# ORI

## Station for testing optical objectives

Fig. 1. Photo of ORI test station

## 1 Basic information:

ORI test station is an universal station for testing of optical objectives. This station enables measurement of all important parameters of optical objectives (MTF, resolution, effective focal length, distortion, vignetting, transmission, back focal length, working focal length, depth of focus, field curvature, chromatic aberration) of optical systems working in all typical spectral bands: VIS, NIR, SWIR, MWIR, and LWIR. Optional ORI stations can be also used for fast indirect measurement of centration/alignment errors and potential reduction of such errors.

## 2 How is built?

ORI test station differs significantly comparing to typical test stations offered on international market. The main reason is that the station uses a concept of inverse imaging for testing optical objectives. This means that the tested objective projects image of a reference target located at its focal plane instead of creating an image at its focal plane. In detail, a target generator module (high intensity radiation source combined with a reference target) is located at the focal plane of the tested objective that projects target image into direction of a reflective collimator combined with an imaging camera. The collimator creates image of the reference target at its focal plane where imaging camera captures and digitizes this image. Quality of this output image of reference target projected by tested objective is evaluated using specialized software that calculates parameters of the objective.

ORI is a modular universal station that can be configured for testing optical objectives working in different spectral bands (1 – VIS-NIR, 2 – SWIR, 3 – MWIR-LWIR) using a series of exchangeable blocks: set of CRI off axis reflective collimators, a series of TG target generators, set CTG controllers, set of mechanical adapters, AEH optical stage, MP mechanical platform, set of spectral filters, set of optical attenuators, set of targets, set of IM electronic imagers (versions optimized for different spectral bands), PC set, frame grabber, TAS-O computer program, and optional set of reference optical objectives. By exchange of these blocks ORI station can be easily converted from version for testing VIS-NIR objectives to a version optimized for testing SWIR objectives or MWIR/LWIR objectives.

## 3 Measurement range and accuracy

Measurement range and measurement accuracy depend on version of ORI station. Precision data is delivered when ORI version is determined. Below is presented general data.

Table. 1. Acceptable parameters of tested objectives

| Parameter | VIS and VIS/NIR objectives | SWIR objectives | MWIR objectives | LWIR objectives |
|---|---|---|---|---|
| Range of acceptable focal length | 7 – 1500 mm | 7 – 1500 mm | 7 – 1500 mm | 7 – 1500 mm |
| Acceptable Optics length | 5 – 450 mm | 5 – 450 mm | 5 – 450 mm | 5 – 450 mm |
| Range of acceptable aperture of tested objectives | 7 – 300 mm | 7 – 300 mm | 7 – 300 mm | 7 – 300 mm |
| Range of acceptable F-number | From 0.7 to 10 | From 0.7 to 5 | From 0.7 to 6 | From 0.7 to 3 |
| Maximal simulated sensor | 18 mm image intensifier tube or 1” sensor (12.8x9.6 mm) | SWIR FPA of dimension: 15x15 mm | IR FPA of dimension: 17.4x13.1 mm | IR FPA of dimension:17.4x13.1 mm |
| Spatial frequency range for MTF measurement | 0 – 400 lp/mm | 0 – 200 lp/mm | 0 – 150 lp/mm | 0 – 100 lp/mm |
| Maximal spatial frequency of resolution target | 456 lp/mm | 228 lp/mm | – | – |
| Off-axis angle range[1] (can be extended) | from $0^0$ to $30^0$ | from $0^0$ to $30^0$ | from $0^0$ to $30^0$ | from $0^0$ to $30^0$ |

Table. 2. Measurement range and measurement relative uncertainty

| Parameter | Visible/NIR objectives | SWIR objectives | MWIR objectives | LWIR objectives |
|---|---|---|---|---|
| MTF measurement uncertainty | ± 0.02 (at MTF >0.2) | ± 0.02 (MTF>0.2) | ± 0.02 (MTF >0.2) | ± 0.02 (MTF >0.2) |
| MTF measurement repeatability | ± 0.01 (when MTF >0.2) | ± 0.01 (MTF >0.2) | ± 0.01 ( MTF >0.2) | ± 0.01 (MTF >0.2) |
| Focal length measurement relative uncertainty[2] | ≤1% | ≤1% | ≤1.5% | ≤ 2% |
| Distortion measurement relative uncertainty[3] | ≤ 4% | ≤ 4% | ≤ 6% | ≤ 6% |
| Distortion measurement sensitivity | ≤ 0.6% | ≤ 0.6% | ≤ 0.8% | ≤ 0.8% |
| Vignetting measurement relative uncertainty | ≤ 3% | ≤ 3% | ≤ 4% | ≤ 4% |
| Relative transmission mea- | ≤ 3% | ≤ 3% | ≤ 5% | ≤ 5% |

[1]Maximal FOV of tested objective is equal to two times of off-axis angle range
[2]Uncertainty of measurement of focal length is typically better than 1%. Value in data sheet is conservative value for a case of poor quality objective when image is blurred.
[3]But not better than indicated by sensitivity value

| | | | | |
|---|---|---|---|---|
| surement relative uncertainty | | | | |
| Absolute transmission measurement relative uncertainty | ≤ 4% | ≤ 4% | ≤ 6% | ≤ 6% |
| Back focal length measurement relative uncertainty | ≤ 1% | ≤ 1% | ≤ 1.5% | ≤ 2% |
| Working focal length measurement relative uncertainty | ≤ 1% | ≤ 1% | ≤ 1.5% | ≤ 2% |
| Depth of focus measurement relative uncertainty | ≤ 4% | ≤ 5% | ≤ 6% | ≤ 6% |
| Field curvature measurement relative uncertainty | ≤ 6% | ≤ 8% | ≤ 9% | ≤ 10% |
| Chromatic aberration measurement relative uncertainty | ≤ 5% | – | – | – |

Attention: Measurement uncertainties presented in table above should be treated as approximate values. Uncertainties of some of parameters (focal length, back focal length, distortion, depth of focus, field curvature) do depend not only on quality of ORI test station but even more on quality of image projected by tested objective. Better image quality better measurement. This relationship occurs because measurement of these parameters requires to mark edges of image of reference target. More blurred edges means that measurement errors are higher.

**VERSIONS**

ORI stations can be delivered in many different versions. The version is described using three letter code (ABC) presented in the table below.

Table. 3. Definition of codes used to describe versions of ORI test system

| | 1 | 2 | 3 |
|---|---|---|---|
| **Code** | **Aperture range/ focal length range** | **Test capabilities** | **Spectral range** |
| A | 7-70mm<br>7-200mm | MTF (on – axis) | VIS/NIR |
| B | 7-100mm<br>7-400 mm | MTF (on – axis, off – axis, sagittal, tangential), effective focal length and optionally resolution (only for VIS-SWIR range) | LWIR |
| C | 7-150mm<br>7-600 mm | As in point B but additionally: distortion, vignetting, relative transmission | MWIR/ LWIR |
| D | 7-200 mm<br>7-800 mm | As in point C but additionally: absolute transmission | MWIR/LWIR/ VIS/NIR |
| E | 7-250 mm<br>7-1000 mm | As in point D but additionally: back focal length, working focal length, depth of focus, field curvature | SWIR/VIS/NIR |
| F | 7-300 mm<br>7-1500 mm | As in point E but additionally: chromatic aberration (for VIS/NIR optics) | MWIR/LWIR/ SWIR |
| G | 7-400 mm<br>7-2500 mm | | MWIR/LWIR/<br>SWIR/VIS/NIR |

## 4 Options

ORI can be delivered in a series of additional options to expand test capabilities:

1. Version optimized for testing U-turn (folded) optical objectives. Please add letter U to code of chosen version. Detail mechanical drawings of tested U-turn objective are to be delivered.
2. Version capable to do testing of sensitivity of objective to stray light. Range at least to 2000:1. Please add letters SL to code of chosen version.
3. Version that enables fast indirect measurement of centration/alignement errors (and potential reduction of such errors) by direct measurement of negative effects of such errors. Please add letters BOR to code of chosen version.
4. Optional versions of ORI can be delivered for testing objectives of focal length as short as 1mm and FOV as big as 120º can be delivered. Please add WFOV to typical code of chosen ORI station.
5. Optional versions of ORI can be delivered for testing objectives of aperture as high as 700mm and focal length as 6000 mm. Please add BIG to typical code of chosen ORI station.
6. Version optimized for testing optical objectives for NVDs (simulation of glass input image intensifier tubes) can be delivered. Please add letters NV to typical code of chosen ORI station.
7. Version optimized for athermality testing of VIS/NIR/SWIR /MWIR/LWIR objectives can be delivered. Please add letters EX to typical code of chosen ORI station.
8. If different combination of spectral range of tested optics (or additional UV band) is needed please contact Inframet.

Example: ORI-CDC means the following ORI test system: 1) C – maximal aperture of tested optical objectives equals 150mm, maximal focal length equals 600mm, 2) D – test system capable to measure MTF (on – axis, off – axis, sagital, tangential), effective focal length, distortion, vignetting, absolute transmission; 3) C – MWIR/ LWIR objectives can be tested.

## 5 Why ORI station?

There are several differences in design and overall performance that make ORI unique on international market.
From design point of view there are two main differences: special measurement method, and exclusive use 2D imaging cameras to capture image generated by tested MWIR/LWIR optical objective.

ORI test station uses inverse imaging method for testing optical objectives. This method requires to use a series of off – axis reflective collimators of different apertures and focal lengths to achieve proper magnification and sufficient light intensity of images of the reference targets created at collimator focal plane. Output image of magnified blurred image of reference target is always captured using 2D imaging cameras working in different spectral bands.

Inverse imaging test method based on 2D imaging cameras creates two challenges for the manufacturer. First, high manufacturing costs because a set of off – axis collimators and a set of imaging cameras for different spectral bands are needed. Second, advanced algorithms for calibration and image processing are needed to convert typical imaging cameras into imaging radiometers capable to capture precision spatial intensity distribution of images generated by tested objective.

Typical test stations for testing optical objectives met on market are practically typical reflective image projectors used for testing thermal imagers/SWIR imagers/VIS-NIR cameras with an additional module: a video microscope that captures magnified image of a reference target at focal plane of the tested optical objective. Analysis of quality of captured images gives data that can be used to calculate parameters of tested optical objective.
The video microscope method reduces requirements on the collimators as a single off – axis reflective collimator can be used to built a test station capable to test optical objectives of different apertures and focal lengths. However, the video microscope method can enable fast and accurate tests of optical objectives only if the video microscope can capture total image from the tested objective without noticeable degradation and in short time. It is relatively easy to fulfill this condition when designing video microscopes for VIS-NIR spectral band. There are commercially available ultra bright (capable to capture total image) near perfect microscope objectives and high-res CCD/CMOS cameras. However, it is extremely difficult to design near perfect ultra bright optical objectives (F-number as low as 1) for video microscopes for SWIR/MWIR/LWIR bands that would not degrade quality of magnified image. It is possible to correct image degradation but any correction limits also measurement accuracy. Next, SWIR/MWIR/LWIR cameras are costly. Therefore the test stations based on video microscope method typically use a scanning imager built using cooled discrete SWIR/MWIR/LWIR detector. This technology is cheaper but is also much slower comparing to use of 2D imaging cameras employed in ORI station. Some of our competitors try to use 2D imaging cameras but so far succeeded only for LWIR band.
The design differences between ORI and typical test stations create big differences from operational point of view:

1. Measurement speed of ORI when testing MWIR-LWIR lenses is several times higher due to exclusive use of 2D cameras. Design improvements of tested MWIR objective done by precision positioning of some optical elements can be carried out within minutes when hours are needed to do the same using station based on scanning discrete detectors offered by competitors who offer automatic systems but very slow.

2. Reliability of ORI is much higher due to simple mechanical design and manual operation. It is difficult to damage ORI mechanics.
3. ORI station is more universal as it make possible to test of ultra bright objectives (F number below 1) that are important for many applications.

Because of these reasons automatic test stations based on video microscope method offered by competitors looks impressive only at beginning. Some of Inframet customer used competitors test stations and switched to Inframet ORI stations due to advantages listed in table below.

Table. 4. Differences between ORI and typical test stations

| Feature | ORI station | Competitor station |
|---|---|---|
| Design concept | Inverse imaging | Video microscope |
| Image analysis method | 2D imaging cameras for all spectral bans | Scanning cameras for MWIR-LWIR band |
| Accurate testing of fast IR objectives | Yes. Ability to test lenses of F number as low as 0.7 | No. Typically can test accurately objectives of F number not lower than 1.2 |
| Measurement speed of IR objectives | High. Fast analysis of 2D images | Low. Several minutes are needed to get a single measurement when testing MWIR-LWIR lenses |
| Reliability | High. Simple system manually operated. | Limited. Many movable parts for automatic control |

## 6 Recommendations

Honest recommendation of Inframet for potential customers in form of four basic rules are presented below:

1. If station for testing mass manufactured small VIS-NIR objectives (aperture below 40 mm) is needed then buy a competitor test station based on video microscope method.
2. If universal station for testing small/medium quantities of objectives of different apertures and for different spectral bands (VIS/NIR/SWIR/MWIR/LWIR) then buy a typical version of ORI optimal for size of tested optics and required test capabilities.
3. If station for testing mass manufactured SWIR/MWIR/LWIR objectives is needed then contact Inframet for modified ORI station optimal for your application. We can deliver special versions optimized for mass production.
4. If station for testing space quality of large VIS-NIR objectives is needed then please consider ORI test station. Inframet can deliver special version of ORI optimized for specified space objective.

To justify these claims we state that some of best in the world optical objectives for SWIR/MWIR/LWIR spectral bands have been developed with using ORI test station. Next, the conclusion on superiority of ORI stations is based on an objective analysis of current market situation. Inframet can optionally deliver both reference list and detail market review for potential customers of ORI station.

Version 7.1

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