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**Final Report for Miniature
Laser Ignited Bellows Motor**

**Document No.
49NA-02-94**

Developed For:

**Los Alamos National Laboratory
Group M-7
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Abstract

A miniature optically ignited actuation device has been demonstrated using a laser diode as an ignition source. This pyrotechnic driven motor provides between 4 and 6 lbs of linear force across a 0.090 inch diameter surface. The physical envelope of the device is 1/2 inch long and 1/8 inch diameter. This unique application of optical energy can be used as a mechanical link in optical arming systems or other applications where low shock actuation is desired and space is limited.

An analysis was performed to determine pyrotechnic materials suitable to actuate a bellows device constructed of aluminum or stainless steel. The aluminum bellows was chosen for further development and several candidate pyrotechnics were evaluated. The velocity profile and delivered force were quantified using an non-intrusive optical motion sensor.

DISCLAIMER

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TITLE FINAL REPORT FOR MINIATURE LASER IGNITED BELLOWS MOTOR		PROCEDURE NO. 49NA-02-94, Rev -	
		ISSUE DATE 18 FEB 1994	
MODEL N/A	FUNCTIONAL CATEGORY LASER BELLOWS		SUB CATEGORY PYRO
SPECIMEN ID N/A	EST START DATE 18 APR 1993	REVISION LETTER -	DATE 2/18/94
LOCATION EBCo/ASP	EST COMP DATE 18 FEB 1994		
APPLICABLE DOCUMENTS		NUMBER	REVISIO
2) CALIBRATION SYSTEMS REQUIREMENTS 4) EBAC GENERAL SAFETY PROCEDURES 5) ETL GENERAL OPERATING PROCEDURES		MIL-STD-45662 PS 0038/11 GTP 0014	A H N/C
APPLICABLE INTERFACE WITH OTHER TESTS			
1) EXPLOSIVE TEST LABORATORY TESTING PROCEDURES - VOD		GTP 0001	B
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FINAL REPORT FOR MINIATURE
LASER IGNITED BELLOWS MOTOR

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1.0 INTRODUCTION

A small optical to mechanical link has been developed for uses where low velocity force is required. This device uses a small B/KNO₃ charge to actuate a miniature rolling bellows. This laser diode ignited system provides approximately 4 lbs of force over 0.1 inches of displacement. The device was designed to move a small barrier either into or out of the way to provide means for a miniature optical arming feature. The overall size of the device is less than 1/2 inches long and 1/8 inches in diameter. A mounting feature allows simplified integration into new or existing systems. This device has been developed as EBCo part number 235699-1.

2.0 SCOPE

The purpose of this program is to select the pyrotechnic material and develop manufacturing techniques for the laser ignited miniature bellows. The intent of this program is to demonstrate this new technology and to ultimately manufacture deliverable prototypes. As part of this effort, an optical switching technique has been developed to roughly determine the velocity profile of the bellows when fired in the unrestrained state.

3.0 SAFETY

The items tested contain pyrotechnic materials. These materials are sensitive to heat, friction, impact and electro-static discharge. Bulk quantities of pyrotechnic, or subassemblies and test articles containing pyrotechnic must be handled with care and in accordance with the standard procedures for handling such materials.

Laser diodes and Nd:YAG lasers were used for initiation of the test articles. These devices use firing units charged to high voltage and discharge cohesive collimated light. Proper interlock protection for Nd:YAG laser and safety procedures were used throughout this program. Only Ensign-Bickford personnel trained in the use of laser systems or laser firing units were allowed to handle and use the electronics, lasers, and test units.

All testing was accomplished in accordance with EBAC General Safety Procedures (PS 0038/11).

4.0 ANALYSIS OF DESIGN

The challenges of this development program were to balance the gas output to desired force, ignite with a 1 Watt rated laser diode, and to downsize processes to manufacture such a small complex device.

4.1 BELLOWS MATERIALS ANALYSIS

The force is dictated by the material used for the bellows. This analysis assumes that in order to sufficiently move the bellows, plastic deformation must occur. This requires that the yield point of the selected material be exceeded without violating the ultimate strength. Following these guidelines, the pressure required for actuation can be calculated. The results of this basic stress analysis are summarized in Table 1.

Table 1. Pressure Requirements for Bellows Actuation and Burst

Bellows Material	Alloy and Temper	Minimum Actuation Pressure (psi)	Burst Pressure (psi)
Aluminum	1100-0	389	577
Aluminum	1100-H12	1089	689
Aluminum	1100-H14	1555	977
Aluminum	3003-0	467	711
Stainless Steel	302, Annealed	2722	4000

The burst pressure for hardened aluminum alloys is less than the pressure required for actuation. Annealed 302 Stainless Steel, Aluminum 1100-0, or Aluminum 3003-0 are suitable bellows candidate materials. Using this information, the resultant force developed by a fully actuated bellows can be calculated. The force results are listed in Table 2.

Table 2. Force Developed for Various Bellows Materials

Bellows Material	Alloy and Temper	Actuation Force (lbs)	Target Force (lbs)
Aluminum	1100-0	2.64	4.02
Stainless Steel	302, Annealed	17.32	25.45

4.2 PYROTECHNIC MATERIALS ANALYSIS

In order to produce the desired force, several candidate pyrotechnic materials and stoichiometries were considered. Size restraints required that the selected pyrotechnic use the space allocated for the charge holder precisely. This analysis was crucial due to space restraints for the charge allocated given the overall size envelope.

The amount and type of pyrotechnic material was calculated based on the pressure required for actuation using the NASA-Lewis equilibrium thermochemistry code. The results of this analysis are normalized to Ti/KClO₄ and are listed in Table 3. An example of the NASA-Lewis equilibrium output is attached in Appendix A.

Table 3. NASA Lewis Calculation Results

Candidate Pyrotechnic Formulation	Calculated Flame Temperature (K)	Normalized Mass Required to Produce 500 psi
Ti/KClO ₄	5006	1.00
Ti/KClO ₄ + RDX	4155	0.63
RDX + C	3083	0.67
B/BaCrO ₄ /KClO ₄	3872	1.19
BKNO ₃	4044	0.79

The mass calculations were used to select materials for prototype testing. Based on these mass calculations, the first candidates selected for prototype testing were B/KNO₃, Ti/KClO₄, and B/BaCrO₄/KClO₄.

4.3 LASER WELD LOCATION ANALYSIS

The proposed design uses a laser bond weld to secure the formed bellows to the charge holder. This required a thermal analysis in order to assure a safe operation. A finite element analysis was compared to differential scanning calorimetry (DSC) to determine the sensitivity of this attachment method. The graphical output of these analyses are attached in Appendix B.

An endotherm was noted for the KNO₃ component at about 328°C. This was

close to the expected temperature to be induced by the laser welding operation. Although an exothermic reaction is not expected until 540C, the potential damage to the KNO_3 was not worth risking the laser welding operation. Instead, the decision was made to attach the bellows to the charge holder using 3M-2216 structural epoxy.

5.0 DESCRIPTION OF TEST PROGRAM

Each prototype test article resembles P/N 235669-1 in construction, configuration and materials. For each of the test articles the charge material, density, and weight may be varied for the purposes of optimizing the device. Each test uses a fiber optic linear array to track progress of the bellows stroke. The intent is to illuminate the test bed such that fiber optics provide optical amplifiers with enough light to produce a small voltage. As the bellows pass the fiber locations, a drop in potential will be measured to provide time of arrival information. Additional testing was to use foam blocks of known density and strength to assess output force and cleanliness.

5.1 INITIAL PROTOTYPE TESTS

In order to gain information regarding function of the bellows, larger prototypes were used for the initial test series. Larger diameter bellows were fabricated at EBCo and attached directly to fiber optic connectors modified to accept small pyrotechnic charges.

5.2 FINAL MATERIAL SELECTION

Fifteen fiber optic assemblies were bonded to charge holders P/N 235695-1. Three groups of five units each were used to select pyrotechnic material for this application. The original baseline materials were B/ KNO_3 , Ti/ KClO_4 , and Zr/ KClO_4 . The first group used B/ KNO_3 . The decision to use the last two groups was to be based on the success of the first. Because B/ KNO_3 worked as predicted, the final two groups were not loaded with the material alternates.

5.3 CHARGE SIZING

The baseline charge size is to be 6 mg. This is based on NASA Lewis calculations and early prototype testing. This test series used ten fiber optic charge holder assemblies to determine final charge size required. The intent is to reduce the charge size and demonstrate the failure point for bellows actuation.

5.4 SENSITIVITY OF B/KNO₃

The B/KNO₃ material ignites consistently using a 1W laser diode with a 10 ms pulse width. An interface sensitivity test was used to verify reliability. The results of this testing using 200 micron fiber are listed in Table 4. These results are listed based on the calibrated output from the laser diode and do not include line losses.

Table 4. Sensitivity of B/KNO₃

	Test Results
No. of Tests	10
Threshold (50% Level)	536 mW
Standard Deviation	56 mW
All-Fire Level (.999/95%)	909 mW

6.0 TEST RESULTS

6.1 INITIAL PROTOTYPE

Five large prototype units were fabricated with each material listed in Table 5. The B/KNO₃ units all functioned with a 1W laser diode ignition source. All of the units had bellows extension on the order of 0.050 - 0.080 inches. The Ti/KCLO₄ units did ignite with the laser diode, however, the bellows for each of these units burst as a result of overpressurization. The B/BaCrO₄/KCLO₄ loaded units did not ignite using a laser diode. The first two units were disassembled to inspect the surface of the pressing. A small darkened spot was evident on the surface of each of the two pressings indicating that they did receive the laser input but did not sustain a burning reaction. The remaining three units were functioned with a Nd:YAG source. These units did ignite but did not actuate the bellows.

Table 5. Results of Initial Prototype Testing

Pyrotechnic Material	Charge Mass (mg)	Ignition Source	Maximum Extension
B/KNO ₃	6	Laser Diode	0.08
Ti/KClO ₄	6	Laser Diode	Bellows Burst
B/BaCrO ₄ /KClO ₄	6	Nd:YAG	0

6.2 FINAL MATERIAL SELECTION

The results for B/KNO₃ are listed in Table 6. The measured time was between two fiber optics located at the base of the unactuated bellows and at a distance 0.060 inches into the stroke.

Table 6. Final Material Selection Results

Velocity Profile Function Data				
Serial Number	Pyrotechnic Material	Fiber Optic 1 Time (μ sec)	Fiber Optic 2 Time (μ sec)	Average Velocity (mm/ μ sec)
11	B/ KNO_3	0	800	0.0019
9	B/ KNO_3	0	812	0.0018
Foam Block Data				
Serial Number	Pyrotechnic Material	Foam Penetration (inches)	Debris Presence	Comment
4	B/ KNO_3	.035	Yes	Bellows Cracked
5	B/ KNO_3	.013	Yes	Bellows Cracked
6	B/ KNO_3	.026	Yes	Bellows Cracked

6.3 CHARGE SIZING

Efforts were made to reduce the charge mass to 3 mg and increase to 7 mg in order to assess mass relationship to bellows actuation. The 3 mg units failed to function the bellows. The charge cavity size prohibited increasing charge mass beyond 5 to 6 mg therefore the overloaded units were not completed.

6.4 FULL ASSEMBLY SENSITIVITY TESTING

The assembly of the device depended on reliable control of losses at the fiber level. The first measure of this sensitivity was to develop a process to limit the losses of the fiber to charge holder assembly to less than 1 dB. A summary of these measurements is listed in Table 7. The data sheets used to document these measurements are listed in Appendix C.

Table 7. Fiber Loss Measurements

	Test Results
Fibers As Polished	
No. of Fibers Measured	35
Average Loss (dB)	-0.408
Standard Deviation (dB)	-0.184
Fibers Losses After Assembly to Charge Holder	
No. of Fibers Measured	34
Average Loss (dB)	-0.437
Standard Deviation (dB)	-0.148

The assemblies were loaded and bonded with fiber assemblies less than 1dB loss. The process developed for this assembly yielded acceptable results.

The final assemblies were radiographically inspected to determine position and presence of all materials and parts. The radiographs revealed that the charge holder was not seated properly in seven units. In order to determine the potential fiber damage caused by this condition, these units were tested for threshold and compared to 10 units tested without the gap condition. Both test series were performed using a 10 ms pulsewidth applied to a 1W laser diode. Table 8 lists the test summary and the actual data is attached in Appendix D.

Table 8. Final Threshold Test Results

	Test Results
Improperly Seated Assemblies (N = 7)	
Threshold (50% Level)	395 mW
Standard Deviation	0 mW
All-Fire Level (.999 / 95%)	458.98 mW
Correctly Assembled Units (N = 10)	
Threshold (50% Level)	391 mW
Standard Deviation	12 mW
All-Fire Level (.999 / 95%)	638 mW

The improper seating did not impair the functional threshold of the full unit. This is evidenced by the similarity between the test series. The difference between the statistical all-fire levels can be attributed to sample size and the fact that no standard deviation was obtained for the improperly seated units. Any measurable difference should have shown as a function of threshold.

7.0 DISCUSSION

7.1 PROCESS DEVELOPMENT

The success of this miniature component depends highly on an integral charge holder / fiber optic subassembly. In order to offset losses expected in fiber optic interfaces, a smaller core fiber was chosen to increase the power density of the available optical energy. This allows for the fiber to be prepared prior to final assembly into the charge holder. Polishing would not be possible given the restricted space. The Ensign-Bickford Company developed a cleaving technique capable of limiting losses to less than 1dB at the final assembly level. These losses are acceptable for reliable ignition without polishing the fiber in the final assembly.

The charge for the test units was pressed directly onto the fiber to ensure intimate contact between the fiber and the B/KNO₃. A single failure to function was experienced during the development testing. The unit was not seated properly in the case as revealed by radiographic inspection. The threshold testing performed on like units did not reveal this as a cause for the failure. The unit could not be disassembled without either damaging the optical

interface or creating a hazardous condition. Therefore, further efforts to understand the failure were abandoned. The most likely cause lies in the fiber to charge interface.

The unit is designed such that the fiber protrudes a minimum of 0.010 inches into the charge. It is likely that this fiber was damaged during the pressing operation.

The development units were assembled using processes developed specifically for miniaturization. These early development units were then functionally tested to verify analysis and prototype work and to determine force and velocity output.

7.2 FORCE OUTPUT TESTING

The units are designed to function under axial load, therefore, it is desirable to test them in that mode. A crushable foam was selected to determine the approximate output force developed by each test unit. The bellows must develop at least 2.64 lbs to actuate. The goal for total nominal developed force is 4.02 lbs. A polyurethane foam was selected with a minimum compressive strength to require at least 2.0 lbs to crush in order to assess the total nominal force output.

Each of the test articles were bonded to the test block utilizing the existing mounting flange and two part epoxy. This bonding method successfully held each test unit during function. Three of the units extended approximately 0.060 inches into the foam block and the fourth did not actuate. The failed unit was inspected and revealed that the bellows had been inadvertently bonded in place during assembly. This unit burst under the developed pressure. This lesson learned resulted in careful inspection of the bellows area after final assembly. The area filled with epoxy cannot be readily viewed with the unaided eye. Future assembly will necessarily require magnification.

7.3 VELOCITY TESTING

To assess the overall impulse of the delivered force, a simple velocity measurement sensor was devised. Two donor fiber optics are aligned across a channel with acceptor fiber optics. Each donor / acceptor pair is placed at a known distance from the unextended bellows. Using white light as a source, the acceptor fiber picks up the light and is then connected to a photo-diode to produce a small voltage. Upon function of the unit, this optical path is broken resulting in a voltage drop across the photo-diode. This voltage is monitored using an oscilloscope to determine a time difference between the donor / acceptor pairs. This measurement scheme allows for determination of average bellows velocity without interrupting the function.

The results of this test technique ranged from excellent to no results at all. During function of the bellows motor into air, the test bellows for the first unit did not stay intact. This indicated that the unit probably is producing too much gas for function without axial load. The resultant velocity is not for the entire bellows for this test unit, but for the aluminum end free from the assembly. This first velocity was on the order of $0.1 \text{ mm}/\mu\text{sec}$ which is not believable. The second and third units functioned correctly and the velocities measured are as listed in Table 6. Several additional units were attempted with no results obtainable using this technique.

8.0 FURTHER DEVELOPMENT WORK

The ideal miniature bellows will function under load to produce the desired force and be able to function in air without expelling products of reaction. The feasibility of such a device has been demonstrated. The device developed produces very low velocity and approximately 4 lbs of linear force.

The formed bellows process must be refined for an further study. The drawing process developed yielded 10 units (65 delivered) without hairline cracks. These cracks were not visible to the unaided eye, but are readily inspectible using standard radiographic technique. The development units delivered to Los Alamos had no cracked bellows.

Attempts to seal the bellows were only partially successful. Using an RTV silicone bead around the interior circumference of the bellows reduced the soot present on the foam witness blocks dramatically. However, this technique did not eliminate it completely.

The fiber optic system of measurement has some merits. A better fixture would include a movable shutter to completely eliminate light leakage. Although the test were performed in the dark, several data points were lost due to stray light.

The foam block technique appears to be the best test to determine force and cleanliness. Polyurethane, isocyanurate, and many other foams provide different strength characteristics which could be specifically matched to force requirements. All of them act as adequate witness for clean actuation.

9.0 PUBLICATIONS RESULTING FROM THIS WORK

- 1) S.L. Renfro and T.M. Beckman; "Miniature Laser Ignited Bellows Motor"; presented to NASA Pyrotechnics Symposium; Sandia National Laboratory; February 8-9, 1994.

Appendix A

Nasa-Lewis Thermochemistry Code Output
(Contains 5 Pages)

BKNC

ASA Lewis - Chemical Equilibrium and Transport Properties of Complex Chemical S
y Sanford Gordon & Bonnie McBride
- Modified by: L. Caveny, Ft Washington, MD, 7 July 1989

Date=02/27/1993 Time=18:40:59.17

EACTANTS Lalipop Calculation - T/KP Date=02/27/1993 Time=18:40:59.17
1.0000 .0000 .0000 .0000 .0000 30.000000
1.0000 N 1.0000 0 3.0000 .0000 .0000 70.000000 - 117760.00 S

AMELISTS
Calden: T
INPT2
ASE =

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= 500.000000 3250.000000 0.000000E+00 0.000000E+00
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SIA = T
MHG = F
SQM = F
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HO = 500.000000 3250.000000 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
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0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
0.000000E+00 0.000000E+00 0.000000E+00 0.000000E+00
RATIO = F
F = F
PCT = F
A = F
IX = -1.000000 -1.000000 -1.000000 -1.000000
-1.000000 -1.000000 -1.000000 -1.000000
-1.000000 -1.000000 -1.000000 -1.000000
-1.000000 -1.000000 -1.000000 -1.000000
-1.000000 -1.000000 -1.000000 -1.000000
-1.000000 -1.000000 -1.000000 -1.000000
P = F
PP = F
PP = F
V = F
V = F
V = F
KT = F
HOCK = F
ETN = F
RACE = 0.0000000000000000E+000
O = 0.0000000000000000E+000
O = 0.000000E+00
ONS = F
DEBUG = 0
HI = F
IUNIT = T
NHG = F
RNSPT = T
RPACC = 9.999000000000000E-001
IF = F
ODATA = F
= 1.0000000000000000E+030
= 1.0000000000000000E+030

```

30/10/10/50

o INPT2 value given for OF, EQRTAT, FA, OR FPCT

pecies being considered in this system

J 3/79	B	J 6/66	BN
J 6/66	B2O	J12/64	B2O2
J12/67	KO	J12/61	K2
J 9/64	NO2	J12/64	NO3 RAD
J12/64	N2O5	J12/70	N3
J 3/79	B(S)	J 3/79	B(L)
J12/61	K(L)	J 6/71	KO2(S)

J 6/68	BO
J 6/71	B2O3
K11/77	K2O
J 3/77	N2
J 3/77	O
J 6/66	BN(S)
J 6/63	K2O(S)

J
J
J
J
J
J
J

pecies with transport properties
pure species

02	BO N2	B2 N2O	B2O3 N2O4
----	----------	-----------	--------------

f = 2.333333

enthalpy
kg-mol (deg k)/kg

effective fuel
h_{pp}(2)
.00000000E+00

effective oxidant
h_{pp}(1)
.58612889E+03

.4

g-form.wt./kg

b_{0p}(i,2)
.92506934E-01
.00000000E+00
.00000000E+00
.00000000E+00

b_{0p}(i,1)
.00000000E+00
.98908837E-02
.98908837E-02
.29672651E-01

.2
.6
.6
.2

oint itn	t	B2O
1	16	3429.25
dd B(L)		
1	5	4044.23

K
-17.958
-19.032

N2	BO
-27.443	-28.508
-27.968	-28.342

oint itn	t	B
2	6	4668.89

KBO2
-65.493

N2	BO
-26.556	-27.179

Thermodynamic equilibrium combustion properties

Pressures

title: Lalipop Calculation - T/KP Date=02/27/1993 Time=18:41:03.68

case no. 1

Chemical formula

fuel B 1.00000
oxidant K 1.00000 N 1.00000 O 3.00000

Mass
(see
1.
1.

O/F= 2.3333 Percent fuel= 30.0000 Equivalence ratio= 2.17

thermodynamic properties

, Mpa	3.4474	22.408	
, atm	34.023	221.15	
, deg K	4044.2	4668.9	
rho, kg/cu m	4.1224	26.1546	
number of species-	Gas: 25;	Condensed: 9	
Enthalpy of all species:			
, kJ/kg	3411.32	3411.32	
Enthalpy of gases only:		(lhc)	
, kJ/kg	2097.47	1642.52	
Enthalpy of condensed phase only:		(lhc)	
, kJ/kg	1313.85	1768.80	
, kJ/kg	1313.85	1768.80	
, kJ/kg	-28974.7	-32267.5	
, kJ/(kg) (K)	8.0079	7.6418	
, mol wt	40.209	45.310	
dlv/dlp)t	-1.24232	-1.26053	
dlv/dlt)p	3.5682	3.3643	
p, kJ/(kg) (K)	7.1987	5.5336	
gamma (s)	1.1408	1.1297	
son vel, m/sec	976.7	983.8	

transport properties (gases only)

Conductivity in units of milliwatts/(cm) (K)

visc, millipoise 1.1872 1.3191

with equilibrium reactions

p, kJ/(kg) (K)	3.5028	2.7610
conductivity	5.5020	4.9983
randtl number	.7558	.7287

with frozen reactions

p, kJ/(kg) (K)	1.2257	1.2468
conductivity	1.9819	2.2040
randtl number	.7342	.7462

mole fractions

	.01525	.01442
N	.00253	.00455
O	.34382	.27753
O2	.00095	.00225
2	.00010	.00019
2O	.01673	.01385
2O2	.05354	.04732
2O3	.00446	.00734
	.13640	.09591
BO2	.07093	.11731
O	.00002	.00012
2	.00048	.00127
O	.00010	.00026
2	.00003	.00013
	.10282	.10547
(L)	.00007	.00023
Total moles	.25179	.31185
Moles of gas	.03324	.03207
	.02487	.02207

mass fractions: line 1 for all products (lhc)
line 2 for gaseous products only

Additional products which were considered but whose mole fractions were less than

```
Note: weight fraction of fuel in total fuels and of oxidant in total oxidants
Date=02/27/1993      Time=18:41:04.12
```

```
1 Elapsed time, s      4.95
```

DATE=02/27/1993 TIME=18:41:04.12
NASA Lewis - Chemical Equilibrium and Transport Properties of Complex Chemical S
by Sanford Gordon & Bonnie McBride
- Modified by: L. Caveny, Ft Washington, MD, 7 July 1989

DATE=02/27/1993 TIME=18:41:04.12
Stopped after processing all input data.
DATE=02/27/1993 TIME=18:41:04.12

2 Elapsed time, s .00
End of CET85 ver 7Jul89/lhc
stop - Program terminated.

Appendix B

Thermal Analysis and DSC Results
(Contains 2 Pages)

ANSYS 5.0

Main Cnds

Reference

balh1Cmds ,CoordSys ,View ,Map ,NumColor ,View ,Scaling ,GraphCtl ,Annotate

Select *Command System FINISH

FN

The
Ensign-Bickford
Company

1A111011BW
TIME .002 SEC, 1200 DEG F AT WELD SURFACE

SEP 2, 1993
8:01:17
NODAL SOLUTION
TIME=.002
TEMP
SMN =70
SMX =1200
-100

Pick Legend for more

Date: Sep 07, 1993 5:47pm
Scanning Rate: 20.0 C/min
Sample Wt: 1.760 mg Path: C:\PE\
File 1: 932125 KCH

PERKIN-ELMER DSC7

Appendix C

Fiber Assembly Data Sheets
(Contains 7 Pages)

Fiber Data Sheet

Serial Number	Repolish (Y/N)	Connector End Comments	Cleaved Surface Defects	Defect Location	Losses (dB)
1	NO	Zero Defects	NO		- .2564
2	..	very slight chip at outer dia.	NO		- .4743
3	NO	Zero Defects	YES	slight raised outer edge	- .3238
4	NO		YES	" "	- .3218
5	..		NO		- .244
6	NO		YES	slight raised outer edge	- .1573
7	NO		NO		- .3532
8	NO	very slight chip at outer dia.	YES	Raised outer edge	- .3464
9	..		NO		- .3445
10	NO	Zero Defects	NO		- .3430
11	NO		NO		- .3598
12	NO	" "	YES	slight raised outer edge	- .3159
13	NO	" "	YES	" "	- .3458
14	NO	very slight chip at outer dia.	YES	" "	- .5442
15	NO	Zero Defects	YES	" "	- .2701
16	NO	" "	NO		- .4555
17	NO	" "	YES	slight raised outer edge	- .3548
18	NO	" "	NO		- .2590
19	NO	" "	NO		- .4373
20	NO	" "	NO		- .4585
21	NO	" "	YES	slight raised outer edge	- .6710
22	NO	very slight chip at outer dia.	YES	" "	- .3632

[illegible]

HP File Name ----- LALIPOP
 Diode Ser # ----- 148E
 Date of Test ----- 10 Feb 1994

Power In (W) Power Out (W) Transmittance (Db)

INFO. ONLY TRANSMISSION DATA FOR FIBER AFTER CHARGE HOLDER BONDING.

Serial Number : 1

.2954	.2756	-.3013
.2959	.2758	-.3055
.296	.2755	-.3117
AVE .2958	.2756	-.3062

Serial Number : 2

.2954	.2765	-.2872
.2959	.2766	-.2929
.296	.2768	-.2913
AVE .2958	.2766	-.2905

Serial Number : 3

.2954	.2729	-.3441
.2959	.2726	-.3562
.296	.2708	-.3864
AVE .2958	.2721	-.3622

Serial Number : 4

.2954	.2711	-.3728
.2959	.2709	-.3834
.296	.2716	-.3736
AVE .2958	.2712	-.3766

Serial Number : 5

.2954	.1489	-2.975
.2959	.1498	-2.956
.296	.1504	-2.94
AVE .2958	.1497	-2.957

Serial Number : 6

.2954	.2542	-.6523
.2959	.2543	-.658
.296	.2537	-.6697
AVE .2958	.2541	-.66

Serial Number : 7

.2954	.268	-.4228
.2959	.2683	-.4252
.296	.2683	-.4267
AVE .2958	.2682	-.4249

Serial Number : 8

.2954	.259	-.5711
.2959	.259	-.5785
.296	.2591	-.5782
AVE .2958	.259	-.5759

Serial Number : 9

	.2954	.2684	-.4163
	.2959	.2682	-.4269
	.296	.2682	-.4283
AVE	.2958	.2683	-.4238

Serial Number : 10

	.2954	.2811	-.2155
	.2959	.2877	-.1221
	.296	.2877	-.1235
AVE	.2958	.2855	-.1537

Serial Number : 11

	.2954	.2695	-.3985
	.2959	.2702	-.3946
	.296	.2701	-.3977
AVE	.2958	.2699	-.3969

Serial Number : 12

	.2954	.2642	-.4848
	.2959	.2648	-.4823
	.296	.2634	-.5068
AVE	.2958	.2641	-.4913

Serial Number : 13

	.2954	.2801	-.231
	.2959	.2809	-.2259
	.296	.2811	-.2243
AVE	.2958	.2807	-.2271

Serial Number : 14

	.2954	.2528	-.6763
	.2959	.2572	-.6087
	.296	.2563	-.6254
AVE	.2958	.2554	-.6368

Serial Number : 15

	.2954	.2723	-.3536
	.2959	.2685	-.422
	.296	.2676	-.4381
AVE	.2958	.2695	-.4046

Serial Number : 16

	.2954	.2697	-.3953
	.2959	.2699	-.3994
	.296	.2725	-.3593
AVE	.2958	.2707	-.3847

Serial Number : 17

	.2954	.2515	-.6987
	.2959	.2518	-.7009
	.296	.252	-.6989
AVE	.2958	.2518	-.6995

Serial Number : 18

	.2954	.2655	-.4635
	.2959	.2704	-.3914
	.296	.2712	-.38
AVE	.2958	.269	-.4116

Serial Number : 19

	.2954	.2737	-.3314
	.2959	.2748	-.3213
	.296	.2803	-.2367
AVE	.2958	.2763	-.2965

Serial Number : 20

	.2954	.2536	-.6626
	.2959	.2543	-.658
	.296	.2559	-.6322
AVE	.2958	.2546	-.6509

Serial Number : 21

	.2954	.2713	-.3696
	.2959	.2729	-.3514
	.296	.2733	-.3465
AVE	.2958	.2725	-.3558

Serial Number : 22

	.2954	.2662	-.452
	.2959	.2754	-.3118
	.296	.2683	-.4267
AVE	.2958	.27	-.3968

Serial Number : 23

	.2954	.2687	-.4114
	.2959	.2694	-.4075
	.296	.2698	-.4025
AVE	.2958	.2693	-.4071

Serial Number : 24

	.2954	.2643	-.4831
	.2959	.2639	-.4971
	.296	.2638	-.5002
AVE	.2958	.264	-.4935

Serial Number : 25

	.2954	.265	-.4716
	.2959	.2672	-.4431
	.296	.2672	-.4446
AVE	.2958	.2665	-.4531

Serial Number : 26

	.2954	.274	-.3266
	.2959	.2741	-.3324
	.296	.2742	-.3322
AVE	.2958	.2741	-.3304

Serial Number : 27

	.2954	.2798	-.2356
	.2959	.2811	-.2228
	.296	.2813	-.2212
AVE	.2958	.2807	-.2265

Serial Number : 28

	.2954	.2599	-.556
	.2959	.2601	-.56
	.296	.2515	-.7075
AVE	.2958	.2572	-.6078

Serial Number : 29

	.291	.2514	-.6353
	.2916	.2523	-.6287
	.2917	.2445	-.7666
AVE	.2914	.2494	-.6769

Serial Number : 31

	.291	.2696	-.3317
	.2916	.2713	-.3134
	.2917	.2723	-.2989
AVE	.2914	.2711	-.3147

Serial Number : 32

	.291	.2575	-.5312
	.2916	.2578	-.535
	.2917	.258	-.5332
AVE	.2914	.2578	-.5331

Serial Number : 33

	.291	.2653	-.4016
	.2916	.2656	-.4056
	.2917	.2654	-.4104
AVE	.2914	.2654	-.4059

Serial Number : 34

	.291	.246	-.7296
	.2916	.2464	-.7315
	.2917	.2461	-.7382
AVE	.2914	.2462	-.7331

Serial Number : 35

	.291	.2703	-.3205
	.2916	.2704	-.3278
	.2917	.2708	-.3229
AVE	.2914	.2705	-.3237

Summary

Serial Number : 1	Db Loss : -.3062
Serial Number : 2	Db Loss : -.2905
Serial Number : 3	Db Loss : -.3622
Serial Number : 4	Db Loss : -.3766

Serial Number : 5	Ob Loss : -2.957
Serial Number : 6	Ob Loss : -.66
Serial Number : 7	Ob Loss : -.4249
Serial Number : 8	Ob Loss : -.5759
Serial Number : 9	Ob Loss : -.4238
Serial Number : 10	Ob Loss : -.1937
Serial Number : 11	Ob Loss : -.3969
Serial Number : 12	Ob Loss : -.4913
Serial Number : 13	Ob Loss : -.2271
Serial Number : 14	Ob Loss : -.6368
Serial Number : 15	Ob Loss : -.4046
Serial Number : 16	Ob Loss : -.3847
Serial Number : 17	Ob Loss : -.6995
Serial Number : 18	Ob Loss : -.4116
Serial Number : 19	Ob Loss : -.2965
Serial Number : 20	Ob Loss : -.6509
Serial Number : 21	Ob Loss : -.3558
Serial Number : 22	Ob Loss : -.3968
Serial Number : 23	Ob Loss : -.4071
Serial Number : 24	Ob Loss : -.4935
Serial Number : 25	Ob Loss : -.4531
Serial Number : 26	Ob Loss : -.3304
Serial Number : 27	Ob Loss : -.2265
Serial Number : 28	Ob Loss : -.6078
Serial Number : 29	Ob Loss : -.6769
Serial Number : 31	Ob Loss : -.3147
Serial Number : 32	Ob Loss : -.5331
Serial Number : 33	Ob Loss : -.4059
Serial Number : 34	Ob Loss : -.7331
Serial Number : 35	Ob Loss : -.3237

Appendix D

Sensitivity Test Data
(Contains 4 Pages)

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 Cincinnati, Ohio 45241 / (513) 777-6672.

Please press RETURN to continue.

Enter name of data file lalip0p1 group B wk 44

uSig Sensitivity Test Analyzer Version 2.1A Serial Number 1057
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angle sensitivity test. Serial Number 1057.

muMin = 300, muMax = 500

Linear Normal Response Assumed. Units=mw

Analyzing file lalip0p1 Using Linear Normal Response.

Stimulus	Failures	Successes
351.,	1,	0
366.,	1,	0
380.,	1,	0
388.,	1,	1
390.,	0,	1
396.,	1,	0
408.,	0,	1
420.,	0,	1
448.,	0,	1

Number of stimulus values = 9, Number of tests = 10

Mu = 391.3 (mw)

Sigma = 11.6 (mw)

0.0010 Level = 355.6 (mw)

0.9990 Level = 427.0 (mw)

Estimated Lower Bound of Variance of Mu = 40.4 (mw^2)

Estimated Lower Bound of Variance of Sigma = 66.2 (mw^2)

Estimated CoVariance of Mu and Sigma = 5.78 (mw^2)

The log of the likelihood function = -3.575

The maximum possible individual confidence = 0.990

The maximum possible joint confidence = 0.965

Calculating confidence levels. Please be patient

0.500 Individual Confidence Interval = 0.203 Joint Confidence Region

Mu=(	386.9,	396.1)	Sigma=(	7.1,	19.6)
------	--------	--------	---------	------	-------

0.0010 level=(	330.5,	369.4)	0.9990 level=(	412.5,	453.2)
----------------	--------	--------	----------------	--------	--------

0.800 Individual Confidence Interval = 0.560 Joint Confidence Region

Mu=(	381.4,	402.5)	Sigma=(	4.8,	33.6)
------	--------	--------	---------	------	-------

0.0010 level=(	287.2,	376.6)	0.9990 level=(	405.0,	497.9)
----------------	--------	--------	----------------	--------	--------

J.900 Individual Confidence Interval = 0.742 Joint Confidence Region
Mu=(376.5, 408.4) Sigma=(3.9, 49.9)
0.0010 level=(236.7, 379.4) 0.9990 level=(402.1, 549.1)

J.950 Individual Confidence Interval = 0.854 Joint Confidence Region
Mu=(369.7, 416.0) Sigma=(3.4, 78.6)
0.0010 level=(147.9, 381.2) 0.9990 level=(400.3, 638.4)

J.990 Individual Confidence Interval = 0.964 Joint Confidence Region
Mu=(-BIG_NUMB,+BIG_NUMB) Sigma=(2.6,+BIG_NUMB)
0.0010 level=(-BIG_NUMB,+BIG_NUMB) 0.9990 level=(-BIG_NUMB,+BIG_NUMB)

P
bad command or file name

:\>musig

MuSig

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Serial Number 1057
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Cincinnati, Ohio 45241 / (513) 777-6672.

Please press RETURN to continue.

Enter name of data file lalgap

MuSig Sensitivity Test Analyzer Version 2.1A Serial Number 1057
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Angle sensitivity test. Serial Number 1057.
MuMin = 300, MuMax = 500
Linear Normal Response Assumed. Units=mW

Analyzing file lalgap Using Linear Normal Response.

Stimulus	Failures	Successes
348.,	1,	0
374.,	1,	0
377.,	1,	0
392.,	1,	0
397.,	0,	1
406.,	0,	1
437.,	0,	1

Number of stimulus values = 7, Number of tests = 7

Mu = 394.50 (mW)

Sigma = 0 (mW)

0.0010 Level = 394.50 (mW)

0.9990 Level = 394.50 (mW)

The log of the likelihood function = 0.000

The maximum possible individual confidence = 0.998

The maximum possible joint confidence = 0.992

Calculating confidence levels. Please be patient

0.500 Individual Confidence Interval = 0.203 Joint Confidence Region

Mu=(392.00, 397.00)

Sigma=(0, 2.03)

0.0010 level=(387.96, 397.00) 0.9990 level=(392.00, 401.03)

0.800 Individual Confidence Interval = 0.560 Joint Confidence Region

Mu=(391.65, 397.35)

Sigma=(0, 5.72)

0.0010 level=(376.15, 397.00) 0.9990 level=(392.00, 412.41)

0.900 Individual Confidence Interval = 0.742 Joint Confidence Region

Mu=(388.52, 399.60)

Sigma=(0, 11.73)

0.0010 level=(357.01, 397.00) 0.9990 level=(392.00, 431.20)

0.950 Individual Confidence Interval = 0.854 Joint Confidence Region

Mu=(385.02, 403.16)

Sigma=(0, 20.10)

0.0010 level=(332.13, 397.00) 0.9990 level=(392.00, 458.98)

0.990 Individual Confidence Interval = 0.964 Joint Confidence Region

Mu=(374.64, 421.06)

Sigma=(0, 61.96)

0.0010 level=(208.60, 397.00) 0.9990 level=(392.00, 596.35)

Appendix E

Miniature Laser Ignited Bellows Motor
presented to
NASA Pyrotechnics Symposium

(Contains 9 Pages)

MINIATURE LASER IGNITED BELLOWS MOTOR

Steven L. Renfro
The Ensign-Bickford Company
Simsbury, CT

Tom M. Beckman
The Ensign-Bickford Company
Simsbury, CT

Abstract

A miniature optically ignited actuation device has been demonstrated using a laser diode as an ignition source. This pyrotechnic driven motor provides between 4 and 6 lbs of linear force across a 0.090 inch diameter surface. The physical envelope of the device is 1/2 inch long and 1/8 inch diameter. This unique application of optical energy can be used as a mechanical link in optical arming systems or other applications where low shock actuation is desired and space is limited.

An analysis was performed to determine pyrotechnic materials suitable to actuate a bellows device constructed of aluminum or stainless steel. The aluminum bellows was chosen for further development and several candidate pyrotechnics were evaluated. The velocity profile and delivered force were quantified using an non-intrusive optical motion sensor.

Introduction

A small optical to mechanical link has been developed for uses where low velocity force is required. This device uses a small B/KNO₃ charge to actuate a miniature rolling bellows. This laser diode ignited system provides approximately 4 lbs of force over 0.1 inches of displacement. The device was designed to move a small barrier either into or out of the way to provide means for a miniature optical arming feature. The overall size of the device is less than 1/2 inches long and 1/8 inches in

diameter. A mounting feature allows simplified integration into new or existing systems.

Design Analysis

The challenges of this development program are to balance the gas output to desired force, ignite with a 1 Watt rated laser diode, and to downsize processes to manufacture such a small complex device.

The force is dictated by the material used for the bellows. This analysis assumes that in order to sufficiently move the bellows, plastic deformation must occur. This requires that the yield point of the selected material be exceeded without violating the ultimate strength. Following these guidelines, the pressure required for actuation can be calculated. The results are summarized in Table 1.

The burst pressure for hardened aluminum alloys is less than the pressure required for actuation. Annealed 302 Stainless Steel, Aluminum 1100-0, or Aluminum 3003-0 are suitable bellows candidate materials. Using this information, the resultant force developed by a fully actuated bellows can be calculated. The force results are listed in Table 2.

In order to produce the desired force,

several candidate pyrotechnic materials and stoichiometries were considered. Size restraints required that the selected pyrotechnic use the space allocated for the charge holder precisely. This analysis was crucial due to space restraints for the charge allocated given the overall size envelope.

The amount and type of pyrotechnic material was calculated based on the pressure required for actuation using the NASA-Lewis equilibrium thermochemistry code. The results of this analysis are normalized to Ti/KClO_4 and are listed in Table 3.

The mass calculations were used to select materials for prototype testing. Based on these mass calculations, the first candidates selected for prototype testing were B/KNO_3 , Ti/KClO_4 , and $\text{B/BaCrO}_4/\text{KClO}_4$.

Initial Prototype Testing

In order to gain information isolated to function of the bellows, larger prototypes were used for the initial test series. The results of the first two groups of five prototypes each are listed in Table 4.

The B/KNO_3 resulted in an acceptable charge weight for the desired extension. The other candidates did not perform successfully. The $\text{B/BaCrO}_4/\text{KClO}_4$ loaded devices would not ignite using the output from a 1 W laser diode. The Ti/KClO_4 loaded devices resulted in burst of the bellows. The burn rate of the Ti/KClO_4 did not provide the low velocity required for this application.

Sensitivity of B/KNO_3

The B/KNO_3 material ignites consistently

using full power 840 nm diode with a 10 ms pulse width. An interface sensitivity test was used to verify reliability. The results of this testing using 200 micron fiber are listed in Table 5. These results are listed based on the calibrated output from the diode and do not include line losses.

Process Development

The success of this miniature component depends highly on an integral charge holder / fiber optic subassembly. In order to offset losses expected in fiber optic interfaces, a smaller core fiber was chosen to increase the power density of the available optical energy. This allows for the fiber to be prepared prior to final assembly into the charge holder. Polishing would not be possible given the restricted space. The Ensign-Bickford Company developed a cleaving technique capable of limiting losses to less than 1dB at the final assembly level. These losses are acceptable for reliable ignition without polishing the fiber in the final assembly.

The charge for the test units was pressed directly onto the fiber to ensure intimate contact between the fiber and the B/KNO_3 .

The development units were assembled using processes developed for miniaturization. These early development units were then functionally tested to verify analysis and prototype work and to determine force and velocity output.

Force Output Testing

The units are designed to function under axial load, therefore, it is desirable to test them in that mode. A crushable foam

was selected to determine the approximate output force developed by each test unit. The bellows must develop at least 2.64 lbs to actuate. The goal for total nominal developed force is 4.02 lbs. A polyurethane foam was selected with a minimum compressive strength to require at least 2.0 lbs to crush in order to assess the total nominal force output. Figure 2 illustrates the test setup and Figure 3 illustrates the results of the four units tested using this method.

Each of the test articles were bonded to the test block utilizing the existing mounting flange and two part epoxy. This bonding method successfully held each test unit during function. Three of the units extended approximately 0.060 inches into the foam block and the fourth did not actuate. The failed unit was inspected and revealed that the bellows had been inadvertently bonded in place during assembly. This unit burst under the developed pressure. This lesson learned resulted in careful inspection of the bellows area after final assembly. The area filled with epoxy cannot be readily viewed with the unaided eye. Future assembly will necessarily require magnification.

Velocity Testing

To assess the overall impulse of the delivered force, a simple velocity measurement sensor was devised. This article is illustrated in Figure 2.

The velocity fixture is quite simple. Two donor fiber optics are aligned across a channel with acceptor fiber optics. Each donor / acceptor pair is placed at a known distance from the unextended bellows. Using white light as a source, the acceptor fiber picks up the light and

is then connected to a photo-diode to produce a small voltage. Upon function of the unit, this optical path is broken resulting in a voltage drop across the photo-diode. This voltage is monitored using an oscilloscope to determine a time difference between the donor / acceptor pairs. This measurement scheme allows for determination of average bellows velocity without interrupting the function.

The results of three of these test units are presented in Figure 4. During function of the bellows motor into air, the test bellows for the first unit did not stay intact. This indicated that the unit probably is producing too much gas for function without axial load. The resultant velocity is not for the entire bellows for this test unit, but for the aluminum end free from the assembly. The second and third units functioned correctly and the velocities measured are for the bellows.

Further Development Work

The Ensign-Bickford Company is continuing to develop this product under contract for Los Alamos National Laboratory. The ideal miniature bellows will function under load to produce the desired force and be able to function in air without expelling products of reaction. The final development phase is to concentrate on optimizing the charge size in order to meet these goals.

Discussion

The analysis and prototype phase contributed to development of the miniature bellows motor. More work needs to be done to refine the design. A pyrotechnic device to deliver a small amount of force is possible and has been demonstrated.

Table 1. Pressure Requirements for Bellows Actuation and Burst

Bellows Material	Alloy and Temper	Minimum Actuation Pressure (psi)	Burst Pressure (psi)
Aluminum	1100-0	389	577
Aluminum	1100-H12	1089	689
Aluminum	1100-H14	1555	977
Aluminum	3003-0	467	711
Stainless Steel	302, Annealed	2722	4000

Table 2. Force Developed for Various Bellows Materials

Bellows Material	Alloy and Temper	Actuation Force (lbs)	Target Force (lbs)
Aluminum	1100-0	2.64	4.02
Stainless Steel	302, Annealed	17.32	25.45

Table 3. NASA Lewis Calculation Results

Candidate Pyrotechnic Formulation	Calculated Flame Temperature (K)	Normalized Mass Required to Produce 500 psi
Ti/KClO ₄	5006	1.00
Ti/KClO ₄ + RDX	4155	0.63
RDX + C	3083	0.67
B/BaCrO ₄ /KClO ₄	3872	1.19
BKNO ₃	4044	0.79

Table 4. Results of Initial Prototype Testing

Pyrotechnic Material	Charge Mass (mg)	Ignition Source	Maximum Extension
BKNO ₃	6	Laser Diode	0.08
Ti/KClO ₄	6	Laser Diode	Bellows Burst
B/BaCrO ₄ /KClO ₄	6	Nd:YAG	0

Table 5. Ignition Threshold Test Results Using 840 nm Diode

	Test Results
No. of Tests	10
Threshold (50% Level)	536 mW
Standard Deviation	56 mW
All-Fire Level (.999/95%)	909 mW

Figure 1 Miniature Laser Ignited Bellows

Figure 2 Force and Velocity Test Setup

Figure 3 Force Output Test Results

Figure 4 Results of Velocity Tests

Appendix F

Test Plan for Proof of Principle Program for
Laser Ignited Pyrotechnic Ordnance Product
Document No. 49NA-01-93

(Contains 23 Pages)

**Test Plan for Proof of Principle Program for
Laser Ignited Pyrotechnic Ordnance Product**

**Document No.
49NA-01-93**

Developed For:

**Los Alamos National Laboratory
Group M-7
P.O. Box 1663
Los Alamos, New Mexico 87544**

Prepared By:

TITLE TEST PLAN FOR PROOF OF PRINCIPLE PROGRAM FOR LASER IGNITED PYROTECHNIC ORDNANCE PRODUCT		PROCEDURE NO. 49NA-01-93, Rev -	
		ISSUE DATE 18 NOV 1993	
MODEL N/A	FUNCTIONAL CATEGORY LASER BELLOWS		SUB CATEGORY PYRO
SPECIMEN ID N/A	EST START DATE 18 APR 1993	REVISION LETTER	DATE
LOCATION EBCo/IR&D	EST COMP DATE 31 DEC 1993	-	11/18/93
APPLICABLE DOCUMENTS		NUMBER	REVISIO
2) CALIBRATION SYSTEMS REQUIREMENTS		MIL-STD-45662	A
4) EBAC GENERAL SAFETY PROCEDURES		PS 0038/11	H
5) ETL GENERAL OPERATING PROCEDURES		GTP 0014	N/C
APPLICABLE INTERFACE WITH OTHER TESTS			
1) EXPLOSIVE TEST LABORATORY TESTING PROCEDURES - VOD		GTP 0001	B
TEST CONTACT			
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Test Plan for Proof of Principle Program for
Laser Ignited Pyrotechnic Ordnance Product

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1.0 SCOPE

The purpose of this program is to select the pyrotechnic material and develop manufacturing techniques for the laser ignited miniature bellows. The intent of this program is to demonstrate this new technology and to ultimately manufacture deliverable prototypes. As part of this effort, an optical switching technique will be developed to roughly determine the velocity profile of the bellows when fired in the unrestrained state.

2.0 SAFETY

The item to be tested contains pyrotechnic materials. These materials are sensitive to heat, friction, impact and electro-static discharge. Bulk quantities of pyrotechnic, or subassemblies and test articles containing pyrotechnic must be handled with care and in accordance with the standard procedures for handling such materials.

Lasers will be used for initiation of the test articles. These devices use firing units charged to high voltage and discharge cohesive collimated light. Proper interlock protection for Nd:YAG laser and safety procedures shall be used throughout this program. Only Ensign Bickford personnel trained in the use of laser systems or laser firing unit are allowed to handle and use the electronics, lasers, and test units.

All testing will be accomplished in accordance with EBAC General Safety Procedures (PS 0038/11).

3.0 DESCRIPTION OF TEST ARTICLE

Each test article will resemble P/N 235669-1 in construction, configuration and materials. For each of the test articles the charge material, density, and weight may be varied for the purposes of optimizing the device. Each test will use a fiber optic linear array to track progress of the bellows stroke. The intent is to illuminate the test bed such that fiber optics provide optical amplifiers with enough light to produce a small voltage. As the bellows pass the fiber locations, a drop in potential will be measured to provide time of arrival information. For this test series, a total of 35 fiber optic assemblies may be prepared in order to obtain 15 data points required for the program.

3.1 FINAL MATERIAL SELECTION

Fifteen fiber optic assemblies are to be bonded to charge holders P/N 235695-1. Three groups of five units each will be used to select pyrotechnic material

for this application. The baseline materials are B/KNO₃, Ti/KClO₄, and Zr/KClO₄. The first group will use B/KNO₃ and the last two groups will be based on the success of the first. If B/KNO₃ works as predicted, the final two groups will be used to determine density of charge required for reliable output.

3.1 CHARGE SIZING

The baseline charge size is to be 6 mg. This is based on NASA Lewis calculations and early prototype testing. This test series will use ten fiber optic charge holder assemblies to determine final charge size required. The intent is to reduce the charge size and demonstrate the failure point for bellows actuation.

4.0 TEST ARTICLE ASSEMBLY

All of the fiber optic assemblies will be bonded to the charge holders as required for this work. A total of 30 fiber charge holder assemblies shall be bonded in preparation for the test article assembly.

4.1 GENERAL TEST ARTICLE ASSEMBLY

- 4.1.1 Obtain EBOC-HCS fiber with approximately 125 μ m core. Stock material is acceptable for this use.
- 4.1.2 Cut at least 30 lengths to approximately 1 meter.
- 4.1.3 Install SMA 905 connector on one end of each length. Assign serial number to each assembly.
- 4.1.4 Polish connector end of fibers. Use deionized water / woolite solution to wet polishing wheel. Inspect polished surface of each fiber under magnification and repolish if any defects present. Record any repolished fibers by serial number in Appendix A.
- 4.1.5 Remove cladding from remaining end of fiber and cleave using scoring fixture. Inspect cleaved end of fiber under magnification. Any surface defects in excess of 5 micron shall be noted on data sheet in Appendix A.
- 4.1.6 Measure and record fiber losses by serial number on data sheet in Appendix A.

- 4.1.7 Obtain QC accepted Charge Housing (P/N 235695-1) and Motor Case (P/N 235694-1)
- 4.1.8 Install Motor Case (P/N 235694-1) into fiber with the flanged side towards the cleaved end. Insert cleaved end of fiber into Charge Housing (P/N 235695-1) until fiber protrudes into charge cavity. At this point, the Motor Case may be secured with white tape away from the working area such that it does not interfere with subsequent operations.
- 4.1.9 Mix EPO-TEC-353 epoxy in accordance with manufacturers instructions.
- 4.1.10 Fill small syringe with epoxy from 4.1.9.
- 4.1.11 Backfill each fiber cavity in the charge housing until epoxy is present as a fillet around the fiber in the charge cavity.
- 4.1.12 Carefully pull the fiber from the charge cavity until approximately 0.010 inches above flush with respect to the bottom surface of the charge cavity. Epoxy on the cleaved surface of the fiber is not allowed.
- 4.1.13 Secure fiber and housing and allow to cure for 16 hours minimum.
- 4.1.14 Measure fiber losses of each assembly and record in Appendix B.
- 4.1.15 Mix EPO-TEC-353 epoxy in accordance with manufacturers instructions.
- 4.1.16 Fill small syringe with epoxy from 4.1.15.
- 4.1.17 Backfill each assembly as necessary with epoxy and allow to cure for 16 hours minimum.
- 4.1.18 Carefully remove excess epoxy until charge housing easily seats into motor case. Do not pull fiber to test fit the assembly.

4.2 FINAL MATERIAL SELECTION

- 4.2.1 Obtain QC accepted BKNO_3 . Submit moisture and volatile sample to EBAS. Maximum moisture and volatile content not to exceed 0.2%.
- 4.2.2 Weigh the first five assemblies from 4.1.18 and record in Appendix B.
- 4.2.3 For each of the five assemblies, weigh 8 mg samples of BKNO_3 and load into charge cavity using miniature funnel and 0.060 inch diameter press

pin. The loading pressure shall be approximately 16,000 psi as calculated on the 0.060 inch diameter press pin.

- 4.2.4 Record loaded weight of each of the five assemblies from paragraph 4.2.2.
- 4.2.5 Obtain QC accepted Piston (P/N 235696-1) and Bellows (P/N 235698-1)
- 4.2.6 Insert each piston into bellows.
- 4.2.7 Mix 3M-2216 in accordance with manufacturers instructions.
- 4.2.8 Apply adhesive from 4.2.7 around circumference of loaded charge housing. The bead width should be approximately 0.010 inches wide and located as close to the charge end as possible.
- 4.2.9 Slide bellows assembly from 4.2.5 onto charge housing until bellows seats on locating flange.
- 4.2.10 Wipe excess epoxy from surface of assembly. Allow assembly to cure for 16 hours minimum.
- 4.2.11 Mix 3M-2216 in accordance with manufacturers instructions.
- 4.2.12 Apply adhesive from 4.2.11 around circumference of assembly from 4.2.20. Two beads should be used, one around the fiber end with the second around the seam of the bellows. This will insure complete bonding between the housing, bellows, and motor case.
- 4.2.13 Slide the housing assembly into the motor case until seated. Do not pull on the fiber to seat the assembly. Allow to cure for 16 hours minimum.
- 4.2.14 Mix 3M-2216 in accordance with manufacturers instructions.
- 4.2.15 Backfill the cavity in the motor case as necessary with 3M-2216. Allow the assembly to cure 16 hours minimum.
- 4.2.16 The remaining 10 units will be manufactured per 4.2.1 through 4.2.15 pending the results of function testing.

4.3 CHARGE SIZING

- 4.3.1 The units for charge sizing will be assembled per 4.2.1 through 4.2.15

pending the results of function testing. The variables will be charge mass and density. The actual values shall be recorded in Appendix C.

5.0 DATA REQUIREMENTS

Each experimental group consists of five units. Of these units, three will be used for velocity profiling with the remaining two units to be fired into styrofoam witness blocks to assess actuation force and cleanliness.

5.1 VELOCITY PROFILE

- 5.1.1 Secure test article to base such that bellows end is illuminated by light source. The light source must be approximately perpendicular to the direction of bellows travel and directly in the line of sight of the fiber optic array.
- 5.1.2 Align first fiber optic such that edge of fiber face is as close as possible to the end of the bellows.
- 5.1.3 Align the second fiber optic, parallel to the first, at 0.060 inches from the center of the first. Record the actual distances from the end of the bellows to the first fiber and between fibers in Appendix D data sheet.
- 5.1.4 Verify that optical amplifiers produce positive response by turning off light source with oscilloscope sampling. The trigger source should be function of the laser diode with at backsamples of approximately 50 μ sec. The fibers should be sampled as channels 1 and 2 with a total function window of approximately 20 msec.
- 5.1.5 Turn On Light Source and connect SMA 905 connector to laser firing unit.
- 5.1.6 Adjust power to maximum output and reset oscilloscope.
- 5.1.7 Function test unit and record function time and bellows velocity data in Appendix D.
- 5.1.8 Each velocity test unit shall be functioned per 5.1.1 through 5.1.7.

5.2 FOAM BLOCK TEST

- 5.2.1 This test will be used to determine force and assess debris present during each test. Two units from each group of five will be tested

against a soft foam target approximately 0.1 inches thick.

- 5.2.2 Secure test article such that bellows end is against 0.1 inch thick styrofoam target.
- 5.2.3 Connect SMA 905 connector to laser firing unit.
- 5.2.4 Adjust power output to maximum.
- 5.2.5 Function test unit and record results in Appendix E.
- 5.2.6 Each foam block test unit shall be functioned per 5.2.1 through 5.2.5.

Appendix A

Fiber Data Sheets
(Contains 2 Pages)

Fiber Data Sheet

Serial Number	Repolish (Y/N)	Connector End Comments	Cleaved Surface Defects	Defect Location	Losses (dB)
1	NO	Zero Defects	NO		-.2564
2	NO	very slight chip at outer Dia.	NO		-.4743
3	NO	Zero Defects	YES	slight raised outer edge	-.3238
4	NO	" "	YES	" "	-.3218
5	NO	" "	NO		-.2244
6	NO	" "	YES	slight raised outer edge	-.4573
7	NO	" "	NO		-.3832
8	NO	very slight chip at outer Dia.	YES	Raised outer edge	-.3464
9	NO	" "	NO		-.3445
10	NO	Zero Defects	NO		-.3430
11	NO	" "	NO		-.3598
12	NO	" "	YES	slight raised outer edge	-.3159
13	NO	" "	YES	" "	-.3488
14	NO	very slight chip at outer Dia.	YES	" "	-.5446
15	NO	Zero Defects	YES	" "	-.2701
16	NO	" "	NO		-.4555
17	NO	" "	YES	slight raised outer edge	-.3548
18	NO	" "	NO		-.2890
19	NO	" "	NO		-.4373
20	NO	" "	NO		-.4585
21	NO	" "	YES	slight raised outer edge	-.6710
22	NO	very slight chip at outer Dia.	YES	" "	-.3632

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Appendix B

Loaded Assembly Data Sheets
(Contains 2 Pages)

[illegible]

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Appendix C

Charge Sizing Data Sheets
(Contains 1 Page)

Charge Sizing Data Sheets

Serial Number	Charge Material	Charge Mass	Loading Pressure

Appendix D

Velocity Profile Test Data
(Contains 1 Sheet)

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Back side

Appendix E

Foam Block Test Data
(Contains 1 Sheet)

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