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Key technologies for IR zoom lenses : aspherics and athermalization

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ABSTRACT

Following the trend in Broadcast TV and Video, more and more infra-red systems require zoom lenses. The purpose of this paper is to point out two key technologies, aspherics and athermalization, and to adress the most difficult industrial aspect of these technologies : measurement.

INTRODUCTION

Infra-red zooms are now used in fielded systems with four main applications [1]

- thermal imagery (FLIR) Fig 1
- tracking (IRST) Fig 2
- laser beam riding
- simulation for IIR seekers

The manufacture of IR zoom lenses has been possible thanks to:

- perfectly optimized lens design
- high precision aspheric surfaces
- high efficiency and reflection coatings
- perfectly optimized mechanical design to achieve optical axis stability and repeatability [2]

The main concerns about IR zoom lenses in manufacturing and integration are the verification by measurement that aspheric surfaces are in conformance with their specification, and the verification by test that athermalization of the lens allows keeping the same optical performances at low and high temperature as at 20°C.

ASPHERIC SURFACES

Aspheric surfaces improve performance

Aspherics are used in all 8-12 um zoom lenses. By reducing the number of optical elements of the zoom lenses, they:

- improve lens transmission
- lower weight
- reduce lens volume
- reduce cost

All Angenieux zoom lenses use at least 1 aspheric surface (Tracking or laser beam riding) 2 aspheric surfaces (thermal imagery) up to 4 aspheric surfaces (simulation).

In 3-5 um zoom lenses, the chromatic aberrations correction requires use of several optical materials in most optical groups of any zoom lens, thus making enough optical surfaces to prevent the need for aspheric surfaces. Two exceptions are zoom lenses with very wide field-of-view that require an aspheric front element and zoom lenses with very narrow wavelength bandwidth that can be made without chromatic correction.

Aspheric surface specifications are demanding

Departure of the actual aspheric surface from a theoretical surface is specified as follows for diffraction limited zoom lenses.

{ 0,3 um maximum for "complex" zoom
8-12 um { lenses
{ 0,5 um maximum for "simple" zoom lenses

{ 0,2 um minimum for "simple" zoom lenses
3-5 um { 0,5 um minimum for front lens of
{ wide FOV zoom lens

Available technologies are able to meet specifications

Diamond turning process capability is typically within a 0.1 um departure from the theoretical surface with recent Diamond turning machines used by skilled manufacturers.

A vapor deposition process proprietary to Angenieux has a capability of 0.02 to 0.2 um (depending on the theoretical aspheric surface departure from best fit sphere) [3].

Measurement is difficult

Mechanical measurement is the most commonly used. It gives a surface profile along a given diameter of the surface. Obtaining a complete map of an aspheric surface requires time consuming (and costly) measurement, with great difficulty to control tilt between profiles of different diameters. A mechanical measurement cannot prove conformance of an aspheric surface to its specification, it can only prove non conformance.

Optical measurement may be easy on aspheric surfaces with small departure from best fit sphere. The knife edge method has been used for a very long time to control parabolic mirrors for astronomy. This measurement can be very accurate, does not require tooling, but is time consuming and not able to measure aspheric surfaces with significant departure from best fit sphere, and therefore can be used only in a few cases for IR lenses.

Modern ways of aspheric surface measurements require an interferometer with a null lens (or hologram) to allow data acquisition. Drawbacks are that each different aspheric surface requires a specific null lens which is itself not measured as a complete unit. This leads to costly specific tooling and risk of systematic error.
Having experienced the pitfalls of all these kinds of measurement for more than 15 years on IR zoom lenses, we came to the decision of

developing our own measurement system, to enable measurement of the whole aspheric surface without requirement for specific tooling.

Deflectometry allows accurate measurement without specific tooling.

The basic principle is derived from the knife-edge method and is known as "Ronchi". Knife edge is replaced by a "Ronchi" ruling, allowing measurement of aspheric surfaces in the case of large departure from best fit sphere (fig 3). This device is used to measure aspheric and spheric surfaces for infra-red zoom lenses in our production plant (fig. 4) with a peak-to-valley accuracy of +/-0.05 um and RMS accuracy of +/-0.01um. Several systems are also used in ESSILOR where this deflectometer design originiated, to measure aspheric and tonic surfaces.

ATHERMALIZATION

Athermalization of IR zooms are needed to keep performances at extreme temperatures

As for single Field of View or Dual Field of View IR lenses, IR zoom lenses need athermalization to keep the same MTF at the required image plane position at all temperatures. We will review the existing athermalization concepts used in IR zoom lenses with their advantages and drawbacks.

Optical athermalization requires manufacturing logistics support.

8-12 um IR zoom lens cannot practically be athermalized by optical design optimization. Basic optical material is Germanium and its refraction index varies too much with temperature that the mechanical mounts and structure would need to be in plastic material with very high expansion coefficient.

The 3-5 um IR zoom lens can be optically athermalized. This looks simple for the optical designer but is often very complex for the manufacturing engineering engineers. On paper, optical materials, mechanical material and links between them are defined by precise parameter values. In production you know that each parameter of this value has to have a tolerance, and you have a lot of this involved in a zoom lens.

So you will need to be able to adjust athermalization on each lens (especially wide aperture lenses) or on each lot (if a lot is made of materials of the same lot or the same manufacturer). The adjustment will have to be done at least at the long and short focal-lengths of the zoom. It can be made by modification of the radius of curvatures of the lens-elements. This requires short time notice and requires optimized in house logistics when lens-elements are manufactured in the same plan as for zoom integration, and is a good case for "Just in Time" organisation if lens elements are subcontracted. We use this technology when quantities are very low (a few units), allowing prototype organisation, or when quantities are very large (50 or more per month)

Mechanical passive athermalization is a good trade-off

It can be used at 3-5 um and 8-12 um.

The principle is to use two mechanical materials with very different expansion coefficients to amplify (or reduce) displacement of optical elements with temperature.

At least two devices are needed in a zoom lens to adjust athermalization at long and short focal length.

The drawback is that it is more complex than optical athermalization at 3-5 um.

The advantage is that athermalization adjustment can be made without disturbing optical adjustments, at the end of the integration phase.

We use this technology when quantities are in the range of 1 to 20 per month.

Active athermalization gives the best performance

The drawback of passive athermalization is their performance during temperature transients. If the optronics systems require the same MTF while temperature changes, there are several cases :

- temperature is controlled around the IR lens, for example stabilized at 55°C before use of the lens for mission purposes. Passive optical or mechanical athermalization is suitable in this case.

- temperature is not controlled but temperature variations are very slow. The zoom is protected by the housing of the electro-optic system which is not exposed to quick temperature changes (ground vehicles, tanks, ships). Passive optical or mechanical athermalization can do the job.

- Temperature of the lens may vary quickly, then active athermalization, that is moving one motorized optical element to keep the image plane at the required position [4], is needed to keep performance during temperature transients.

- Motorized focusing is already required. Then athermalization by adding temperature sensors and a few electronic components is less expensive than passive athermalization and gives better performance.

Specifications do not care for temperature

The basic requirement for MTF optical axis position is to keep the same performances from -40° C (-40°F) to +70°C (+158°F) or more and during any temperature transient. Solutions to these requirements exist, and the main problem again is to be able to measure the results in a production plant.

Put the lens in a thermal chamber and the tooling out of it

To make an accurate and reliable measurement or test, the best way is not to have tooling nor test equipment submitted to climatic cycles. The optical measurement bench we use allows reduction to the minimum of tooling needed in the thermal chamber (see fig 5).

All moving parts are outside the thermal chamber.

Reference mirror is linked to the IR zoom lens mechanical interface for optical axis position measurement. Target includes knife edge (X and Y) to measure MTF, parallel slits to measure focal lengths, perpendicular slits and hole to measure optical axis position. Target link to IR lens is designed to simulate system image plane position (and its displacement when temperature changes). Accuracy of MTF measurement is 0.02 at all temperatures, from -54°C to +100°C.

CONCLUSION

IR zoom lenses are used in a growing number of applications. They require more design and manufacturing knowledge than Single or Dual Field of View and cannot be produced to fill electro-optic systems needs without real measurement capabilities of aspheric surfaces and lens athermalization. TQM is mandatory for IR zoom lenses and the availability of measurement devices will play a key role in widening IR zoom lens applications.

[1] Zoom lenses for infra-red applications - SPIE 1986 Innsbruck - Jacques DEBIZE, Pierre NORY.
[2] Near infra-red and visible zoom system with high boresight shift stability - SPIE 1983 Geneva - Jacques ANGENIEUX, Charles Le Roux, André MASSON.
[3] Aspherics precision manufacturing by vacum evaporation - SPIE 1983 Geneva - Jacques ANGENIEUX, Yvon ROUCHOUSE, André MASSON.
[4] Use of zoom converter to perform focusing and thermal compensation - SPIE 1985 Cannes - Pierre NORY.

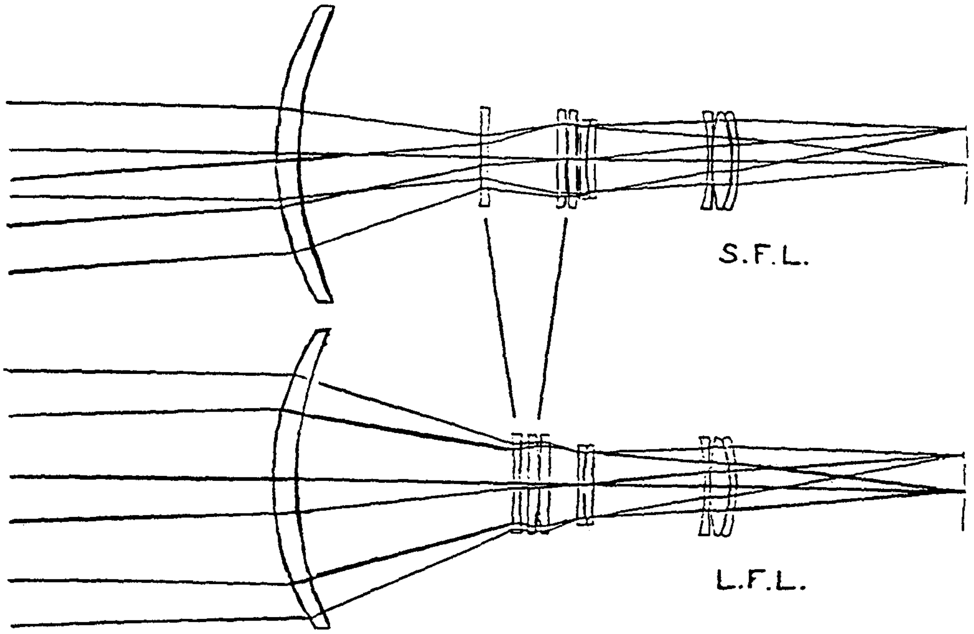


Figure 1

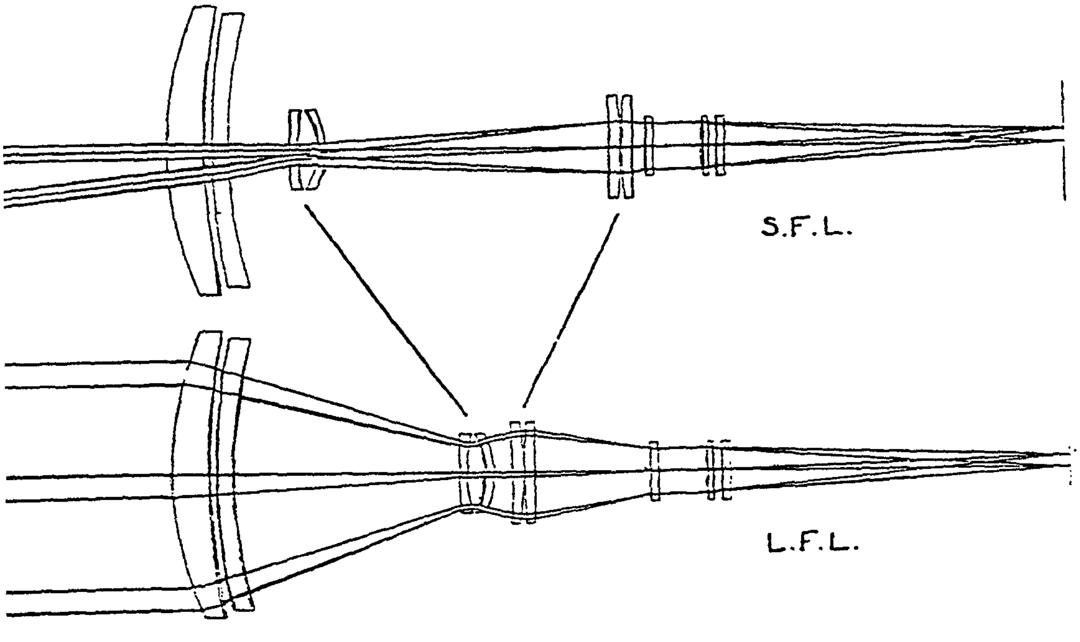
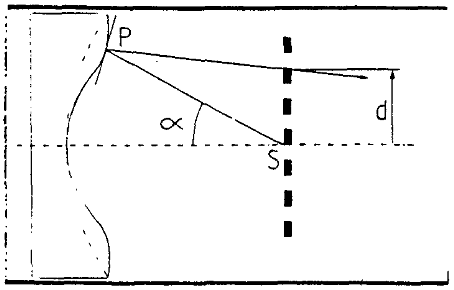
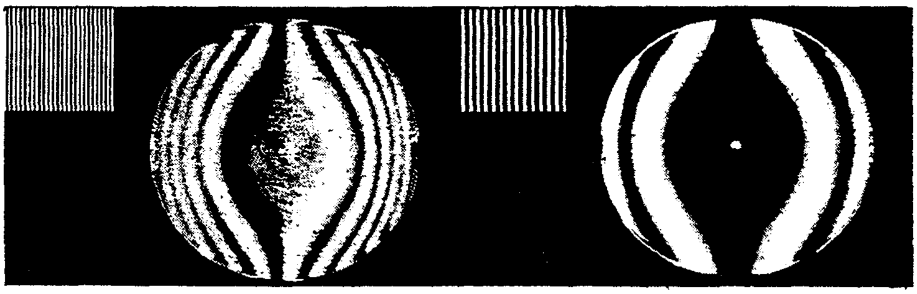


Figure 2



RONCHI DEFLECTOMETER PRINCIPLE

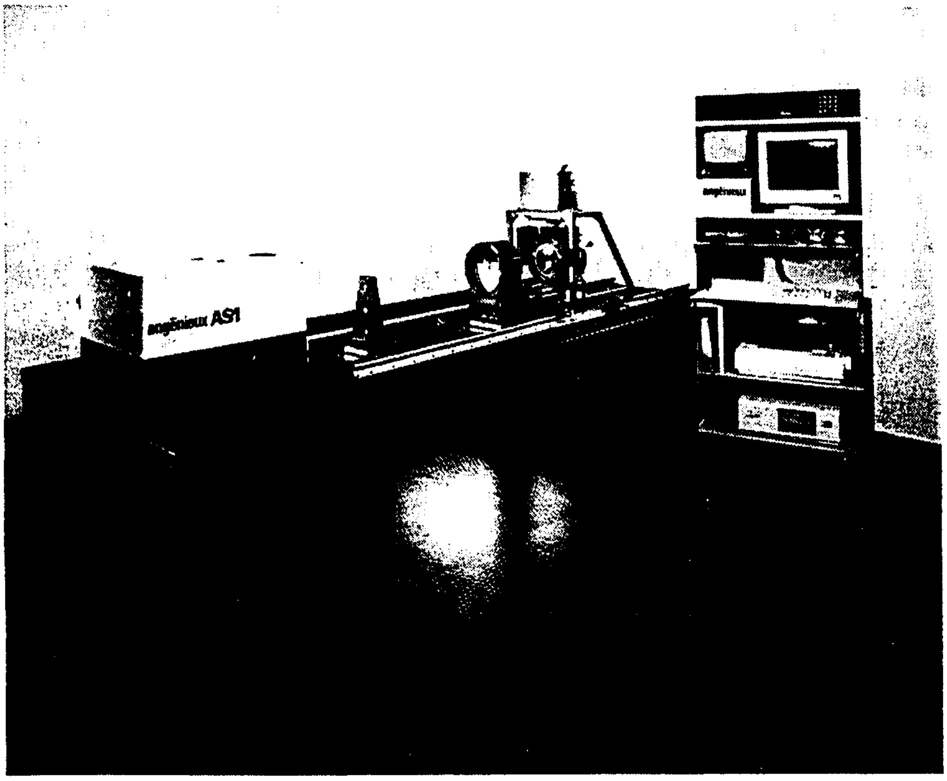
Figure 3a



FRINGE PATTERN OF SAME SURFACE WITH

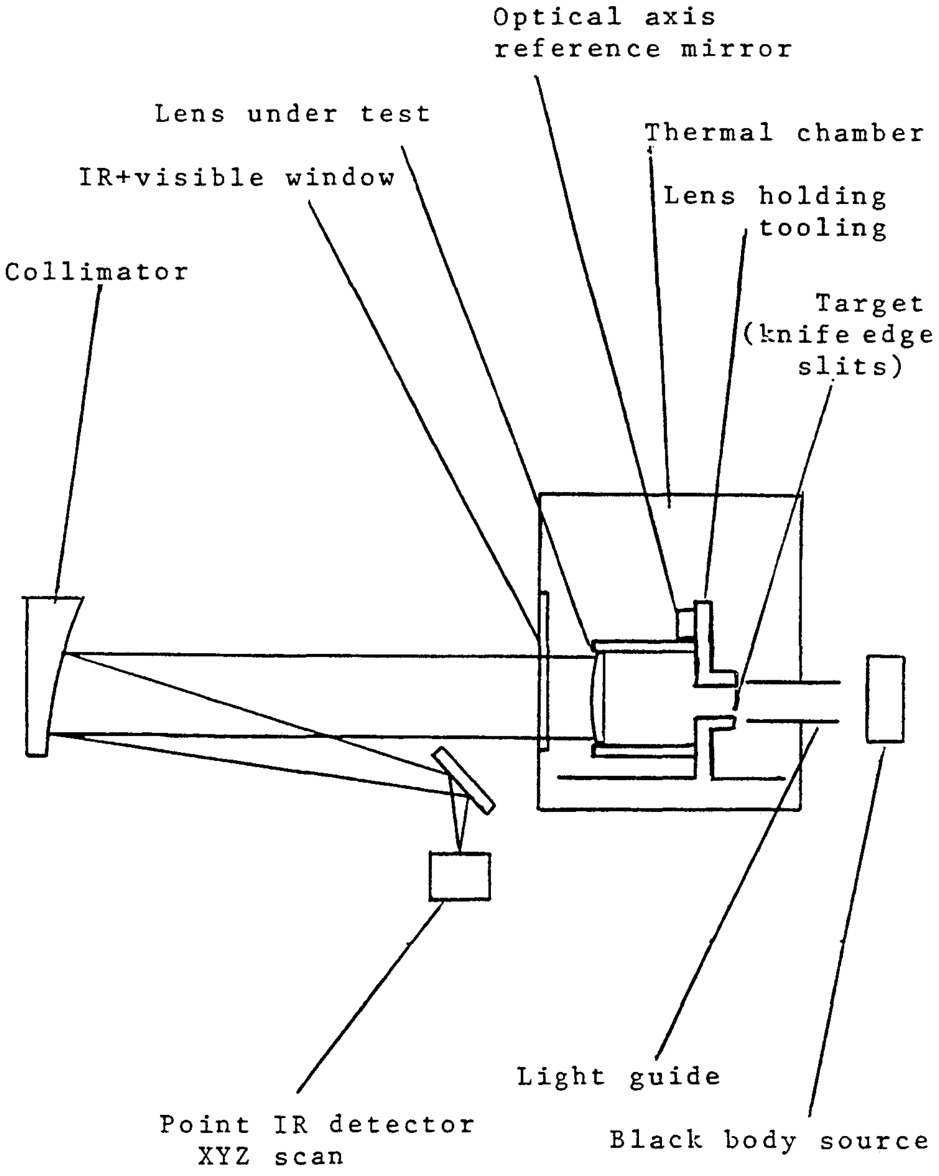
2 DIFFERENT GRIDS

Figure 3b



ASPHERIC SURFACE MEASURED WITH
DEFLECTOMETER

Figure 4



MTZ, optical axis, image plane position, transmission, focal-lengths measurements
IR zoom lens measurement bench

Figure 5