, University of California, Davis; C. Brent Dane, Metal Improvement Company, Inc.; Lloyd Hackel, Lawrence Livermore National Laboratory; September 9, 2003.

Presentation at Aeromat 2004 Conference, Seattle, WA.
"High Throughput Production Laser Peening: A Very Successful Technology Transfer"; Lloyd Hackel.

Presentation at ASME PVP 2004 FANP Laser Peening, San Diego, CA
"Application of Laser Peening for the Mitigation of Alloy 600 PWSCC in Commercial Nuclear Power Plants"; Framatome ANP an AREVA and Siemens Company, and Applied Research Center.

Presentation to Army Arsenel- Watervilet, NY
"Rounding and Straightening of Medium and Large Caliber Gun Barrel Using Laser Peening"; Lloyd Hackel, Jon Rankin, Hao-Lin Chen (Lawrence Livermore National Laboratory); and Michael R. Hill (University of California, Davis)

Presentation to USAF, Wright Patterson AFB, OH
"Laser peening could initiate a whole new concept in engineering enabling long lifetime in overload conditions"; Lloyd Hackel, Lawrence Livermore National Laboratory Laser Science & Technology; Michael R. Hill, Material Performance Laboratory, Department of Mechanical and Aeronautical Engineering, University of California, Davis; May 10, 2004

Presentation to Boeing C17 Program – Long Beach, CA
"Laser Peening to Improve Lifetime and Performance of Aircraft"; Lloyd A. Hackel; June 4, 2004.

Presentation at ExxonMobil, Houston, TX
"Update on Application of Laser Peening to Improve Performance of Structural Steels for ExxonMobil"; Michael R. Hill, Jasleen Bhoon, Matthew Lee, Kevin Liu, Jon Rankin, Lloyd Hackle, Hao-Lin Chen, Brent Dane, Fritz Harris; August 12, 2004

Internal LLNL Report, Laser Science and Technology Program, NIF Programs "Hydrogen Permeation Study in Titanium Alloy"; Report Summary; Tania Zaleski, Lloyd Hackel, Hao-Lin Chen, Bassem El-Dasher, Lawrence Livermore National Laboratory Laser Science & Technology; Kevin K. Liu, Michael R. Hill, Material Performance Laboratory, Department of Mechanical and Aeronautical Engineering, University of California, Davis; September 9, 2004

Copyright Activity

An overall concept for robotic motion and control was developed and submitted, and resulted in the following copyrights, which have been licensed to MIC:

(1) 131 Drawings for Laser Peening System 4/24/03 Drawing Package, LLNL Code Release No. UCRL-MI-153040, CP00838

(2) Laser Peening Software for Rolls Royce BR710 Jet Engine Disk, Version 3.0; LLNL Code Release No. 2003032, CP00837

(3) Laser Peening Software for Rolls Royce Trent 500 Low Pressure Fan Blade, Version 4.0; LLNL Code Release No. 155832, CP 00873

(4) Laser Peening Software – Multiblade Capability and Implementation for the 524Guc and Trent 800 0ff Blades, Version 1.0; LLNL Code Release No. 155907, CP00979

The copyrights listed above are currently licensed to MIC.

Subject Inventions

Joint Subject Inventions:

IL-10483, Patent pending

U.S. Patent No. 6,410,884 (LLNL Docket IL-10558) - *Contour Forming of Metals by Means of Laser Peening*; issued 6/25/02 ; Inventors: Lloyd A. Hackel, Fritz Harris (MIC)

U.S. Patent No. 6,423,935 (LLNL Docket IL-10644) - *Identification Marking by Means of Laser Peening*; issued 7/23/2002; Inventors: Lloyd A. Hackel, C. Brent Dane, and Fritz Harris (MIC)

U.S. Patent No. 6,657,160 (LLNL Docket IL-10756A) - *Laser Peening of Components of Thin Cross-Section*; issued 12/2/03; Inventors: Lloyd A. Hackel, John M. Halpin, and Fritz B. Harris Jr. (MIC)

U.S. Patent No. 6,805,970 (LLNL Docket IL-10756B) - *Laser Peening of Components of Thin Cross-Section*; issued 10/19/04; Inventors: Lloyd A. Hackel, John M. Halpin, and Fritz Harris (MIC)

IL-10832, Patent not pursued

IL-10833, Patent not pursued

IL-10927, Patent application anticipated

U.S. Patent No. 6,670,578 (LLNL Docket IL-10975A) - *Pre-loading of Components During Laser Peenforming*; issued 12/30/03; Inventors: Lloyd A. Hackel, John M. Halpin, and Fritz Harris (MIC)

IL-10988, Patent not pursued

IL-10990, Patent not pursued

IL-11081, Patent not pursued

IL-11178, Patent pending

IL-11217A, Patent pending

IL-11218, Patent pending

IL-11221, Patent pending

IL-11250, Patent pending

Sole LLNL Subject Inventions

U.S. Patent No. 6,792,017 (LLNL Docket IL-11000) - *High energy Laser Beam Dump*; issued 9/14/04; Inventor: John Halpin

The above subject inventions will be added by written amendment to LLNL License Agreement No. TL-1382-97, executed on 11/8/97, upon MIC's written request identifying those subject inventions for which it wants exclusive rights.

Background Intellectual Property (BIP)

LLNL disclosed the following BIP for this project.

U.S. Patent No. 5,239,408 (LLNL Docket IL-8899) - *High Average Power Regenerative Laser Amplifier With Passive Switching and Phase Conjugation;* issued 8/24/93; Inventors: Lloyd A. Hackel, C. Brent Dane (unlicensed)

U.S. Patent No. 5,689,363 (LLNL Docket IL-9644) - *Long-Pulse-Width Narrow-Band Width Solid State Laser*; issued 11/18/97; Inventors: C. Brent Dane, Lloyd A. Hackel

The above BIP is currently licensed non-exclusively to MIC under LLNL License Agreement No. TL-1382-97, executed on 11/8/97

U.S. Patent No. 6,198,069 (LLNL Docket IL-10167) - *Laser Beam Temporal and Spatial Tailoring for Laser Shock Processing*; issued 3/6/01; Inventors: C. Brent Dane, Lloyd A. Hackel

The above BIP is currently licensed nonexclusively to MIC under LLNL License Agreement No. TL-1382-97, executed on 11/8/97.

G. Acknowledgement

Participant's signature of the final report indicates the following:

1) The Participant has reviewed the final report and concurs with the statements made therein.
2) The Participant agrees that any modifications or changes from the initial proposal were discussed and agreed to during the term of the project.
3) The Participant certifies that all reports either completed or in process are listed and all subject inventions and the associated intellectual property protection measures generated by his/her respective company and attributable to the project have been disclosed and included in Section E or are included on a list attached to this report.
4) The Participant certifies that if tangible personal property was exchanged during the agreement, all has either been returned to the initial custodian or transferred permanently.
5) The Participant certifies that proprietary information has been returned or destroyed by LLNL.

6-Oct-2005

Fritz B. Harris, Division Manager 26-0 — Date
Metal Improvement Company, Inc.

11/7/05

Brent C. Stuart, LLNL Principal Investigator — Date
Lawrence Livermore National Laboratory

12/6/05

Karena D. McKinley, IPAC Director — Date
Lawrence Livermore National Laboratory

Attachment I – Final Abstract

Laser Shot Peening System

Final Abstract (Attachment I)
CRADA No. TC-1369-96
Date Technical Work Ended: February 28, 2004

Date: June 22, 2005 Revision: 3

A. Parties

This project was a relationship between Lawrence Livermore National Laboratory (LLNL) and Metal Improvement Company, Inc. (MIC).

The Regents of the University of California
Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550

Brent C. Stuart, L-470
Tel: (925) 424-5782
Fax: (925) 423-6195

Metal Improvement Company, Inc.
10 Forest Avenue
Paramus, NJ 07652

Fritz Harris
Laser Peening Division
Tel: (925) 960-1090
Fax: (925) 960-1093

B. Purpose and Description

This CRADA project was established with a primary goal to develop a laser shot peening system which could operate at production throughput rates and produce the desired depth and intensity of induced shots. The first objective was to understand all parameters required for acceptable peening, including pulse energy, pulse temporal format, pulse spatial format, sample configuration and tamping mechanism. The next objective was to demonstrate the technique on representative samples and then on representative parts. The final objective was to implement the technology into a meaningful industrial peen.

The original project consisted of the following four phases involving six major tasks:

Phase I: Concept Feasibility
Phase II: Concept Demonstration
Phase III: Prototype Development
Phase IV: Process Commercialization

The estimated duration of this project was three (3) to five (5) years.

As the tasks under each phase of the project were successfully completed, Amendments One through Fifteen to the CRADA were executed to increase the funds-in amount to continue work on the remaining tasks, and extended the duration of the CRADA for an additional eighteen months. Amendment Twelve to the CRADA extended the term of the project, modified the original Task 5 under Phase III and Task 6 under Phase IV. The project consisted of the following major deliverables:

Deliverables:

Phase I: Concept Feasibility
Systematically work the laser system parameters to optimize performance (LLNL)
Laser shot peen appropriate samples (LLNL)
Test samples and sample analysis (MIC)

Phase II: Concept Demonstration
Laser shot peen appropriate component parts (LLNL)
Provide component samples and complete component analysis (MIC)

Phase III: Prototype Development
Final short report on research and development results and outstanding issues. (LLNL)
LLNL to provide research and development results related to laser peening of a variety of parts to meet required residual stress and fatigue testing results. LLNL to treat required number of test parts. (LLNL)

LLNL to define and develop software code and indexing and alignment techniques and hardware as part of its research needed to implement accurate performance of robot for fan blade peening. LLNL to test upgraded code and alignment of hardware. (LLNL)

Final short report on meeting conclusions and outstanding research and development issues. (MIC)
Final report on long duration operation experience of a laser peening system. Report to be shared with DOE Yucca Mountain Project providing realistic evaluation data in support of YMP's license application process. (MIC)

MIC to provide robotic hardware and test results on peening processing. MIC will verify acceptable performance of part peening technology. (MIC)

MIC to provide robotic hardware and evaluate LLNL research results. (MIC)

MIC to verify performance of robot programming for fan blade and disc peening. (MIC)

Phase IV. Process Commercialization
LLNL will recommend improvements to enhance performance and reliability of the laser peening prototype system at MIC. (LLNL)

MIC to define additional research and development needed for the existing prototype production laser system and for future systems. (MIC)

MIC will rigorously test system performance and reliability for the purpose of improving the prototype production laser system. (MIC)

MIC will report on performance progress to enable improvements for their laser system and share knowledge with LLNL in the upgrade of possible government laser systems. (MIC)

All of the task and deliverables for this project were successfully completed. The overriding accomplishments were a very successful technology transfer that has resulted in a new business that is proving to be highly beneficial to the US economy and to the safety of air travel.

C. Benefit to Industry

Benefits of longer lasting more reliable components are and will abound for industry. Aircraft engines are already more safe and reliable. Three engine models are already having components peened and two more are imminently on the way. Many more will follow. Aerospace, automotive, oil industry and medical applications are becoming numerous. Value created is already measured at over $3.5B and will increase that the rate of up to $10B per year.

D. Benefit To DOE/LLNL

The most significant advantage of this project for DOE will be application of the laser peening technology to eliminate stress corrosion cracking on canisters for the Yucca Mountain Nuclear Waste Disposal Program. Estimated savings over thermal annealing are at the $1B level. Laser peenforming, a related technology also developed under the CRADA, has the potential to save an additional $2B. Stronger materials and new forms of materials for NNSA applications are also being developed.

There is a broad potential use for this technology including the treatment of aircraft and industrial components. This laser technology was developed as part of the Laser Programs Directorate. The improvements and enhancements of LLNL's current high power glass solid state laser technology and newer advances in the custom designed solid state lasers will benefit the DOE/DP critical technologies of high power laser system development which are crucial to the NIF project.

E. Project Dates

August 4, 1997 to February 28, 2004