KEYWORDS: laser ranging, metrology

ABSTRACT:
In spite of apparent simplicity of work concept testing medium/long range laser range finders is a difficult task both during field tests and laboratory tests. A short review of methods used to test LRFs is presented in this paper. Two test stations that enable expanded testing of LRFs are presented two.

1 INTRODUCTION

Laser range finders (LRFs) are one of most important and commonly used types of optronic systems in both military, paramilitary and civilian applications. Testing LRFs look apparently very simple. Just to shoot and check at which conditions the tested LRF generates proper distance indication. Practically situation is much more complicated.

Testing is a relatively easy task only in case of short range (range below say 1 km) LRFs used in recreational applications like golf, hunting etc. Final users of such LRFs with basic technical know-how can easily carry out accurate performance tests by shooting to a series of real targets at field conditions [1-2]. Situation becomes much more difficult in case of medium/long range (distance from about 2 km to 40 km) LRFs used in military/paramilitary application due to two reasons.

First, results of field tests of medium/long range LRFs depend on atmospheric conditions and this dependency significantly reduces repeatability and accuracy of necessary field tests.

Second, field tests of medium/long range LRFs done by shooting to real military targets are costly, time consuming and often difficult to carry out due to a set of logistical problems.

Due to these two reasons final evaluation of military type LRFs is rarely done by shooting to real targets at field conditions. At the same time situation on market is rather chaotic. Some manufactures of LRFs present in catalogues value of maximal range calculated for perfect atmosphere, and some even present maximal range as a maximal distance that can be detected by receiver electronics in case of hypothetical strong pulse. Only a small group of manufacturers of LRFs present in catalogues measurement data that enables relatively precision performance evaluation of these LRFs.

It may be surprising to readers to learn that in spite of importance of LRFs for modern armed forces testing and evaluation of these devices has received small attention. It is difficult to find even a dozen of scientific papers devoted to this subject that were published during last decade [3-8]. There are no standards that regulate testing military LRFs. There are no books devoted to testing LRFs. Situation with testing LRFs is in sharp contrast to situation with testing thermal imagers where there are military standards, a long series of scientific papers and educational books. There are several manufacturers of commercial test systems [9-11]. However, in absence of international standards these manufacturers propose different solutions for testing LRFs.

This paper present a review of present metrology of laser ranging. The paper present also new test stations that could potentially significantly improve situation in this metrology.

2 METHODS OF TESTING LRFs

Final users of military type LRFs are mostly interested to know this set of parameters:
1. maximal operational range,
2. minimal discrimination distance (minimal distance at which two targets can be discriminated),
3. measurement accuracy,
4. angular size of laser beam (related to minimal angular size of target of interest),
5. boresight errors (how accurately target of interest can be shoot).

All these parameters are directly or indirectly related to operational performance of LRFs but the first one is considered as the most important.

Methods of testing LRFs can be divided into two main groups: A)Field tests, B)Laboratory tests.
long distances,
2. Shooting LRFs to artificial targets located at short distance via a medium of regulated attenuation.

Field tests of LRFs using method 1 are rarely done due to significant drawbacks of this method (high result variability due dependency of test results on variable atmospheric conditions, and high cost of field tests with real targets). Method no 2 is much more popular.

In detail method no 2 proposes to measure at field conditions a single parameter called extinction ratio (ER). Measurement of this parameter is typically done by shooting the LRF into direction of a small reference target placed at some relativeley short distance, attenuating radiation emitted/received by tested LRF, and checking at what attenuation level the LRF stops giving proper distance indications. In this way Extinction Ratio can be understood as a maximal attenuation (in dB) when tested LRF is still capable to work properly. The distance between the tested LRF and test target is typically in range from 0.5 km to 1.2 km. The rule is that the distance should be long enough to assure that time dependent gain in receiver electronic is at maximal level. There is not standard that regulate measurement of ER of LRFs. Different manufactures do tests at different distances and using targets of different reflectance.

There is a direct relationship between ER and maximal operational range of tested LRF. Therefore measurement of ER can be potentially considered as final performance tests of military type LRFs. Apparently drawbacks of method no 2 are the same as drawbacks of method no 1: field measurements of ER are costly, time consuming and sometimes variable due to unpredictable behavior of atmosphere. However, drawback of method 2 are the same as of method no 1 but at much lower level.

Costs of field tests using method 2 are several times lower than costs of similar tests using method no 1. Repeatability and accuracy of ER measurement using method no 2 are several times better than repeatability and accuracy of measurement of maximal operational range using method no 1.

Due to direct relationship with maximal operational range ER is considered as the best parameter to evaluate performance of military type LRFs in specialist literature [11-13]. Next, ER parameter is typically presented in catalogs of high-end LRFs [15-18].

Ideal laboratory tests should deliver the same information about performance of tested LRFs as provided by field tests but during tests at convenient laboratory conditions. The laboratory tests can be divided into two main groups:
1. Measurement of design parameters.

The first method based on a concept of measurement at laboratory conditions a series of parameters like pulse energy (or pulse power), pulse time width, pulse repetition frequency, beam divergence, receiver sensitivity. These parameters are later used for indirect determination of performance capabilities of tested LRF.

The second method is based on idea of direct measurement of performance parameters like ER, distance discrimination, accuracy, boresight errors at laboratory conditions.

Majority of commercial test stations use exclusively method 1 [9,10] but test stations based on method 2 are under development [13,14]. This paper present results of project to develop test stations capable to use both methods of laboratory testing [19]. Two test stations (coded as LTF and LTE) are presented:
- LTF station – to enable performance tests of LRFs at laboratory conditions,
- LTE station – to deliver support for ED project.

3 STATION FOR PERFORMANCE TESTS

LTF station is a compact, mobile test station based on a concept of a test station that would imitate in laboratory/depot conditions measurement of extinction ration ER of tested laser range finders without necessity of time consuming, costly field tests.

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The LTF station is built from two main blocks: LTE main block and PC with software. The LTE main block is built from an external attenuator module, receiver objective, receiver target, receiver integrator, receiver attenuator, fiber optics, transmitter attenuator, transmitter integrator, transmitter target and transmitter objective. When transmitter of tested LRF emits optical pulse the receiver objective focuses incoming laser radiation at plane of the receiver target plate. The latter module simulates the small reflector target used during ER measurement – only radiation that hits the target can be transmitted. Next, the receiver integrator converts incoming directional radiation into diffuse radiation that is latter attenuated using receiver attenuator module. After this the fiber optics (fixed distance about 1.2 km) transmits incoming radiation with some temporal delay. At the end of fiber channel is located transmitter attenuator that reduces again power of laser pulse. Next, the transmitter integrator improves conversion of incoming directional radiation into diffuse radiation. Finally, the transmitter optics emits collimated beam into direction of receiver of the tested LRF. Divergence angle of emitted beam is by size of transmitter target.

Both targets (receiver target, transmitter target) emit visible light. Therefore it is easy to test team to align tested LRF with optical axis of LTE test station if tested LRF is equipped with optical viewer or cooperate with a TV camera.

It should be also noted that LTE station use symmetrical design. Therefore the convention transmitter/receiver is only for clarification of method of work presented earlier. In fact both channels of LTE can work as receiver channel or transmitter channel depending on design of tested LRF. Measurement of ER is the main task of LTE station. However, the station can simulate several targets located at different distance and enable measurement of distance discrimination.

Tab. 1 Parameters of LTE test station

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral range</td>
<td>700-1700nm</td>
</tr>
<tr>
<td>Calibrated wavelengths</td>
<td>Typical: 1060nm, 1550 band (1540, 1550, 15570), 910 nm</td>
</tr>
<tr>
<td>Number of simulated targets</td>
<td>One (option up to three)</td>
</tr>
<tr>
<td>Simulated target distance</td>
<td>About 1200 m</td>
</tr>
<tr>
<td>Simulated attenuation range</td>
<td>At least 40dB</td>
</tr>
<tr>
<td>Attenuation regulation method</td>
<td>Motorized, PC control</td>
</tr>
<tr>
<td>Max target size</td>
<td>4 mrad</td>
</tr>
<tr>
<td>Minimal target size</td>
<td>0.25 mrad</td>
</tr>
<tr>
<td>Regulation of target size</td>
<td>Step regulation, five values</td>
</tr>
<tr>
<td>Control of target size</td>
<td>Motorized, PC control</td>
</tr>
<tr>
<td>Ability to simulate</td>
<td>Yes, simulation of non parallel</td>
</tr>
</tbody>
</table>

As can be seen from the description presented earlier LTE test station is based on a simple concept of fiber optics loop to create temporal delay of transmitted laser beam and simulate a target at desired distance. This concept has been known for decades. However the crux of LTE station is not the fiber optics loop but a set of calibrated attenuators. Measurement of ER of all types of LRFs (monopulse/multipulse, short range/long range) requires calibrated attenuators capable to offer precision regulation of transmitted optical power with at least 10 000 times dynamic. This value does not sound specially impressive if we compare to other optical attenuators but we could keep in mind that attenuators used in LTE station must also withstand optical pulses of peak power over 10 MW.

In detail LTE station use a set of 4 calibrated attenuators. The first two are external attenuators made from glass windows of limited transmittance. The third one is a set of electrically controlled optical plates of variable transmittance (step regulation of attenuation). The fourth is an optical pipe of regulated length and transmittance (continuous regulation of attenuation). All these attenuators combined together offer desired attenuation.

4 STATION FOR DESIGN SUPPORT

LTE test station enables to use both main methods of testing LTFs: a) measurement of a series design parameters (pulse energy, pulse peak power, pulse time width, pulse frequency, beam divergence, receiver sensitivity, accuracy of distance measurement, distance discrimination, and boresight errors), b) measurement of Extinction Ratio.

Such unique ultra wide test capabilities have been achieved by using dual design of LTE test station. The station can work in two modes. Electronic simulation mode and fiber optics simulation mode. In the first mode advanced electronic modules are used to measure parameters of pulses emitted by transmitter of tested LRF and to generate optical
pulses into direction of receiver of tested LRF. In the second mode simulation of reflected pulses is achieved using fiber optics circuit coupled with high-tech calibrated attenuators.

LTE test station working in fiber optics mode is practically earlier presented LTF station and only electronic mode will be discussed.

The LRF is located in position to have situation when optics of LTE station overlaps optics of tested LRF. The transmitter of LRF emits a single pulse (or a series of optical pulses). The transmitter objective of the LTE station focuses incoming laser radiation at plane of the transmitter target slider that regulates active size of optical integrator. The latter module uniformly integrates incoming radiation and passes it to attenuator module. After passing the attenuator the radiation reached optical detector module. The latter module converts incoming optical pulse into electronic pulse that is sent both to signal analyzer module and to pulse generator module. The signal analyzer module records temporal profile of incoming pulse and send such data to PC. Pulse generator module generates with some temporal delay electrical pulse that is sent to pulse light source. The latter module emits optical pulse that after suitable attenuation, spatial integration is emitted into direction of receiver of tested LRF.

LTE station offer advantages of both two methods of testing LRFs:

1. **Electronic simulation**: measurement of parameters of pulses emitted laser transmitters, simulation of multiply targets at variable distance with variable pulse amplitude.
2. **Reliability of fiber optics simulation** (temporal and spectral profiles of pulses coming to receiver match exactly profiles of pulses emitted by transmitter).

3. Some of test results obtained using electronic simulation can be verified by tests using fiber optics simulation.

4. **Ultra expanded test range**:
   - **Electronic mode**: pulse energy, pulse peak power, pulse time width, pulse repetition frequency, missing pulse, pulse coding, distance measurement accuracy (test for both single target or multiply targets), distance discrimination, relative receiver sensitivity
   - **Fiber mode**: extinction ratio ER, distance measurement accuracy (single distance).

5. **Ability to test both monopulse LRFs and multipulse LRFs**
6. **LRFs working at all typical wavelengths can be tested**: 905/910 nm, 990 nm, 1060 nm, 1540 nm, 1550 nm, 1570 nm.
7. **Ability to simulate targets of different angular size** (from 0.25 mrad to 4 mrad).
8. **Fully computerized test system**. Distance target-LRF, target size, system attenuation can be controlled from PC. The incoming pulses and digitally recorded and analysed.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of tested LRFs</td>
<td>Both mono-pulse LRF and multi-pulse LRFs</td>
</tr>
<tr>
<td>Spectral wavelength</td>
<td>Optimized for testing LRFs of two separate channels but coaxial LRFs can be tested</td>
</tr>
<tr>
<td>Diameter of optics in</td>
<td>905/910 nm, 990 nm, 1060 nm, 1540 nm,</td>
</tr>
<tr>
<td>two optical channels of LTE test station</td>
<td>1550 nm, 1570 nm, 60 mm</td>
</tr>
<tr>
<td>Mode of work</td>
<td>two manually switch modes:</td>
</tr>
<tr>
<td></td>
<td>electronic simulation and fiber optics simulation</td>
</tr>
<tr>
<td>List of measured parameters</td>
<td>pulse energy, pulse peak power, pulse time width, pulse repetition frequency, missing pulses, pulse coding, distance measurement accuracy (test for both single target or multiply targets), distance discrimination, relative receiver sensitivity</td>
</tr>
<tr>
<td>Optical detector type</td>
<td>ultrafast, calibrated InGaAs photodiode (Si photodiode can be optionally delivered for tests of 905/910 nm LRFs)</td>
</tr>
<tr>
<td>Pulse energy range</td>
<td>10 nJ to 200 mJ</td>
</tr>
<tr>
<td>Peak pulse power</td>
<td>1 W to 10 MW</td>
</tr>
<tr>
<td>Pulse width</td>
<td>4-600 ns</td>
</tr>
<tr>
<td>Resolution of pulse</td>
<td>2 ns (option 1 ns)</td>
</tr>
</tbody>
</table>
Software, PC
with night vision sight
Ability  to  test  LRF
laser transmitter
receiver  with  the
Aligning  of  the  laser
sight/TV  camera
internal  optical
transmitter  with
aligning  of  the  laser
measurement
Divergence  angle
Both  modes
discrimination
Distance
calculations
Conditions  for  range
sensitivity  range
Absolute  receiver
Conditions  for  range
calculation
Distance
discrimination
Divergence  angle
measurement
Measurement  of  aligning  of  the  laser
transmitter  with  internal  optical
sight/TV  camera
Aligning  of  the  laser
receiver  with  the
laser  transmitter
Ability  to  test  LRF
with  night  vision  sight
PC
Software

PC  communication
USB 2.0
Working  +5°C  to  35°C
temperature
Storage  -5°C  to  50°C
temperature
Humidity
up  to  95%  (non  condensing)
Dimensions
1360x  33.50x230  (main  module)
plus  typical  PC  dimensions
Mass
52 kg

5  ADVANTAGES  OF  DEVELOPED  TEST  STATIONS

Some  important  parameters  of  laser  range  finders  can  be  accurately  measured  using  simple  measuring  instruments:  pulse  energy  using  optical  energy  meters,  or  pulse  width  using  high  speed  oscilloscopes.  These  measuring  tools  are  rather  low  cost.  Having  a  set  of  optical  energy  meter  and  a  high  speed  oscilloscope  at  price  level  about  3 000  Eur  we  can  measure  accurately  pulse  energy  and  pulse  width  of  all  laser  range  finders  present  on  the  market.  However  knowledge  about  pulse  energy  and  pulse  width  is  not  enough  to  evaluate  performance  of  laser  range  finders  at  real  conditions.  The  users  of  laser  range  finders  are  not  specially  interested  in  what  are  values  of  pulse  energy  and  pulse  width  but  what  is  measurement  range  and  accuracy  of  their  laser  range  finders  at  real  life  conditions.  We  must  keep  in  mind  that  performance  of  LRF  characterized  by  the  same  pulse  energy  can  differ  a  lot.  Therefore  measurement  of  Extinction  Ration  (and  optionally  Distance  Discrimination)  is  needed  for  final  quality  evaluation.

At  the  same  time  a  long  set  of  parameters  like  pulse  energy,  pulse  peak  power,  pulse  time  width,  pulse  repetition  frequency,  missing  pulses,  pulse  coding,  distance  measurement  accuracy  (test  for  both  single  target  or  multiply  targets),  distance  discrimination,  receiver  sensitivity  are  needed  to  enable  design  optimisation  during  R&D  projects.  Other  desired  features  on  ideal  stations  can  be  listed  as:  simulation  of  targets  of  different  angular  sizes,  simulation  of  multiply  targets,  checking  angular  divergence  of  the  emitted  beam,  checking  aligning  of  the  laser  emitter  with  reference  optical  axis,  checking  aligning  of  the  laser  receiver  with  the  laser  transmitter.
The earlier discussed LTF and LTE test stations fulfill all these requirements on ideal stations for testing LRFs.

6 CONCLUSIONS

Testing laser range finders has received relatively little attention from scientific community in spite importance of this technology at defense applications. Two novel computerized stations for testing LRFs are presented in this paper. LTF station is a compact, mobile test station that enables to carry out final performance tests (measurement of extinction ration ER) of tested laser range finder at laboratory conditions. LTE is the first commercially available test station that enables both measurement all design parameters (pulse energy, pulse peak power, pulse time width, pulse repetition frequency, missing pulses, pulse coding, distance measurement accuracy (test for both single target or multiple targets), distance discrimination, receiver sensitivity) of LRFs needed for R&D works and manufacturing line and final quality parameters (extinction ratio, operational range). Both stations present unique features not met on market and enable tests of virtually all laser range finders.

Acknowledgments

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