Alignment procedure for Bruker IFS 120 spectrometers

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This document provides you with a short description of the alignment procedure used at IMK for many years [Hase, 1995]. In the details, it applies to the high-resolution spectrometers IFS 120M and IFS 120HR manufactured by Bruker, but the basic considerations may be helpful for a variety of Fourier spectrometers.

The alignment by direct visual inspection of laser fringes using a telescope is somewhat dangerous. Never forget to introduce appropriate diffusor stages and/or filters when looking into the laser beam. Also, working at the uncovered spectrometer may lead to damage of optical surfaces or mechanical devices inside the instrument. *The authors and IMK refuse any warranties with respect to the use of this manual. In no event shall the authors or IMK be responsible for any direct, indirect or consequential damages neither to the spectrometer nor the health of the user.*

• General considerations

A Fourier spectrometer generates intensity modulations to uncover the spectral composition of the radiation under study. Thereby, two beams are derived from the incoming beam by amplitude division at the beamsplitter and a path difference is introduced before the recombination of the beams. The resulting intensity in the recombined beam is given by the path difference and the spectral composition to be derived. In the measurement process, the path difference is varied and the associated intensity fluctuations are recorded. The intensity fluctuations are assigned to the optical path difference by means of a laser.

The goal of the alignment procedure is to make sure that:

- *The field of view (FOV) in the interferometer is properly defined.* Most spectrometer designs strive for a circular FOV, as is the case for the IFS 120M + IFS 120HR.

- *The beam section in the interferometer is properly defined.* Most designs strive for a circular beam section. In the case of the IFS 120M + IFS 120HR we assume the beam section to be circular with a diameter of 65 mm. A closer look shows that the beam section is curtailed by the detectors for the laser modulation, resulting in a somewhat flattened shape.
  In the case of the IFS 120M + IFS 120HR there is a substantial vignetting of the delayed beam if the FOV and the path difference are both large (measurements in the far IR) [Birk et al., 1996]. Since the loss depends on the optical path difference, the effect degrades the instrumental line shape (ILS), but this is negligible in typical atmospheric measurements.

- *The center of the interference fringes (Haidinger fringes) does not move with respect to the FOV for all opds.* The origin of these circular fringes lies in the fact, that the path difference depends on the inclination of the ray in the interferometer.

- *The laser measuring the optical path difference is collinear with the direction defined by the center of the Haidinger fringes.* If the laser beam direction is inclined with respect to the center of the Haidinger fringes, the wave number scale assigned to the spectrum is stretched. A given signature appears at a wave number position lower than the correct value.

- *The whole FOV and the whole beam section offered by the spectrometer is illuminated evenly by the source (laboratory, sun).* Vignetting leads to loss of signal. Moreover, inhomogenous illumination of the FOV leads to distorted instrumental line shape (ILS).

- *The detector receives the whole radiation.* The FOV is imaged on the detector by additional optical elements. Even if the interferometer is aligned perfectly well, intensity might be lost on its way to the detector e.g. by inaccurate placing of optical elements or the detector itself.

• Required components

To satisfy the requirements mentioned above, the visual inspection of the beam at various positions in the spectrometer and of the Haidinger fringes produced by the interferometer is a favourable method. In case of the Bruker spectrometers, the interchangeability of the beamsplitters is a useful feature in this context. For the visual inspection, the *glass or CaF_2-beamsplitter* is used. It may be suspected, that the alignment depends on the chosen beamsplitter. According to our experience, the effects are hardly to detect. This holds for different beamsplitters of the same type as well as for beamsplitters of different types, e.g. glass vs. CaF_2 (or glass vs. KBr). A close visual inspection of the telescopic image may reveal low contrast Haidinger fringes even in the case of the KBr beamsplitter. This fact can be used to check the compatibility. Moreover, the interference fringes observable in the recombined beam of the path measuring laser should reveal any significant incompatibilities of beamsplitters (for details, see section 'alignment of path measuring laser'). In the following, we assume that the compatibility of the beamsplitters holds to sufficient accuracy.
If the spectrometer does not offer any beamsplitter usable in the visible, the alignment procedure described below may be performed in analogy using an IR laser and an IR sensitive camera.

A *telescope* offering an aperture equal to (or larger than) the beam diameter in the interferometer is required. It is strongly recommended to use the full beam section, because otherwise the optical quality of the system is overestimated (analogy: stopping down a camera lens leads to sharper images). Moreover, - in the presence of optical aberrations - the alignment depends on the selected part of the beam section. We use small refractors (aperture 80 mm, focal length 400 mm) manufactured for amateur astronomy by the Japanese manufacturer Vixen. Simple eyepieces (e.g. orthoscopic or Plössl) with focal length of 8 to 20 mm are appropriate. Additionally, an *eyepiece with crosshairs* or fine grained frozen plate is needed to define the 'plane of infinity' (see below). For the observation of the Haidinger fringes the telescope is used on a stable and fine adjustable *tripod*. For the observation of input and exit aperture the telescope is fixed on an appropriate holder (if to be improvised: use stack of plates) on the scanner arm to achieve the desired position of the telescope.

A *laser* with appropriate coherence length is required. We use a compact HeNe laser (tube length ~20 cm), and have recently been told by John Robinson, NIWA, [Robinson, 2000] that they use a diode laser for the same purpose, that is even more handeable. (To be detectable by eye, the fringe contrast should exceed 10%, so there is no need for a pure single mode laser.) Our lasers are mounted in a *mechanical stage* that allows fine tuning of all necessary degrees of freedom (shift laser tube in the plane perpendicular to beam, rotate direction of laser beam). To refer to this laser unambigously, we use the term alignment laser for this additional laser and interferometric laser for the path measuring laser used in the interferometer in the following.

Two handeable *white light sources* are needed. For the illumination of the entrance aperture the internal quartz bulb source can be used alternatively.

To scatter the laser beam, a *diffusing material* is need. A good choice is the opaque paper used for tracing sketches. In the following, the expression diffusor denotes a stack of opaque papers to achieve even illumination of the whole beam section accepted by the spectrometer. To avoid any ‘hot spots’, use two or more layers, each spaced by 1 cm or so. For the projection of the collimated beam on a white piece of paper, significantly more light is needed than for the direct telescopic observation of the beam, so use diffusors of appropriate transmission in each case.

- Correct use of aids

Whenever the telescope is used, make sure, that it accepts the whole beam section used by the interferometer. *Always make sure, that no unattenuated laser beam falls in the telescope. Especially beware of the unexpanded interferometric laser beam! The interferometric laser beam should be covered securely or the laser switched off whenever using the telescope.*

Whenever a diffusor is attached to an aperture wheels, make sure, that the position of the apertures is not shifted out of its position (the stepper motor fixing the position of the aperture wheel is not very powerful).

- Alignment of collimator

The telescope is focused to infinity by observing a distant object (landscape, moon) using the eyepiece with crosshairs. The crosshairs and the distant object have to appear sharp at the same time! The focus of the telescope is fixed. This guarantees that the crosshairs mark the ‘plane of infinity’ in the following.

The scanner is switched off. The rod is loosened, so that the scanner can be moved by hand. It is moved to the end of the scanner arm. The interferometric laser beam is covered or the laser is switched off. The glass / CaF_2 beamsplitter is inserted. A diffusor is inserted near to the plane of the input aperture on the side of the source (select an aperture you normally use). The aperture has to be illuminated evenly. Also, the full beam section has to be illuminated evenly. Check this using a white piece of paper in the collimated beam. The telescope is brought into the collimated beam, either on the scanner arm or elsewhere behind the interferometer (see below, section ‘alignment of interferometer’). Make sure that the telescope accepts the full beam section. The telescopic image is very bright. Therefore, use a neutral filter behind the eyepiece or introduce an additional diffusing stage next to the first. Now the entrance aperture can be seen in the telescope. Probably, the image of the aperture is more or less fuzzy. Especially in case of the 120M, the large off-axis angles used in the optical system lead to substantial astigmatism: The rim of the

entrance aperture appears sharp in one direction and quite fuzzy in the direction perpendicular to the former. Now, the alignment of the collimator is modified until the entrance aperture appears as a sharp circle at the same time as the crosshairs. If so, the first step of the alignment is finished: *The FOV is defined accurately*.
In practise, the alignment of the collimator is a quite delicate task (see below, section 'alignment of interferometer'). It turns out, that using solely the degrees of freedom foreseen by Bruker, it is impossible to reach a satisfactory sharpness, especially in case of the 120M. We cured this problem by introducing a new degree of freedom: We modified the off-axis mirrors to be rotatable on their baseplates. We informed Bruker about this collimator problem about two years ago. In the meanwhile, they accepted the status as unsatisfactory and now offer an alternative solution to the problem. This solution is *not* equivalent to our approach. Especially, it remains a mystery, why they don't simply set the accurate angle before the integration of the interferometers.
One remark on the 'plane of infinity' is left: If you use a refractor, there is noticeable chromatic aberration: The focal length depends on the wavelength of light. Therefore, use sources of similar spectral composition for the calibration of the focus position and for the illumination of the entrance aperture. Do not use red laser light in this step!

- Alignment of interferometer

The diffusing plates and the telescope are taken away. The alignment laser is incoupled to the interferometer from a position near the source position. If care is taken, it can be achieved, that the laser beam hits the movable cube corner (still at the end of the scanner arm) exactly in the middle and is reflected back into the laser tube several times. This accurate alignment is not necessary for the following, but it may occasionally be useful to have such a marker of the optical axis. Again a diffusor is set near to the entrance aperture. The telescope is set behind the interferometer. It is mounted on a tripod outside the spectrometer. A normal eyepiece is used. In the 120HR there is enough space to send the collimated beam with help of an additional plane mirror out to the telescope, in case of the 120M, the position of the 60° off-axis mirror behind the interferometer is marked and the mirror is removed. Then the collimated beam leaves the base plate instead of being focused on the exit aperture. Again, make sure that the telescope accepts the full beam section. The inner stage of the movable cubecorner is fixed (e.g. by tape), otherwise, the Haidinger fringes would vary to fast for the visual inspection. In the telescope, the fringes fill the circular FOV defined by the entrance aperture. The circular interference fringes are very narrow at maximal optical path difference, and grow larger when the scanner is moved towards zero path difference (ZPD). Near ZPD, it is difficult to determine the position of the fringe center using an aperture diameter appropriate for high resolution infrared measurements and a larger aperture is preferable. It is found that the position of the fringe center with respect to the FOV is very sensitive to the position of the fixed cubecorner near ZPD, and quite insensitive near OPD_{max}. Therefore, to center of the Haidinger fringes in the FOV, the following strategy is applied: First move the scanner to OPD_{max}, choose a small entrance aperture and bring the center of the FOV in coincidence with the center of the fringes by slight alignment of the collimator (In case of the 120M, the 60° off axis mirror collimating the radiation from the entrance aperture is adjusted, in case of the 120HR the plane mirror next to the beamsplitter is adjusted.). Then set a larger entrance aperture, move the scanner near ZPD (depending on the degree of misalignment OPD ~ 10 ... 20 cm) and adjust the fixed cubecorner. This procedure is repeated several times. If the alignment is quite good, you will find, that moving the scanner several cm around ZPD is a very sensitive test to detect residual misalignment of the fixed

cubecorner: The fringes seem to 'flip' when crossing the ZPD position, unless the alignment is perfect. *Now the alignment of the interferometer itself is finished.*
Since this step is the very heart of the whole alignment procedure, a few words of caution have to be added at the end of this section:

- When the fringe alignment is ok, do not forget to reassure, that the FOV is still well defined (previous step). In case of the 120M, the degrees of freedom to achieve the correct alignment of the collimator and to achieve the Haidinger fringes centered inside the FOV are mixed up. It may be necessary to go back and forth between the previous step and the interferometric alignment. If any improper vignetting of the beam section is observed at the telescope aperture, you have to rearrange the responsible optical components.
- Correct alignment at ZPD and at OPD_{max} does not guarantee correct alignment in between these extremal positions of the scanner. If never checked before, it is to be expected, that the scanner arm is slightly curved, so the position of the Haidinger fringes should be inspected at various path differences. Both spectrometers, the 120M as well as the 120HR allow some adjustment of the scanner arm. When comparing the adjustment mechanism in the 120HR and the 120M, just this once the solution in the 120M is clearly superior. Note, that in the case of the 120HR the tubes guiding the scanner can be fixed at both ends. It is probably better to fix only the end near ZPD and to loosen the screws at OPD_{max}, to avoid tension in the tubes.
- You will find, that the setting accuracy of the entrance aperture position is insufficient. If another aperture is chosen, the center of the new FOV is not identical with the former. The precision of the mechanical stages in the 120HR and 120M seems to be identical. Since the collimator is faster, the problem is more severe in the 120M. In a strict sense, the 120M can be aligned properly only for a particular entrance aperture. This is a *very* unpleasant shortcoming in the design, we hope, that Bruker will offer a solution soon.
- The screws for the adjustment of the fixed cubecorner are quite inaccessible. Moreover, the position is defined by 4 screws 90° apart instead of using 3 screws 120° apart to define the position unambigously. So the adjustment of the fixed cubecorner is a somewhat cumbersome job.

It might be worth mentioning, that with the scanner at the ZPD position, the wavefront should be flat, if the interferometer is aligned. This offers the possibility to check the optical quality (wavefront error) of the cubecorners. A piece of white paper is put in the parallel beam, e.g. in front of the telescope. A slight manual force on the scanner arm allows to adjust complete darkness over the whole beam section. If brighter patches are noticeable, the optical quality of at least one of the cubecorners is poor.

- Alignment of exit aperture branch

The alignment laser is switched off, instead both the entrance aperture and the exit aperture are illuminated with white light, using diffusing stages as before. The telescope is mounted on the scanner arm again. In case of the 120HR, the plane mirror inserted before is removed, in case of the 120M, the 60° off-axis mirror is remounted in the position marked before. It is checked, that the telescope accepts the full beam section. In the telescope the images of entrance and exit aperture are superimposed. Also the exit aperture should appear as a circle with sharp rim (if not, the relevant optical elements have to be adjusted, in analogy to the description in section 'alignment of collimator'). Both apertures should coincide. According to the standard aperture setting of the Bruker spectrometers, the exit aperture is larger than the entrance aperture. The FOV is defined by the entrance aperture, so the definition of the exit aperture is less crucial. Due to the design shortcomings mentioned above, the correct collinear superposition of the images of entrance and exit aperture can be achieved only for a certain pair of apertures. *With this step, the alignment up to the detector branch is finished.*

- Alignment of path measuring laser (interferometric laser)

  The telescope is taken away. The interferometric laser is uncovered. The interference fringes are observed on a piece of white paper in front of the photodiodes for the detection of the laser modulation. Since the complete interferometer is already adjusted, it is not allowed to readjust any of the optical elements or apertures guiding the infrared beam. Only the mirrors guiding the laser beam are used in the following, to achieve the correct alignment of the interferometric laser :
  - The two partial beams of the laser have to overlap exactly. If so, circular interference fringes are visible with the movable cubecorner at OPD_{max}. Both partial beams (cover each of them) should posses nearly the same beam diameter. The partial beam going the long way tends to form a larger spot. Focus the laser beam (lens collimator on the laser tube) to achieve a comparable narrow spot also for this partial beam. Since the interferometer is already aligned and the direction of the laser beam is determined sensitively by the alignment with the movable cubecorner at OPD_{max}, the laser fringes should be optimal at all path differences. If near ZPD there seem to be dark stripes crossing the spot instead of a uniform intensity modulation over the whole spot diameter, there has gone something wrong with the interferometric alignment!
  - The laser beam should graze neither the edges of the laser windows in the beamsplitter nor the edges of the cubecorners.
  - The laser should pass through the center of both entrance and exit aperture (this condition is fulfilled automatically, if the interferometer and the laser are aligned correctly.
  - The photodiodes for the detection of the laser modulation are adjusted.
  - Remove the tape that fixes the inner stage of the movable cubecorner. Tighten the rod that moves the scanner. Observe the output of the photodiodes when the scanner is moving (use test points on electronic board). The modulation should not fall off with growing path difference too much (not more than ~30% loss at OPD_{max}) and the phase shift between the two laser signals should amount 90°.

  The Bruker 120HR is evacuated in normal operation. Due to the large pressure forces acting on the chamber, the alignment of the interferometer as well as the laser beam degrades slightly due to the resulting deformations. It is possible to look with the telescope from outside through an optical window into the evacuated chamber when performing the fine-tuning of the alignment. Since we do not have the possibility to adjust the optical elements from outside, the fine-tuning of the interferometric alignment is a very cumbersome procedure. In contrast, a small amount of fine-tuning on the laser direction can be performed from outside, by adjusting the mirrors outside the vacuum. *Now the interferometric laser beam is collinear to the optical axis of the IR beam.*

- Alignment of source

  The correct incoupling of the laboratory source (and the solar beam) has to be checked carefully. A white light source or the alignment laser with diffusing stage is put up behind the *exit* aperture and the glass or CaF_2 beamsplitter is inserted. By projecting the beam on a white piece of paper, it can be ensured, that the beam used by the interferometer does not suffer from vignetting between the source and the entrance aperture. *By this step, it is assured, that the full FOV and the full beam section offered by the spectrometer are illuminated.*

- Alignment of detector branch

  The diffusor behind the exit aperture is removed. The detector is removed. Bruker offers a target, that can be inserted instead of the detector and allows to check the beam at the prosition of the detector element. None of the filters used for the IR measurements are in the beam, so that the light can be followed the whole way to the detector (if dichroic mirror is used: see below, this section). The entrance aperture is illuminated using white light or the alignment laser and a diffusor transparent enough to observe the beam in the detector branch on a white piece of paper. Check, that there is no vignetting of the beam. The beam should be centered on all mirrors. The optical quality of the detector branch should also be optimised in a way, that the beam projected on the paper shows no noticeable astigmatism. At the position of the detector, there should be an image of the entrance aperture located, so the spot should be round (not a line!). Again the astigmatism is mainly determined by the axial orientation of the off-axis mirrors.
  If you use a two detector option, the beam is split up by a dichroic mirror and the transmitted beam cannot be followed directly. Note, that the transmitted beam defines the primary detector, in the sense, that the image of the entrance aperture formed on this detector does not move (to first order), if the dichroic mirror is tilted, whereas the image position of the entrance aperture on the secondary detector (reflected beam) can be adjusted by tilting the dichroic mirror. We replace the dichroic mirror by a glass plate (of equal *optical* thickness, identical holder) for the alignment to make the primary detector branch accessible for the observation.

  The fine tuning of the detector branch alignment is done by infrared measurements (use laboratory IR source, for correct incoupling of the radiation into the spectrometer see above, section ‘alignment of source’). The detector signal is maximised by slight adjustments of the off-axis mirror next to the detector. Since various filters are used for the infrared observations, the optimal alignment differs slightly from filter to filter and from the results found without filter. Probably, you use wedged filters. In this case rotating the filter in its setting is an additional degree of freedom, that can be used to achieve optimal signal levels with various filters.

- Cell measurements

  In the end, it should be verified by using low-pressure gas cell measurements, that the alignment of the instrument is satisfactory. The amplitudes of the laser modulation using the different beamsplitters available as well as the ADC-counts achieved in the infrared measurements with various filters and apertures using a thermally stabilised blackbody should also be documented.

References

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