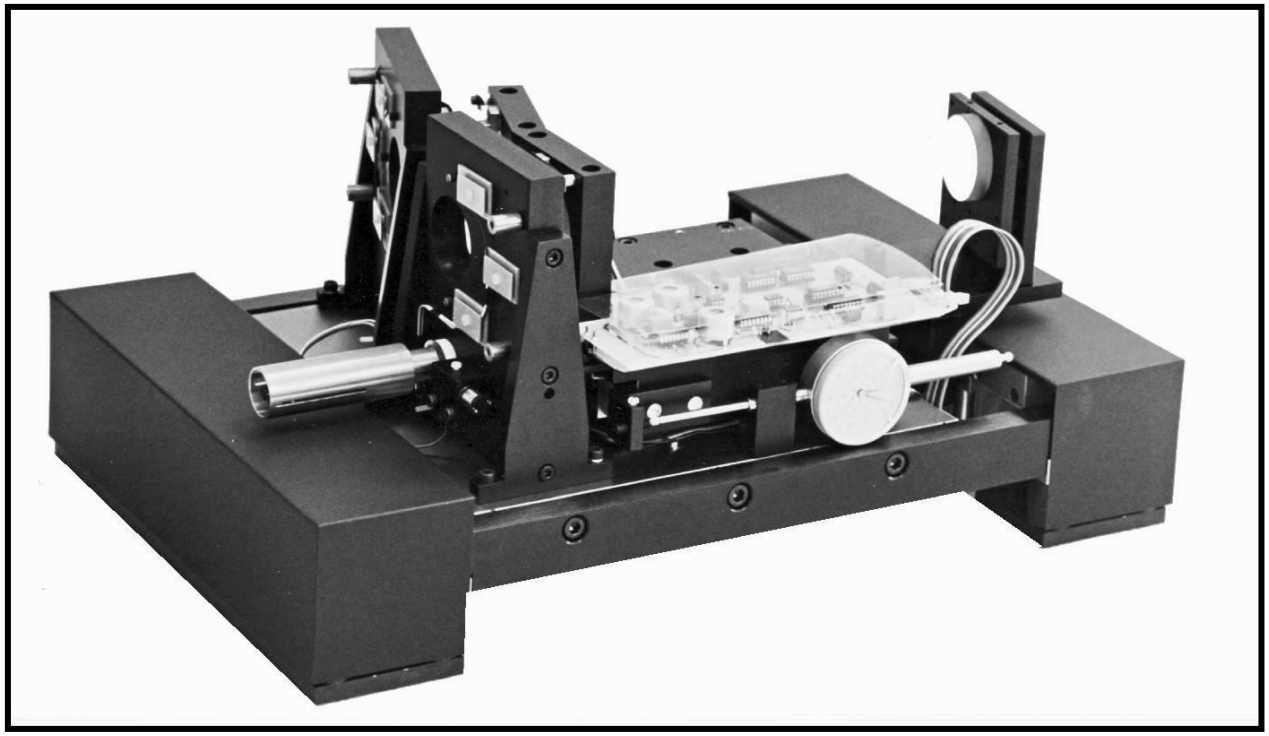
TANDEM FABRY-PEROT SPECTROMETERS
TFP-1 AND TFP-2 HC

Operator Manual



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Safety instructions

The system may only be plugged into a socket with separate ground. Do not disconnect this ground, either at the socket, or by using an ungrounded extension cable.

If you suspect the system to be in any way unsafe, unplug and prevent any possible accidental usage. Contact your nearest service centre.

Before switching on this apparatus make sure that it is connected to the correct mains voltage. Do not remove any cover or allow any metal objects to enter the ventilation slits.

Disconnect from mains before removing any covers. Refer servicing to qualified personnel.

Do not use in potentially explosive surroundings.

The fuses are located in the power socket on the rear side of the control unit.
Do not attempt to change a fuse without first unplugging from the mains. Only replace a fuse with the correct type. Never try to bypass a fuse.

Make sure the ventilation slits in the control unit are not covered and that air can freely circulate. Blocking the slits can lead to overheating which could cause a fire.

1 INTRODUCTION TO FABRY-PÉROT INTERFEROMETRY

1.1 Properties of Fabry-Pérot interferometer

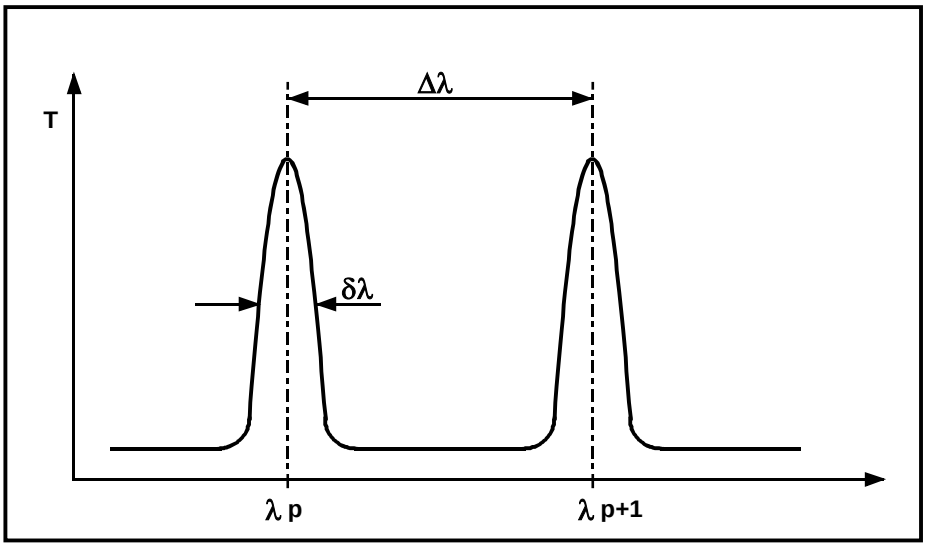
For high resolution spectroscopy where a resolution of MHz to GHz is required, a Fabry-Pérot interferometer (FP) is used. The FP consists of two plane mirrors mounted accurately parallel to one another, with an optical spacing L_1 between them. For a given spacing L_1 the interferometer will transmit only certain wavelengths λ as determined by

$$T = \frac{\tau_0}{1 + (4F^2/\pi^2)\sin^2(2\pi L_1/\lambda)} \qquad 1$$

where τ_0 (<1) is the maximum possible transmission determined by losses in the system, and F, the finesse, is a quality factor depending primarily on the mirror reflectivity and flatness. Equation 1 shows that only those wavelengths satisfying

$$L_1 = ½\ p\ \lambda \qquad 2$$

for integral values of p, will be transmitted. This is illustrated below.



The finesse F is related to the frequency interval between successive transmitted wavelengths $\Delta\lambda = c / (2 \cdot L)$ (known as the free spectral range, FSR) and the width $\delta\lambda$ of a given transmission peak by

$$F = \Delta\lambda/\delta\lambda \qquad 3$$

The FP is used as a spectrometer by varying the spacing L_1 so as to scan the light intensity at different wavelengths. However it is immediately apparent that the measured intensity at a given spacing is the sum of the intensities at all wavelengths satisfying condition 2.

An unambiguous interpretation of the spectrum is thus impossible unless it is known *a priori* that the spectrum of the light lies entirely within a wavelength spread < $\Delta\lambda$.
It is true that since

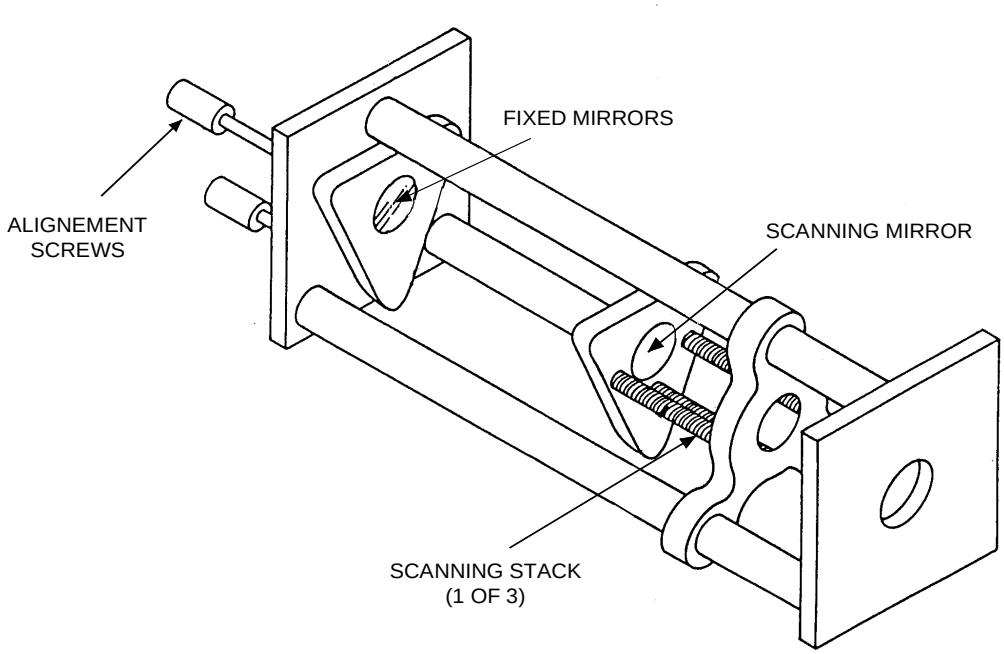
$$\Delta\lambda = \lambda^2/2L_1 \qquad 4$$

one may make $\Delta\lambda$ arbitrarily large by decreasing L_1. However $\delta\lambda$ increases proportional to $\Delta\lambda$ and so the resolution decreases. In fact equation 3 shows that the ratio between FSR, $\Delta\lambda$ and the resolution $\delta\lambda$, is just the finesse F. In practice F cannot be made much greater than about 100 due to limitations on the quality of mirror substrates and coatings. The relationship between FSR and resolution is thus fixed within limits determined by the achievable values of F.

1.2 Traditional design of FP and related problems

A design of scanning Fabry-Pérot commonly used in the past is illustrated in Figure 1-1. The structure is based upon 3 low expansion rods which support the 3 piezoelectric scanning stacks. One mirror is attached in some suitable strain-free manner to the ends of the 3 scanning stacks. The second mirror is attached to the end plate of the structure in such a way that approximate alignment parallel to the first mirror may be achieved by means of differential micrometer screws. Exact alignment of the mirrors is achieved by applying suitable bias voltages to the three scanning stacks. The instrument is then scanned by applying a scanning voltage simultaneously to all 3 scanning stacks.

Figure 1-1 Traditional FP design



While such a device can operate quite successfully under some conditions there are several aspects where considerable improvement is to be desired. These are discussed below.

1.2.1 Non-linear scan

Since piezoelectric transducers are somewhat non-linear, the scan produced is not linearly proportional to the scan voltage.

1.2.2 Mirror tilt

Piezoelectric transducers are not entirely homogeneous and so the three scanning stacks do not have identical characteristics. As a result the three stacks do not produce identical displacements and so the mirror tilts during the scan. This loss of parallel mirror alignment is serious for multipass operation of the interferometer.

1.2.3 Tedious to change mirror spacing

The mirror spacing determines the resolution of the interferometer. When the mirror spacing must be changed the scanning mirror assembly must be slid as a whole along the three rods. As a result mirror alignment is lost and the handling produces local temperature changes. The mirrors must be realigned with the micrometer screws and finally with the bias voltages on the scanning stacks. Time must be allowed for the instrument to thermalise again. The coarse mirror alignment is particularly time consuming and the whole process very inconvenient.

1.2.4 Stability

The mean mirror spacing and the parallel alignment should not vary with time. This requires dimensional stabilities of the order of 20 Å. To meet this requirement it is necessary to build the instrument out of low expansion materials which are expensive both to buy and to machine.

1.2.5 The device is not suited for tandem operation

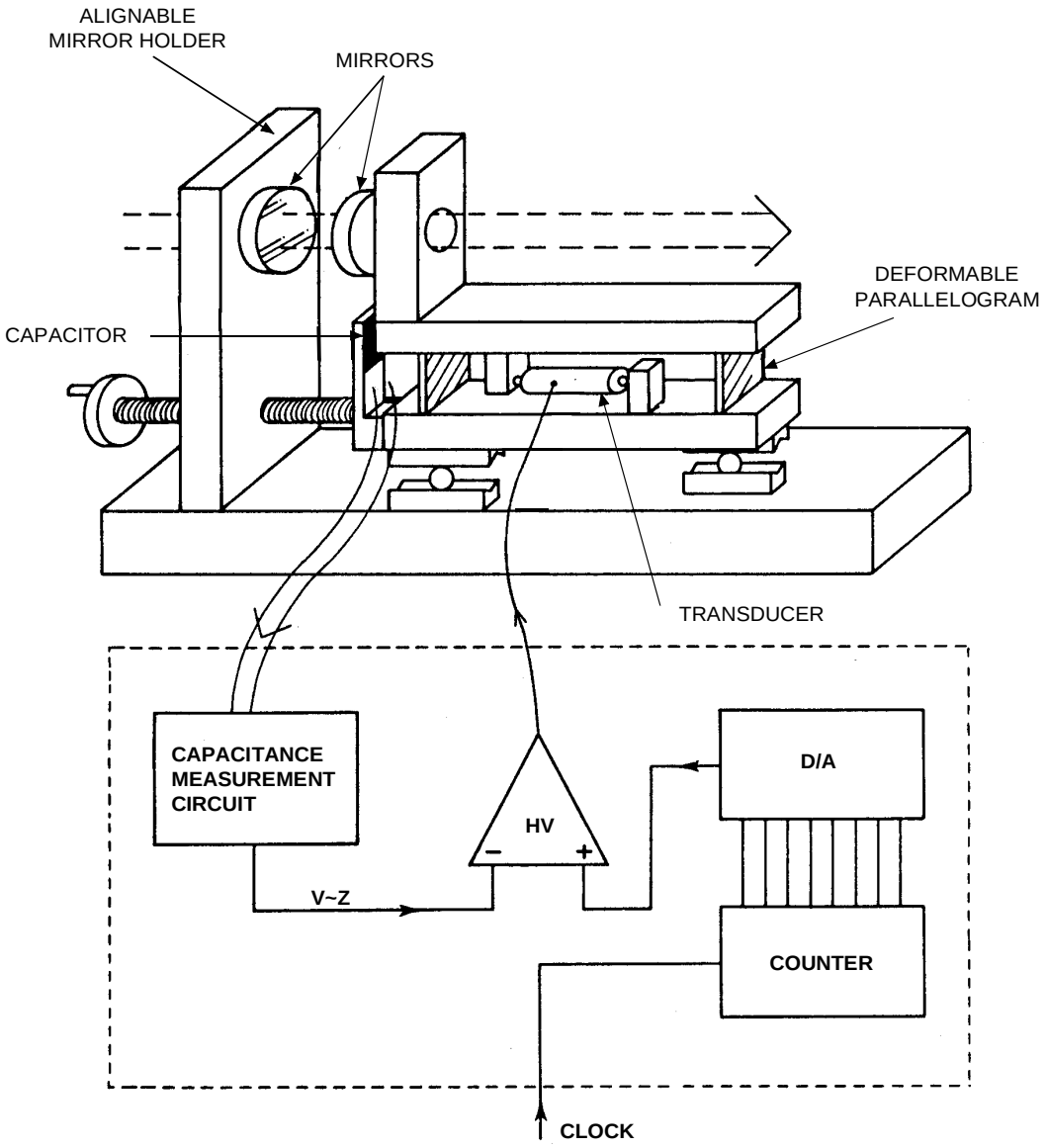
The combination of non-linearity in the scan and rather poor stability makes the synchronous operation of two interferometers in tandem virtually impossible.

In the following a method of constructing an interferometer is described using techniques which are known in other fields but which have not previously been applied to this problem. The resulting instrument gives a very satisfactory solution to all of the above problems.

1.3 Novel parallelogram construction used in TFPs spectrometers

An overview of the construction is indicated in Figure 1-2. The scanning mirror sits on a compound translation stage comprising a deformable parallelogram (for small displacements) attached to a crossed roller translation stage (for large displacements). The latter can be driven by a micrometer screw for obtaining the gross setting of the mirror spacing. The interferometer is scanned by means of a piezoelectric transducer acting on the deformable parallelogram. The mirror spacing is sensed using a capacitive displacement transducer which is used in a feedback loop to control the piezoelectric scanning transducer.

Figure 1-2 Simplified block diagram of scanning stage



A detailed description of the different elements follows.

1.3.1 The compound translation stage

The mirror translation stage must satisfy two conditions. Firstly, during the scan which would normally be a movement of < 3 μm, the parallel alignment of the mirrors must not be detectably altered. Secondly, after a gross change of the mirror spacing over a range of several mm the mirror alignment should have changed so little that strong spectral features are still discernible in the scanned spectrum. In this case a fine mirror adjustment using the piezoelectric alignment transducers will bring the mirrors back into full alignment (the transmitted intensity is maximum at given wavelength when the mirrors are accurately aligned.)

The first condition requires that during a scan of 3 μm all parts of the mirror move by the same distance to within a few Ångstroms. The second condition requires that during a gross movement of a few mm all parts of the mirror move by the same distance to within about ½ μm.
The high accuracy scan movement is achieved using a deformable parallelogram. Such a device has previously found application in infrared spectrometers, where dimensional tolerances are larger in proportion to the larger wavelength involved. However, provided reasonable care is taken in the construction to ensure that opposite sides of the parallelogram have equal dimensions (to within about 10 μm), the device is capable of producing movements of 100 μm and more without detectable tilt and is thus easily capable of achieving the required 3 μm scan.

The scan is actuated by a piezoelectric crystal acting between the upper plate of the rolling stage and the upper plate of the deformable parallelogram stage.

The deformable parallelogram stage sits on a crossed roller translation stage. The high precision translation stage using precision ground steel flats as runners is in itself sufficient for achieving the required suitably tilt free movement over distances of several centimetres.

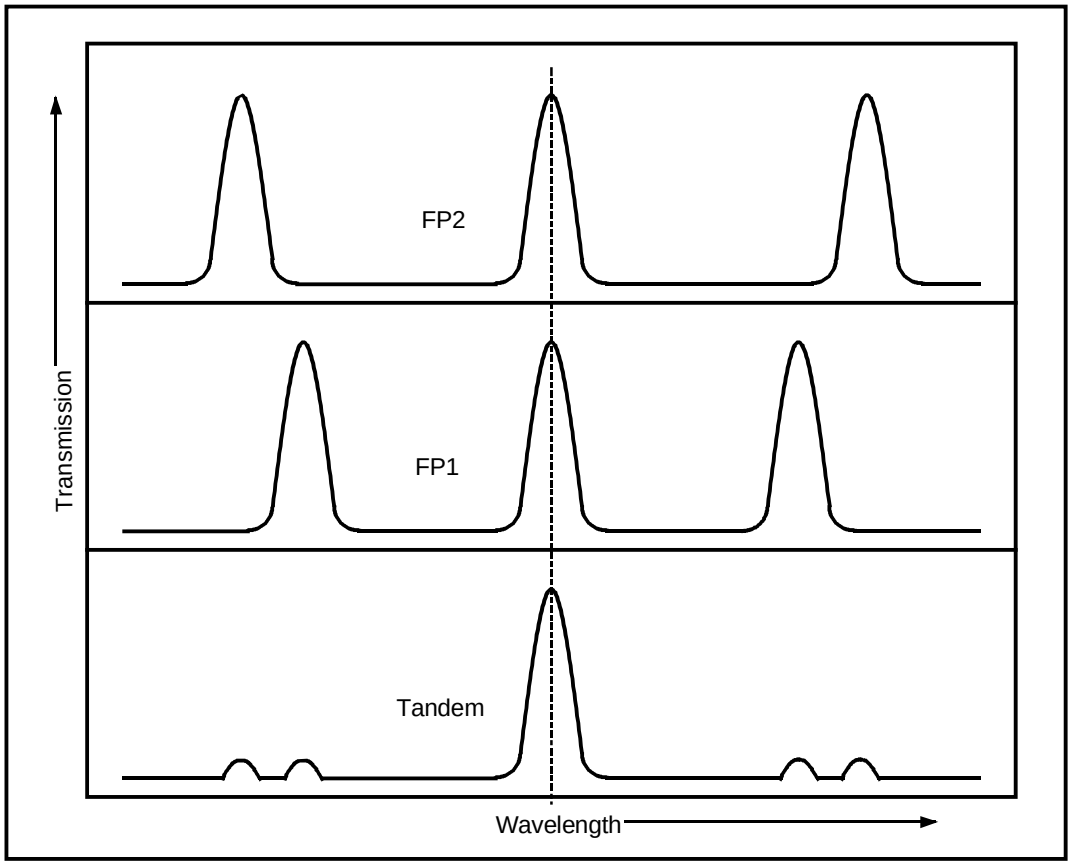
1.3.2 Measurement transducer for mirror spacing

A novel feature of the interferometer construction is the use of a capacitive displacement transducer for measuring the mirror spacing. The output of the transducer is accurately proportional to the spacing between the capacitor plates. The scan is achieved by comparing the scan voltage with the transducer output voltage and thus obtaining a correction voltage for driving the piezoelectric scanning transducer. This feedback scanning system achieves two goals. Firstly, the linearity of the scan is now determined only by the linearity of the displacement transducer and is independent of nonlinearities in the scanning transducer. Secondly, high stability is achieved against thermal expansion - as seen in Figure 1-2, the only paths which are thermally important are the short distances between the mirror holders and the capacitor (including of course the micrometre screw used for setting a given spacing). Any thermal expansion in the rest of the interferometer is entirely compensated by the feedback system.

1.4 Tandem interferometry

There exists a means of increasing the FSR at a fixed resolution by the use of two FP`s in series. The most useful arrangement is a vernier system in which the spacing of the second interferometer L_2 is close to L_1.

Figure 1-3 Tandem principle



The wavelengths transmitted by the combination must simultaneously satisfy:

$$L_1 = ½\ p\lambda \quad \text{and} \quad L_2 = ½\ q\lambda \qquad 5$$

for integral values of p and q.

If the spacings L_1 and L_2 are independently set so as to transmit a given wavelength λ then the combined transmission for light passing successively through both FP1 and FP2 will be as illustrated in Figure 1-3(c). The neighbouring transmission peaks do not coincide - only after several times the FSR of FP1 do the transmission peaks coincide again. Small "ghosts" of the intervening transmission peaks remain since the transmission of either interferometer as shown in equation 1 never falls exactly to zero. The frequency shift range of the tandem system is thus increased by a considerable factor over that of the single interferometer, while the resolution $\delta\lambda$ remains similar. In order that the first ghost is not too obtrusive one should chose L_1 and L_2 such that

$$F > L_1 / (L_1 - L_2)$$

A good practical value for L_2 / L_1 is about 0.95.
To use the tandem interferometer system as a spectrometer, it is necessary to scan the two interferometers synchronously, by simultaneously changing the spacings L_1 and L_2. It is clear from

equations 2 and 5 that to scan a given wavelength increment, the changes δL_1 and δL_2 must satisfy

$$\delta L_1 / \delta L_2 = L_1 / L_2 \qquad 6$$

The magnitudes of δL_1 and δL_2 are typically 1 to a few μm. The only previously known method of satisfying 6 was by use of pressure scanning. Remembering that L is the optical spacing of the mirrors (i.e. the spacing t multiplied by the refractive index n of the gas between the mirrors) one may change L by changing the refractive index of the gas through a pressure change. Since

$$L_1 = n \cdot t_1 \quad \text{and} \quad L_2 = n \cdot t_2$$

we see that condition 6 will be satisfied if the refractive index change is the same for both interferometers. The limitation of the method lies in the scanning range which is limited by the achievable refractive index change. Using air, a pressure change of 1 atmosphere will change L by only 3 parts in 10^4, producing the same relative change in the transmitted wavelengths. Where much larger scans are required, the associated large pressure changes make the system impracticable.

Any practical construction of a tandem scanning interferometer, apart from having a large scan range, must satisfy the following criteria:

Static synchronization

Synchronization requires that the spacings of the two interferometers are never allowed to depart from their correct relative values by as much as 20 Å.

Dynamic synchronization

The correct relative spacings must be maintained over a scan of several μm.

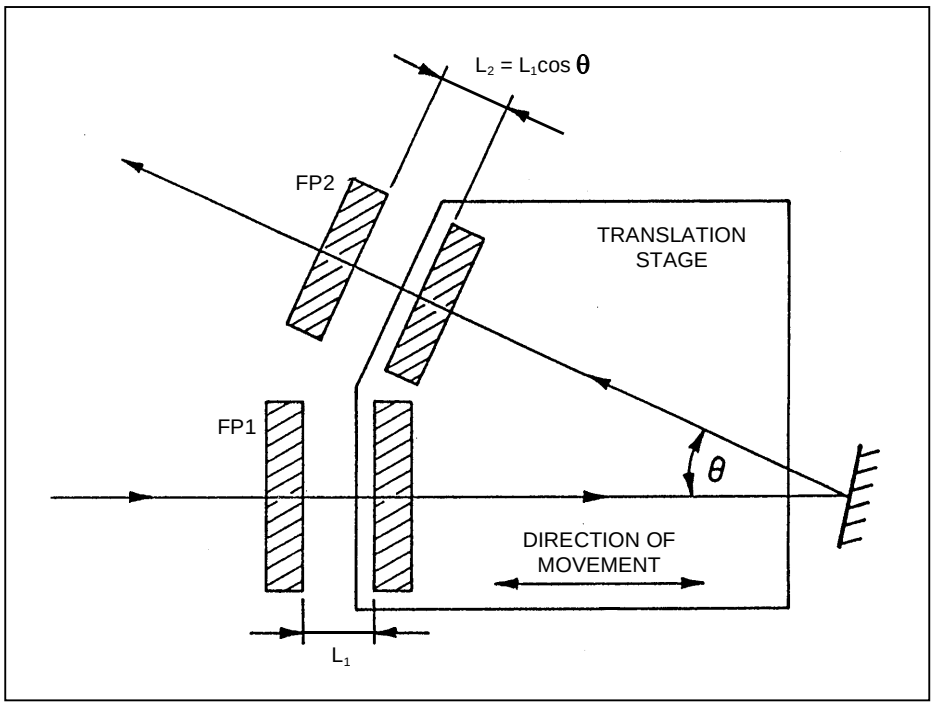
1.5 A practical design of scanning tandem FP

Using the new design of interferometer, based on the concept of a scanning stage, it is now possible to combine two interferometers on the single scanning stage to obtain both statically and dynamically stable synchronisation.

The principle of the tandem scan is seen in Figure 1-4. The first interferometer FP1 is arranged to lie in the direction of the translation stage movement. One mirror sits on the translation stage, the other on a separate angular orientation device. The second interferometer FP2 lies with its axis at an angle θ to the scan direction. One mirror is mounted on the translation stage in close proximity to the mirror of FP1, the second mirror on an angular orientation device which can also allow a small translation of the mirror for adjustment purposes. The relative spacings of the mirrors are set so that a movement of the translation stage to the left would bring both sets of mirrors into simultaneous contact.

A movement of the translation stage to the right sets the spacings to L_1 and $L_1 \cdot \cos\theta$. A scan δL_1 of the translation stage produces a change of spacing δL_1 in FP1 and $\delta L_1 \cdot \cos\theta$ in FP2. In other words relation 6 is satisfied and so the two interferometers scan synchronously. An upper limit on the length of the scan is imposed by the shear displacement of the mirrors of FP2 - after a scan of more than $D/\sin\theta$ (mirror diameter D) the mirrors would no longer overlap. A scan of several cm is easily possible for normal mirror diameters (3÷5 cm). Since the scan lengths in practice rarely exceeds 3 μm this large range should rather be understood as the range over which L_1 may be adjusted without requiring a lateral repositioning of one of the mirrors of FP2.

Figure 1-4 Tandem geometry



The main features of the system are:

- Complete dynamic synchronization over a large scanning range.

- Good static synchronization due to the compact design which enables both interferometers to share the same environment.

1.6 Vibration isolation

The interferometer requires a quiet, vibration free environment.

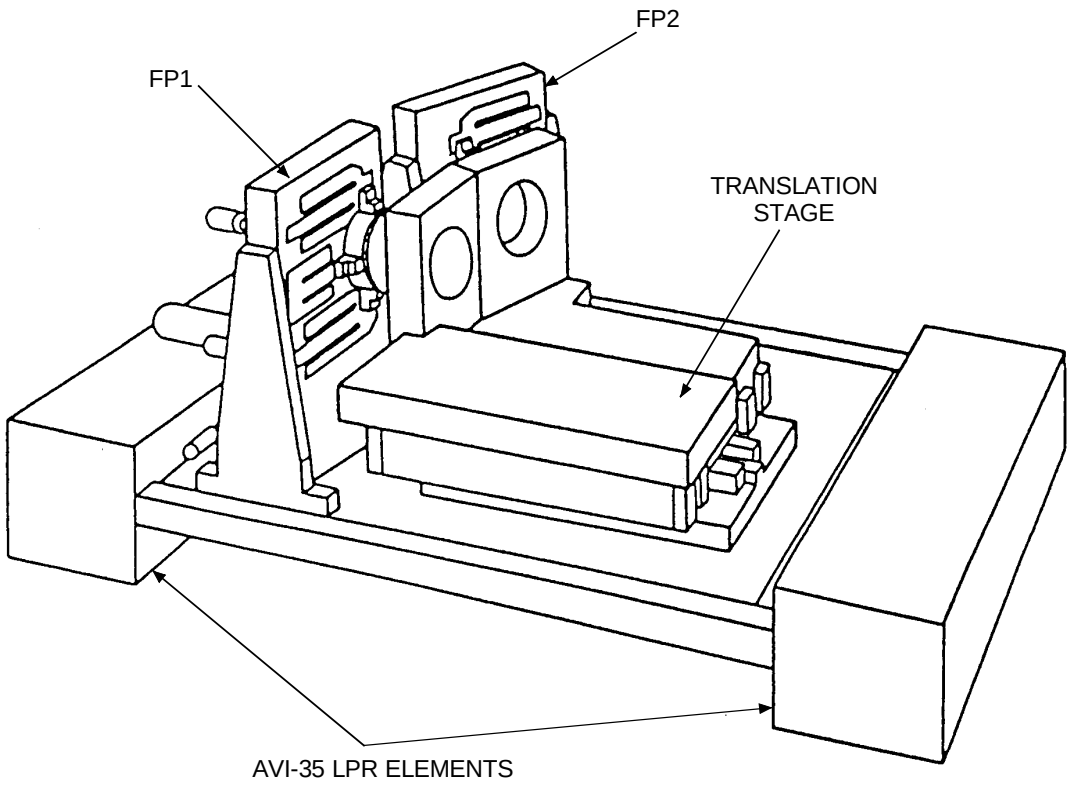
In order to scan a Fabry-Pérot through a single transmission peak a change in mirror spacing of about 25 Å is required. It is apparent that any external influence which distorts the mirror spacing by more than a few Å will seriously degrade the spectrum. Building vibrations, which typically have their maximum amplitudes in the range 10-20 Hz, introduce non-resonant distortions of the interferometer which can make the operation of the spectrometer impossible.

The traditional solution to vibration problems is to isolate the complete optical system from the building by using very soft passive springs in the form of damped air columns. Such a solution is adequate, but has the disadvantage that any vibration sources placed directly on the optical table will, of course, not be isolated from the interferometer. The better solution is to mount the optical table rigidly on the floor, but to isolate the interferometer from the optical table.

Dynamic isolation systems, using feedback control have recently become available and are ideal for this application. They are compact, stiff and with excellent directional and positional stability, unlike the soft passive isolation systems which drift over large displacements at low frequency. Figure 1-5 shows the tandem interferometer mounted on two dynamical isolation mounts. The optical components for multi-passing the interferometer are mounted directly on the optical table, since these components are, in general, not sensitive to building vibrations.

Note that an enclosure is required around the interferometer to protect it from sound waves which can excite high-frequency resonances in the system.

Figure 1-5 Schematic 3D view of the interferomter

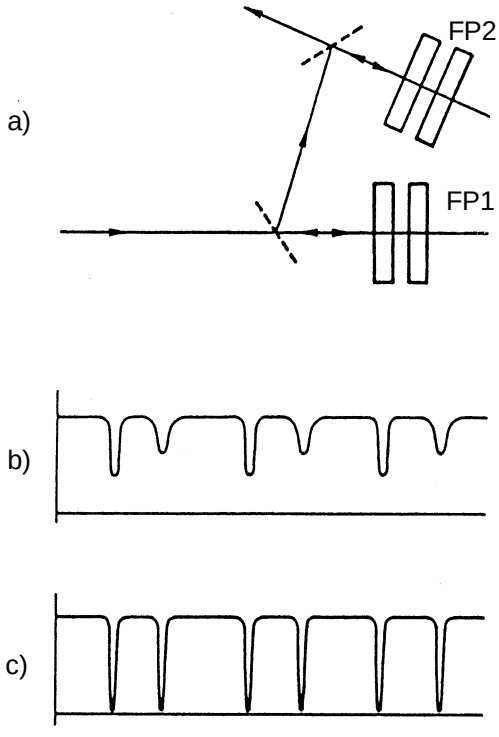


1.7 Prealignment of the interferometer

The interferometer is normally used in a multipass tandem mode. The system can only be made to operate in this mode if both interferometers have been pre-aligned parallel and with the correct relative spacing. The procedure described below uses the signal from the measurement photomultiplier for pre-alignment and can be implemented with only a few optical components.

As shown in Figure 1-6a light is passed through a beam-splitter onto the first interferometer FP1. The reflected light passes via a second beam-splitter onto FP2 whence the doubly reflected beam is directed to the photomultiplier. The light is assumed to be monochromatic (in most experiments this will be the case, since the elastically scattered component normally dominates). The pre-alignment method is based on the fact that when a Fabry-Pérot is transmitting, the reflected intensity tends to zero, a minimum value being obtained when the interferometer is optimally aligned. On scanning the interferometer the photomultiplier signal will, therefore, show a background intensity punctuated by minima whenever either FP1 or FP2 transmits. This is illustrated for a poorly aligned interferometer in Figure 1-6b. Two clearly distinct series of peaks are seen. On independently optimising the alignment of FP1 and FP2 the minima approach zero, as seen in Figure 1-6c. An adjustment of the relative spacing L_1-L_2 will now bring a pair of peaks into coincidence and the pre-alignment of the tandem interferometer is complete. On switching the optical system back to the multi-pass measurement configuration, transmission will be observed with only minor adjustments necessary to optimise the transmission.

Figure 1-6 Prealignment principle



The basic optical system used for achieving alignment in the reflection mode

The measured reflected intensity for two imperfectly aligned interferometers

The intensity after correct alignment but before synchronization

1.8 Stabilizing the Fabry-Pérot

In order to obtain long time stability of an interferometer it is necessary to apply some form of dynamic control in order to maintain both parallel alignment of the mirrors and correct spacing. The means by which this is achieved for a single interferometer is described at length in *J. Phys. E*, **9** (1976) p. 566.

Four successive scans are required in order to obtain error and correction signals for the two axes X and Y to maintain parallelism in a single interferometer. A tandem interferometer system requires many more scans in order to obtain the appropriate correction signals because now correct alignment involves adjustments about 5 axes, namely X1, Y1, X2, Y2 and ΔZ, where ΔZ is a change in the relative mirror spacing L_1-L_2. Of these alignments the ΔZ axis (synchronisation axis) is the most critical and so proportionately more time is spent on stabilising this axis. The scheme employed in the Interferometer Control Unit uses a cycle of 16 scans as shown below.

Scan No.	Axis Stabilised
1,2	Y1
3,4	X1
5-8	ΔZ
9,10	Y2
11,12	X2
13-16	ΔZ

A Z stabiliser is also employed by the Interferometer Control Unit in order to maintain a peak exactly at the midpoint of the scan.

2 OPTICAL LAYOUT OF THE TFP-1 AND TFP-2 HC SPECTROMETERS

The TFP-1 and TFP-2 HC spectrometers share the main scanning stage and interferometer while differing in the surrounding optical system.

Both the optical systems allow the interferometer to be used in the high contrast tandem triple-pass mode and in an alternative mirror alignment configuration, and are designed using a minimum number of components. Refer to the figures in this chapter to identify the meaning of the components abbreviation used in the manual.

The TFP- 1 optical system is shown schematically in Figure 2-2 (tandem configuration) and Figure 2-1 (alignment configuration).

The TFP-2 HC optical system is shown schematically in Figure 2-5 (tandem configuration) and Figure 2-6 (alignment configuration). Some of the components used in the system and here described are protected by the internal dark screens and will not be immediately visible when the instrument lid is open.

2.1 Optical layout of the TFP-1

The optical system allows the interferometer to be used in the high contrast triple-pass tandem mode. The system is shown schematically in Figure 2-2.

The scattered light enters the system at the adjustable pinhole P1. The aperture A1 then defines the cone of light which is accepted. Mirror M1 reflects the light towards the lens L1 where it is collimated and directed via mirror M2 to FP1. Here it passes through aperture 1 of the mask A2 and is directed via mirror M3 to FP2.

After transmission through FP2 the light strikes the 90° prism PR1 where it is reflected downwards and returned parallel to itself towards FP2. It continues through the aperture 2 of A2 to FP1. After transmission through FP1 it passes through lens L1, underneath mirror M1, and is focussed onto mirror M4. This mirror returns the light through lens L1 where it is again collimated and directed through FP1.

The combination of lens L1 and mirror M4 lying at its focus is known as a catseye, and is optically equivalent to a cornercube but has the advantage that it also acts as a spatial filter which filters out unwanted beams such as the beams reflected from the rear surfaces of the interferometer mirrors.

After the final pass through the interferometers, through the aperture 3 of A2, the light strikes the mirror M5 where it directed to the prism PR2. This prism, in combination with the lens L2 and the output pinhole P2, forms a bandpass filter with a width determined by the size of the pinhole. The mirror M6 sends the light to the output pinhole and will have to be adjusted when-ever the laser wavelength is changed.

Provision is made for prealignment using the reflection technique described in section1.7. For prealignment a translation stage moves the beam splitters BS1 and BS2 into position as shown in Figure 2-1. The glass block G1 shifts the light sideways so that it strikes FP1 in the centre. The light reflected from FP1 and FP2 is shifted via the glass block G2 into the output path so that it passes through the output pinhole and on to the photomultiplier.

Prealignment is thus made using the scattered light from your experiment without having to open the enclosure of the spectrometer.

Figure 2-2 TFP-1 Tandem optics

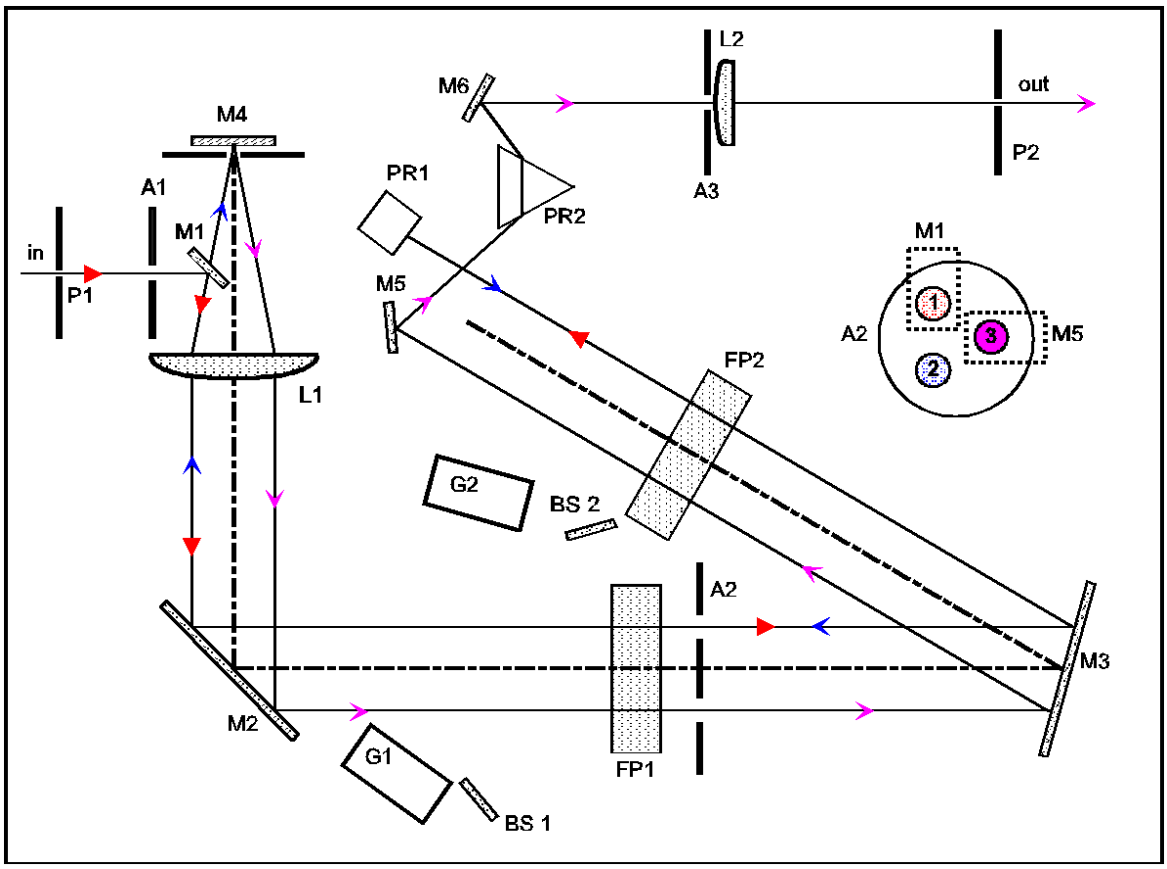
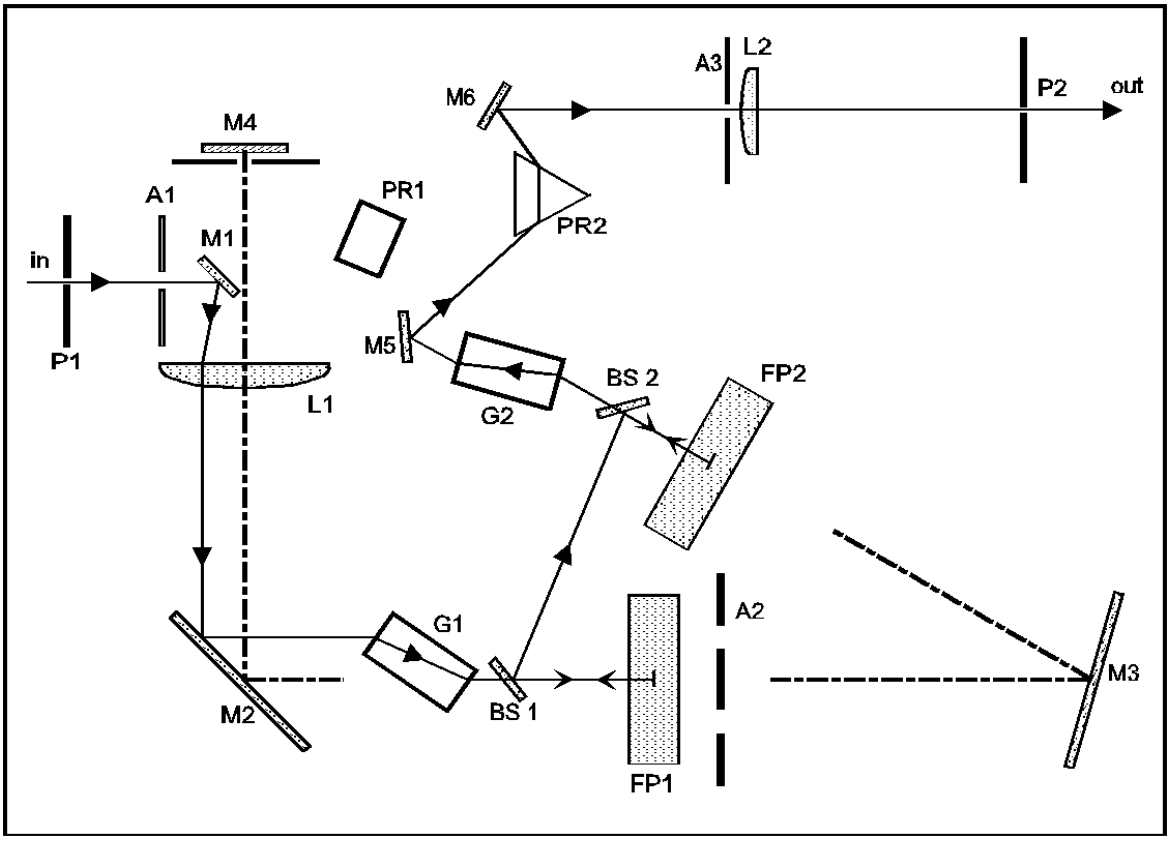


Figure 2-1 TFP-1 Alignment optics



2.2 Optical layout of the TFP-2 HC, differences with TFP-1

The triple pass tandem optical system of TFP-1 described above has still limitations. The contrast is limited to about 10^{11} which is way below the theoretically expected value, and some asymmetry is present in the transmitted peaks.
In a multipass interferometer one would like the individual passes to be independent of each other. In other words there should be no interferometric coupling between the passes. In the standard optics this is approximated by introducing some absorption and some misalignment between the passes. This results in the slight asymmetry and loss of contrast.
Furthermore for simplicity the optical system was laid out as a 3-pass tandem arrangement. This has the disadvantage that the first tandem pass inevitably then lies close to the third (final) pass leading to some cross-talk which again reduces the contrast.
The new high contrast optical system in the TFP-2 HC avoids these problems in two ways. Firstly, the optical layout is a tandem arrangement of two triple pass interferometers. A spatial filter separates the two interferometers and so eliminates any cross-talk between the first and last passes. Secondly, and more importantly, the coupling between passes is eliminated using quarter wave antireflection techniques. This requires no misalignment so that the transmission peaks remain completely symmetrical. Because the multiple reflections between passes are totally eliminated, the contrast is much higher. A contrast of at least 10^{15} is achieved.

2.2.1 Quarter wave optics

The light is reflected between passes using 90° triangular prisms. As shown in Figure 2-3, by aligning the polarisation at 45° to the prism axis, linearly polarised light is converted into circular polarised light, and vice versa. This is very similar to the use of a Fresnel rhomb.

Figure 2-3 Quarter wave optics in TFP-2 HC

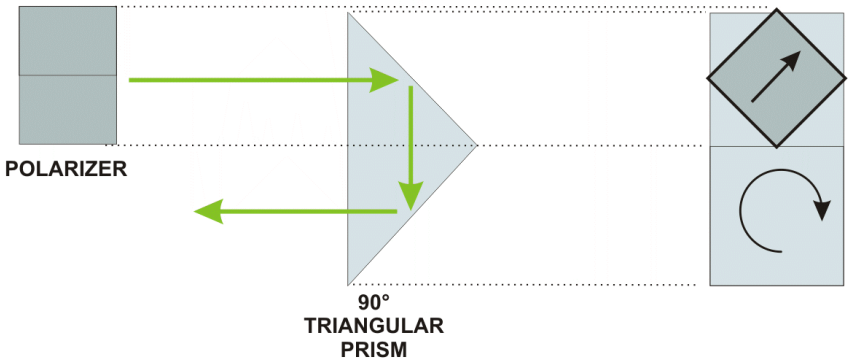
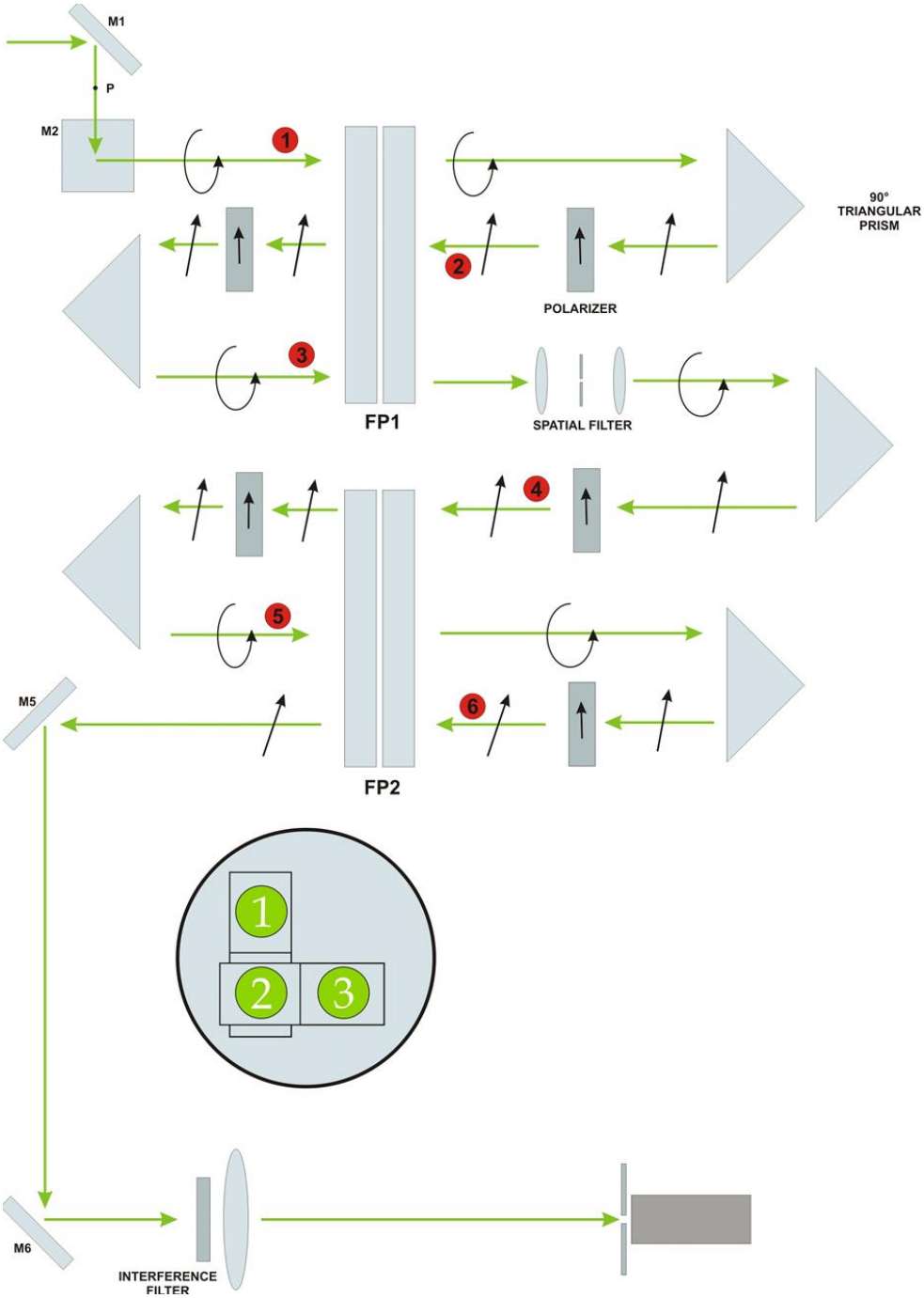


Figure 2-4 shows the optical arrangement. Light enters the spectrometer with vertical polarisation and is converted to circular polarisation at mirror M2 (for simplicity the construction of this mirror is not shown). The light then enters FP1. After the first pass the light is reflected by the prism and becomes again linearly polarised and so passes unattenuated through the polariser. Reflected light will pass again through the prism and when it returns the polarisation will be rotated by 90° and it will therefore not pass the polariser. Thus the multiple reflections between passes are totally eliminated. After 3 passes through FP1 the light passes through a spatial filter before making 3 further passes through FP2.

Figure 2-4 Optical arrangement in TFP-2 HC



2.2.2 Description of the optical system

Figure 2-5 and Figure 2-6 show the optical arrangement in the TFP-2 HC optical plate, respectively for tandem and alignment mode optics configuration.
The scattered light enters the system at the adjustable pinhole P1. The aperture A1 then defines the cone of light which is accepted. Mirror M1 reflects the light towards the lens L1 where it is collimated and directed via the G1 optics group to FP1. The light is then transmitted through the Fabry-Pérot couple FP1 and reaches the vertical retroreflector group G2 after passing the main instrumental mask A2.

Group G2 sends light back on the same direction but at a lower height, so that it goes again through A2 and FP1 (second pass), reaching then horizontal retroreflector group G3.

Light coming from the second pass is shifted horizontally by G3 and sent to FP1, then passing the third and last hole in A2. The scheme of the first three passes position with respect to the section view of FP1 is also reported in Figure 2-5, on the left.

A spatial filter SF1, comprising a pinhole and two small lenses, is used to optically decouple the first Fabry-Pérot couple from the second one. After being transmitted for the third time through FP1, the light reaches optics group G4 going through SF1. There the beam is steered and directed orthogonally towards FP2.

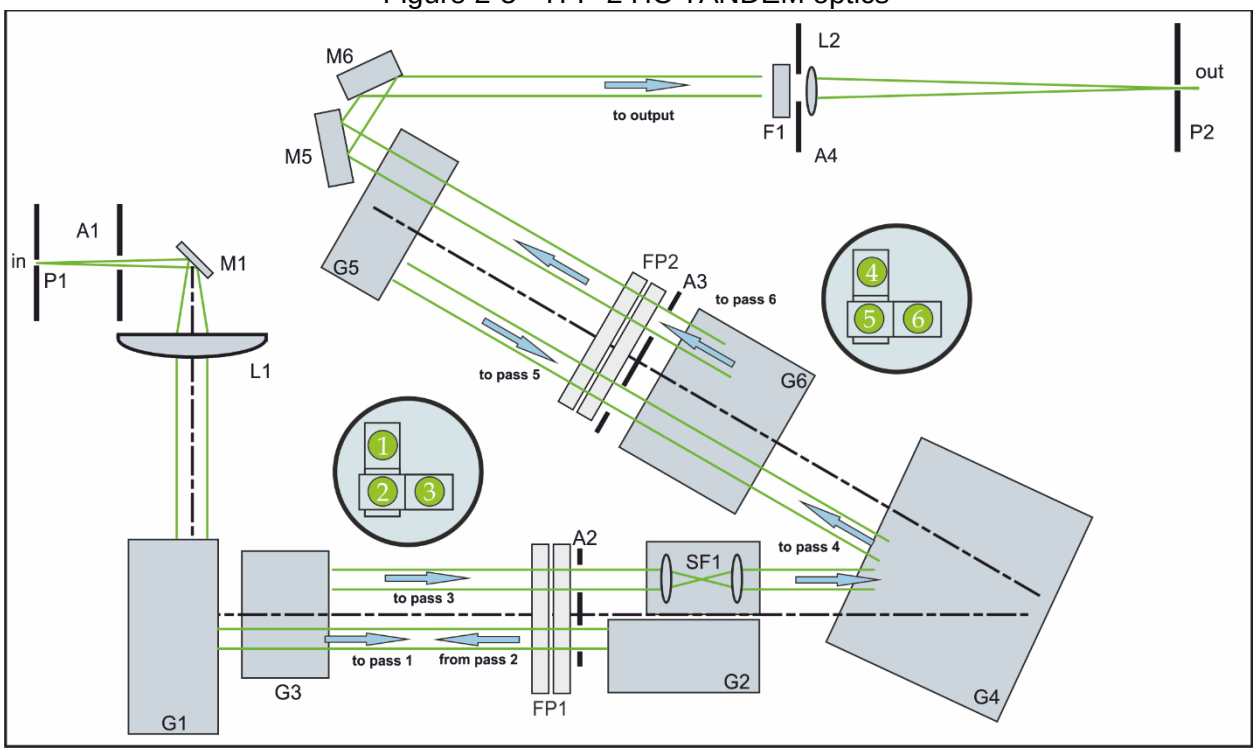
The measurement beam is similarly passed through FP2 for the fourth, fifth and sixth passes of the multipass system, bouncing back and forth between retroreflector groups G5 (vertical) and G6 (horizontal) and passing also each time through aperture A3. The positions of the last three passes with respect to the transverse section of FP2 is shown in Figure 2-5, at right.

After coming out from the sixth pass, light is sent by mirrors M5 and M6 to the final focussing lens L2, whose focus lies on the output adjustable pinhole P2, and then reaches a single photon detector (not shown in figures). Immediately before L2 an interference bandpass filter F1 and an aperture A4 are also present. F1 prevents any wavelength differing more than 1 nm from the nominal one from reaching the lens and the detector.

Provision is made for prealignment using the reflection technique described in section 1.7. For prealignment, a translation stage moves the beamsplitters BS1 and BS2 into position as shown in Figure 2-6. The prism PR1 shifts the light diagonally so that it strikes FP1 in the centre. The light reflected from FP1 is sent to the centre of FP2 through BS2; the resulting backreflected beam is then shifted via the prism PR2 into the output path so that it passes through the output pinhole and on to the detector. The final part of the optical path, including M5 and M6, is shared with the tandem configuration.

Prealignment is usually made using the reference light entering the instrument without having to open the enclosure of the spectrometer.

Figure 2-5 TFP-2 HC TANDEM optics



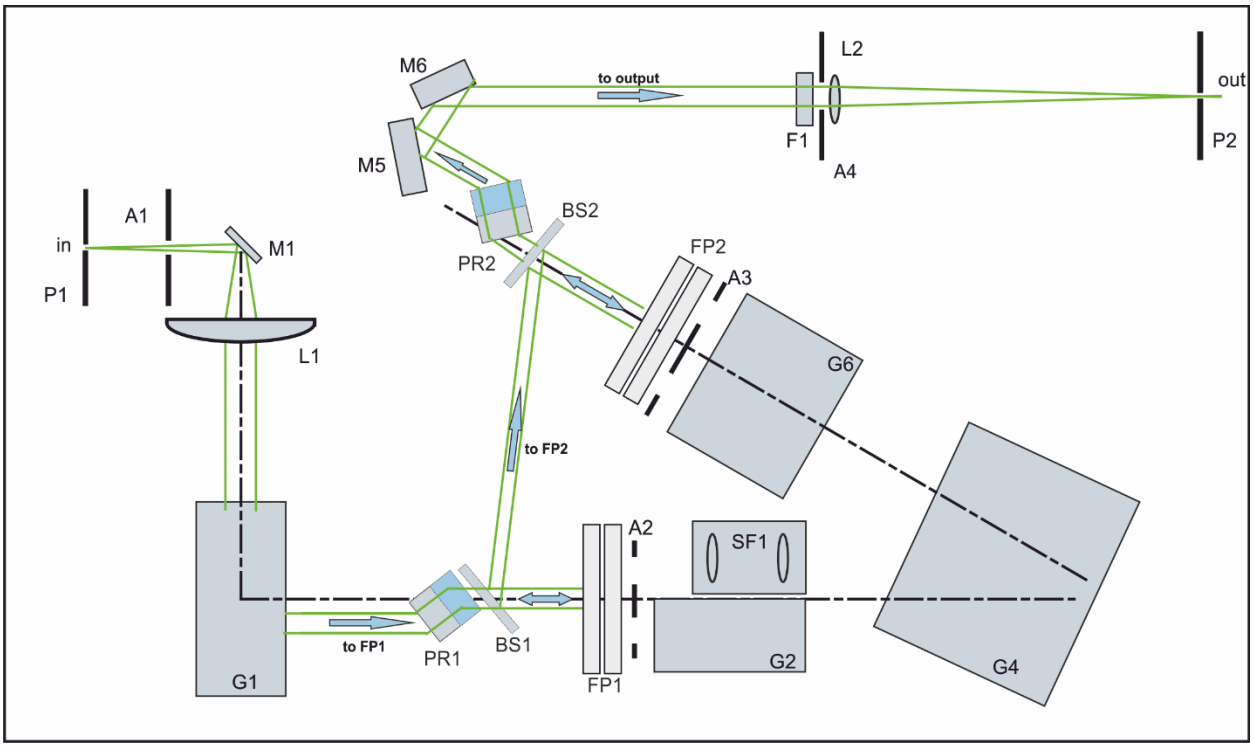


Figure 2-6 TFP-2 HC Alignment optics

3 ASSEMBLY AND INSTALLATION OF THE SPECTROMETER

3.1 Instrument unlocking

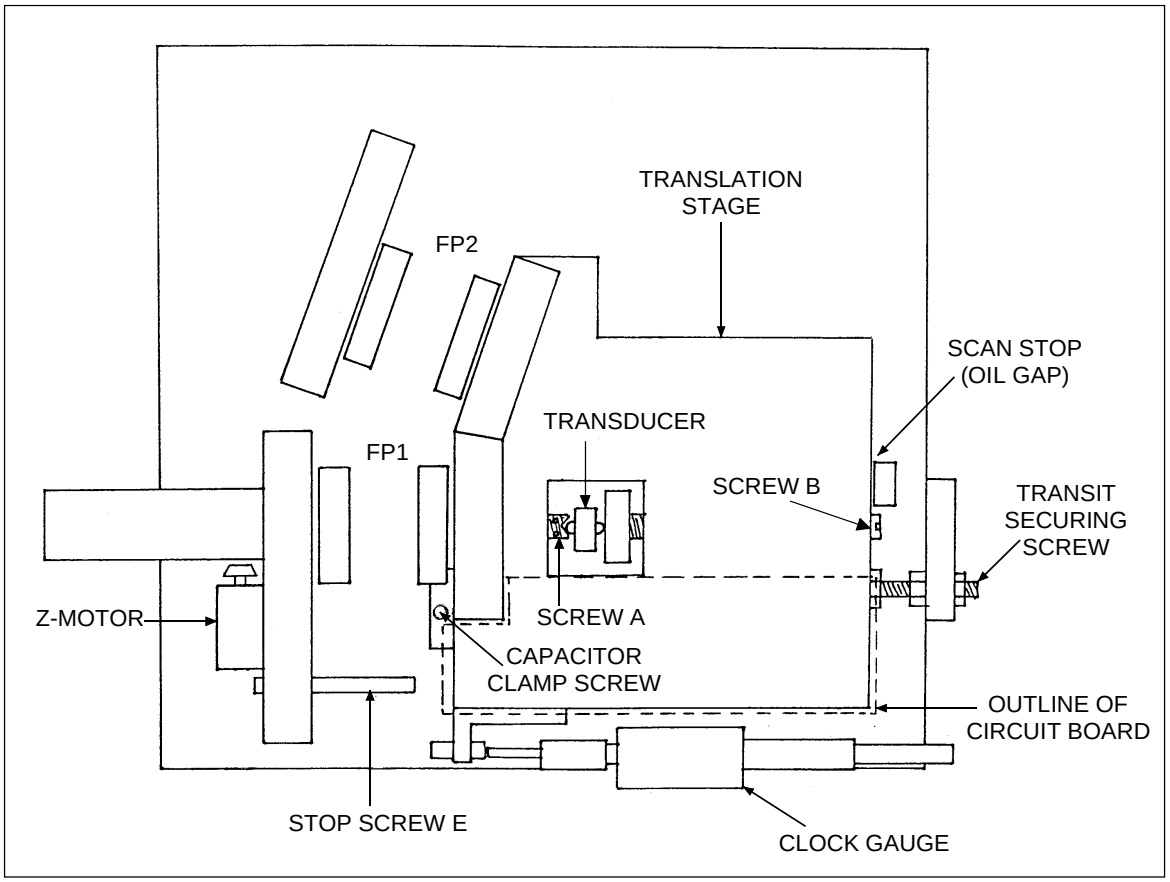
When the interferometer is shipped, various sensitive parts are secured against movement during transport. The instrument is fully assembled with the exception of the interferometer mirrors and the pinhole viewer, which have been removed and packed separately.
Separate instruction sheets are provided with the instrument, containing some preliminary unpacking and unclamping operations, such as:

1 Unlocking of the vibration isolation stage supporting the interferometer, done by removing the three M6 bolts through the interferometer support bars.
2 Unlocking of the interferometer translation stage for changing the mirror spacing, engaging of the motor for adjusting the mirror spacing.
3 Unclamping of the deformable parallelogram scanning stage.

Perform all the operation described in the unpacking instructions sheets, including the electrical connections, before going on with the operation described in this chapter. The FP mirrors installation, which is cited in the unlocking instructions, is described in larger detail in the following section 3.3.

After completing the unpacking and unlocking operation, we recommend that the removed material is stored in a safe place, so that it can be used in the future, if the system needs to be shipped again (i.e. for upgrade or maintenance). In this case, the procedure in section 8.3 describes how to lock again the instrument.
Having unpacked the instrument, the following instructions should be carefully carried out as a preliminary setup and check on the correct operation of the instrument.

Figure 3-1 Schematic top view of the interferometer



3.2 Operation and diagnostics of the vibration isolation system

When operating the system for the first time, set the front panel isolation switch to OFF and switch on power. The green LED will light (indicating power) and all the output saturation warning lights will illuminate. After a few seconds these warning lights will begin to go out or flicker. It may take about 15 seconds for the last ones to go out. After 30 seconds switch the isolation switch to ON and the yellow LED will glow indicating that the system is stabilising.

During normal operation all warning lights should be out. Excessive forces applied to the interferometer will cause input and/or output circuits to saturate - this makes a useful check that all isolation elements are working.

A severe overload causes the system to switch off for a few moments before attempting to stabilise again.

In the normal course of events the front panel isolation switch may be left ON and the system switched on and off using the power switch. After switching on there is a built-in delay of about 20 seconds before the system isolates. During this period the isolation indication lamp blinks.

The system will be operating correctly when all overload indicator lamps are out and the isolation indicator lamp is on.

Note: The rear panel BNC socket gives a multiplexed output showing the signals from all 8 accelerometers. These signals can be viewed on a simple analogue oscilloscope by setting the time base to 20ms and sensitivity to 0.5V. On setting up for the first time it is strongly recommended that you look at this signal, with the isolation switch both ON and OFF - it gives a good impression of how well the system is operating.
Pushing sideways on your optical table should NOT cause any of the LEDs to light up. If they do, the support legs of your table are not rigid enough.

3.3 Mounting the mirrors in the interferometer

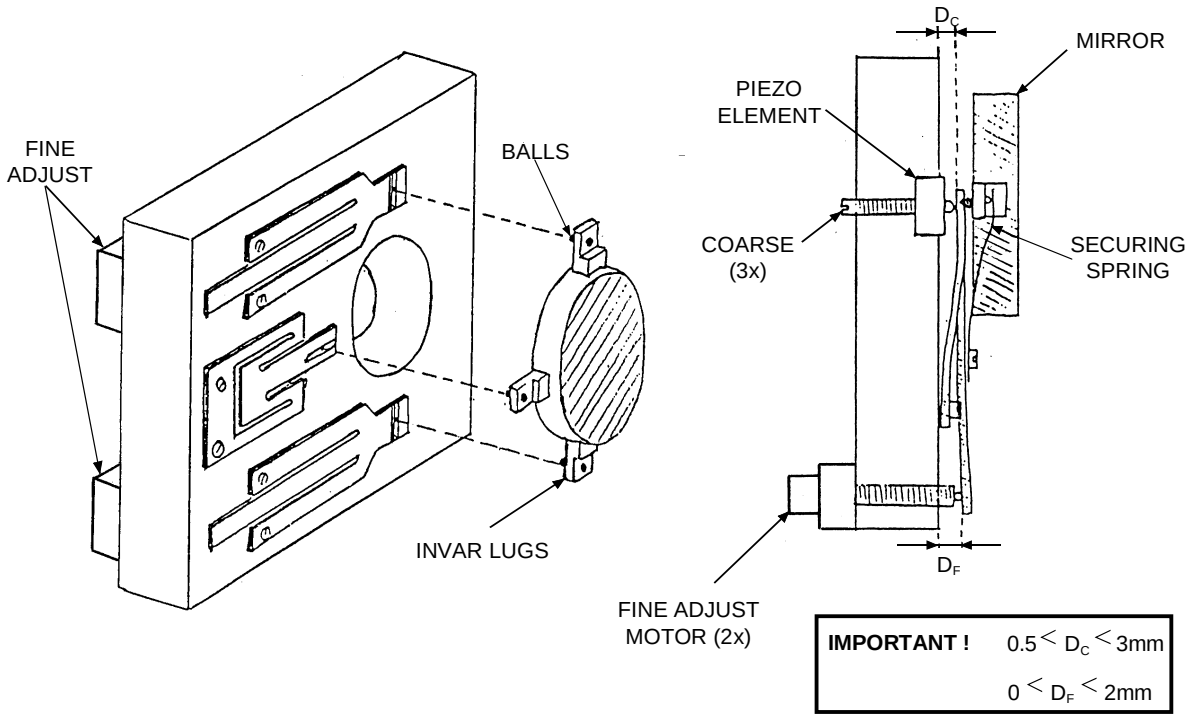
A careful study of Figure 3-2 shows how the mirrors are to be mounted in the interferometer. The two mirrors pairs have been planarity-corrected at factory: a brass ring or an aluminium crown correction devices could have been mounted. These correction device must never be removed or altered.

Each mirror pair is packed in a single box: mirrors of the two pairs must not be mixed. Each mirror is labelled so that they can’t get confused. It is advisable to keep the boxes and the packing material so that they can be reused in case you need to ship the mirrors or to store them for a long time.
The reflective surface of each mirror must go towards the inside of the holder, and is also indicated by a small arrow on the side edge.

The right and left mirror of each pair are not identically mounted: the invar mounting lugs are aligned with the left surface of the left mirror of each pair, while they are positioned about the middle of the mirror thickness on the right mirrors of each pair.

A pair of small bent tip tweezers is useful when moving the bronze securing springs; the bronze springs must be handled gently in order not to strain them : move them just enough to place the mirror, not more.
Particular care should be taken to check that all the three balls are properly sitting inside the guides on the mirror holder, so that the positioning is correct. A little inspection mirror could be useful to check the positioning of the lower ones, which are otherwise not well visible.

Figure 3-2 FP mirrors mounting



1. Move translation stage fully to the right in order to give maximum spacing.

2. **FP2:** Swing all of the mirror securing springs to the side to allow access for mirror.

3. Bring up first mirror (generally the left one is the easier to do) to the mirror holder on the scanning stage. Make sure the balls on the lugs sit securely in the appropriate grooves. Swing securing springs into position, starting from the top and middle one, then adding the bottom one. After moving all the spring in position, use the inspection mirror for a further check of the balls positions.

4. Repeat the operation with second mirror to be mounted on the mirror holder.

5. **FP1:** Before mounting the scanning mirror of FP1 move the spring that will hold the middle lug to the left so that it lies on top of the corresponding lug of FP2.

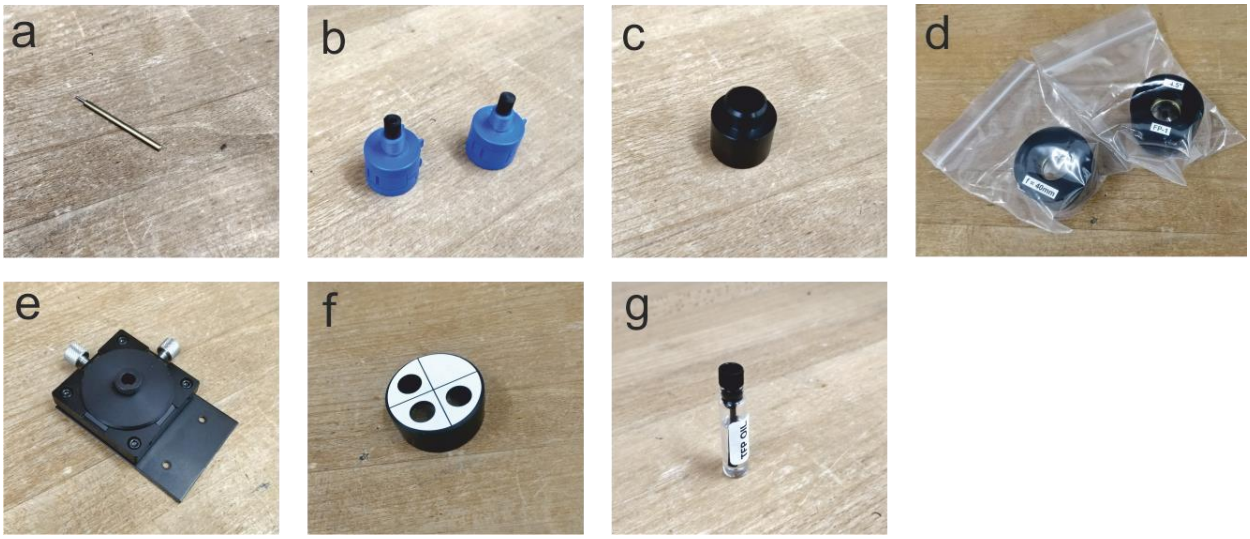
6. Mount mirrors of FP1 as in (1) to (4) above.

The exact relative spacing of FP1 and FP2 will be obtained later when calibrating mirror spacing.

3.4 Accessories provided with the spectrometer

Several accessories are provided with the instrument and are required to perform ordinary or extraordinary maintenance. To ease their identification, some of these are shown in the following pictures:

a) Adjustment tool for scanning piezoelectric transducer and spacing gauge, for adjustments described in sections 3.5, 5.1, 5.2 and 6.3.
b) Spare potentiometers for interferometer control unit knobs.
c) Base for Michelson-style tool, mentioned in section 7.2.5 (**only for TFP-2**).
d) Set of mounted lenses for calibration of FP1 mirror spacing, as described in section 6.3.
e) 10 mm lens assembly, with 2 axes motion knobs, useful for check and alignment of the spectrometer, as described in section 6.1.
f) Passes positioning mask. If inserted on the left side of the FP mirror holders, this mask is used to check the position of the passes across the mirror surface (**only for TFP-2**).
g) Oil for the spectrometer's oil gap, indicated in Figure 3-1 and mentioned in section 5.6.



3.5 First setup of the scanning transducer

The scanning transducer is disengaged for shipping and must be reset to use the spectrometer.

This operation requires that the TFP control unit is switched on. Before doing this, ensure that the detector power switch, located on the rear panel of the unit, is in the "off" position. After pressing the power button on the upper left corner, the four red LED lamps on the front panel must all turn on together, and remain lit. Ensure that the "stabiliser" switch on the front panel of the control unit is in the "off" position.

Figure 3-1 shows the interferometer inside the TFP-1 and TFP-2 HC from top; in the TFP-2 HC, the right part of the interferometer stage is hidden by the right part of the optical plate.

Observe that the transducer adjustment screw A has small transverse holes drilled in it. A special tool is provided to engage in these holes for adjustment. In TFP-2 HC, it may be necessary to change the mirror spacing, using the Z motor (also visible in Figure 3-1, and controlled by means of the front panel on the TFP box), in order to have access to screw A.

Observe the mirror spacing indicated by the dial gauge. Note also the stop screw E which may be used to prevent the mirrors from being brought too close together (don't be afraid – nothing will happen if they do touch). The stop screw is normally **not** set at factory, and it is not required to set it for normal use of the instrument.

The transducer and the scan capacitor must be adjusted correctly for linear scanning. The scan capacitor is a parallel plate capacitor with a nominal spacing of 10 μm. One plate has a swivel mount which can be clamped by the capacitor clamping screw, also shown in Figure 3-1.

1. When the instrument is shipped, the capacitor is unlocked: the adjustment screw A and the capacitor clamp screw are loose. Verify that the capacitor clamp screw is loose and that the 20 μm shim is in place in the scan stop/oil gap. In the TFP-2 Interferometer, the oil gap is visible only in a limited range of mirror spacing: if necessary, change the mirror spacing moving the Z motor until you can see the shim and access the oil gap. Verify that screw A is loose: If the adjustment tool is inserted and if you try to wind (advance) it, you should not feel any resistance.

2. Tighten the capacitor clamp screw. Do not overtighten.

3. Advance screw A until you start to feel a resistance, and then still for about 1/8 of a turn, until the transducer is just tight. In this condition, the 20 μm thick steel shim in the oil gap of the scan stop may be removed (keep it for later, it is a very useful part!).

4. Apply 1 or 2 drops of light machine oil to the oil gap, using the tip of a small screwdriver (refer to section 5.6 for more details).

5. The indicator on the control unit front panel, second from right (n. 14 in Figure 4-2), which measures the Z scan voltage may now indicate full scale. Set the Z knob (n. 15 in Figure 4-2) so that the related indicator shows mid-value. Set the scan amplitude to zero by rotating the control (13 in Figure 4-2) fully counter clockwise. Now attempt to centre the Z scan indicator by rotating screw A: if the indicator is down turn the tool towards the dial gauge, and vice versa. Do not rotate screw by more than ¼ turn. If oscillations occur - you will hear this as a 600 Hz howl of agony - switch off and check section 6.7.1.

6. The transducer and capacitor are now set properly. Remember to remove the tool from screw A.

3.6 Further check of the TFP control unit

1. With scan amplitude set to zero, rotate the Z knob between extreme positions: the scan position indicator should vary over about plus/minus one division of the scale. (The stabiliser switch must still be in OFF position!)

2. Increase scan amplitude control from zero and observe appropriate movement of the Z scan indicator.

3. Observe that movement of the adjustment potentiometers for X1, Y1, ΔZ, X2 and Y2 cause movements of the appropriate indicators over the full scale.

CAUTION

The electronics board over the translation stage has ~200 V present on some components and conductors. Take care that no grounded metal objects or fingers come into contact with this board, for example when adjusting transducer.

4 DESCRIPTION AND USE OF THE TFP SPECTROMETER

This chapter will provide an introduction to the spectrometer and the basic procedures for use. It will also present the main requirements concerning the light inputs to the instruments.

4.1 Components and controls of the spectrometer

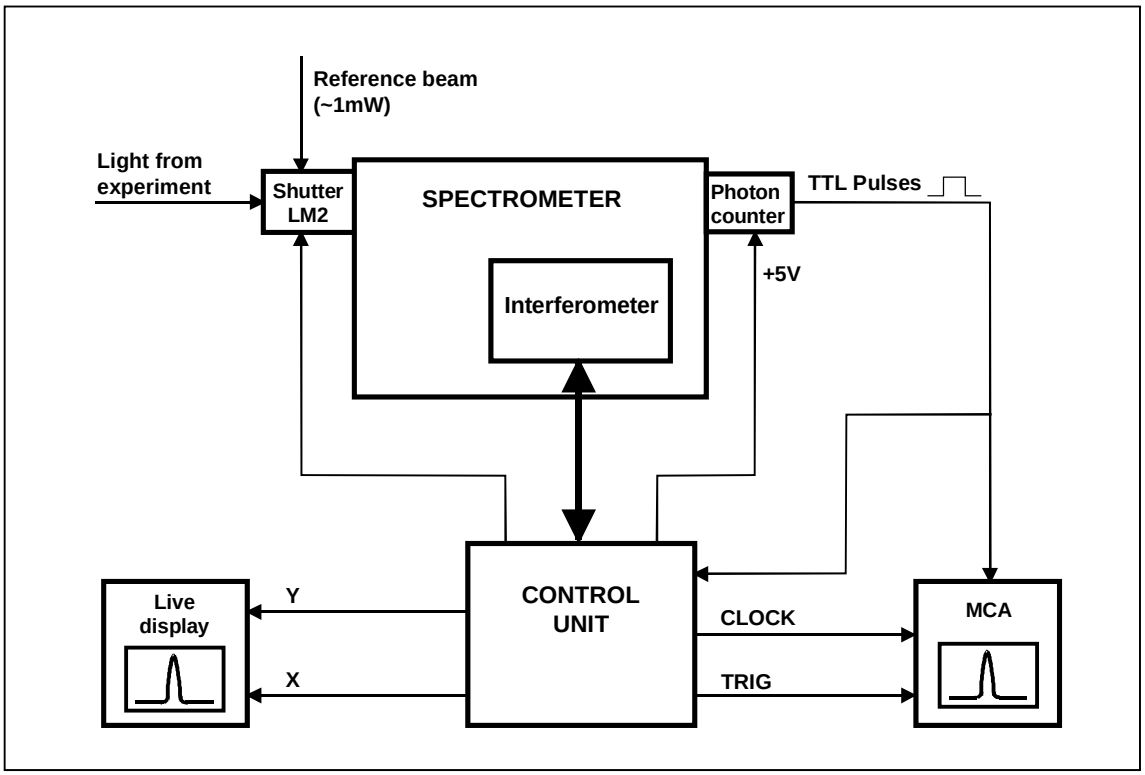
The block diagram of the instrument setup is shown in Figure 4-1; the spectrometer is provided with an input shutter unit (LM2) and a single photon detector. Double detector configurations are also possible.

The spectrometer control unit is connected to the device box by a 25 pin cable, and provides supply to the photon counter and to the shutter unit by means of two more cables. TTL pulses are sent back to the control unit using a BNC cable. It is possible to see the output signal in analogue format using the XY outputs on the back of the control unit and/or on a PC, by means of the GHOST software and Multi Channel Analyser (MCA).

Users equipped with the MCA GHOST external system will need to connect the external GHOST MCA box to the control unit via the CLOCK and TRIG lines. On most modern control unit this connection is made internally and the GHOST software only need to be connected to the control unit by means of the specific DB-9 RS-232 connector.

The input shutter unit contains two different input ports for light. The main one, on the left side, equipped with a manual pinhole wheel, is the input for the experimental light to be analysed. A secondary input on the rear side of the shutter (reference input) is needed for alignment purposes and is usually hit by a sample of the laser light, with a power in the range 1-10 mW.

Figure 4-1 Block diagram of the instrument setup



4.1.1 Interferometer control unit

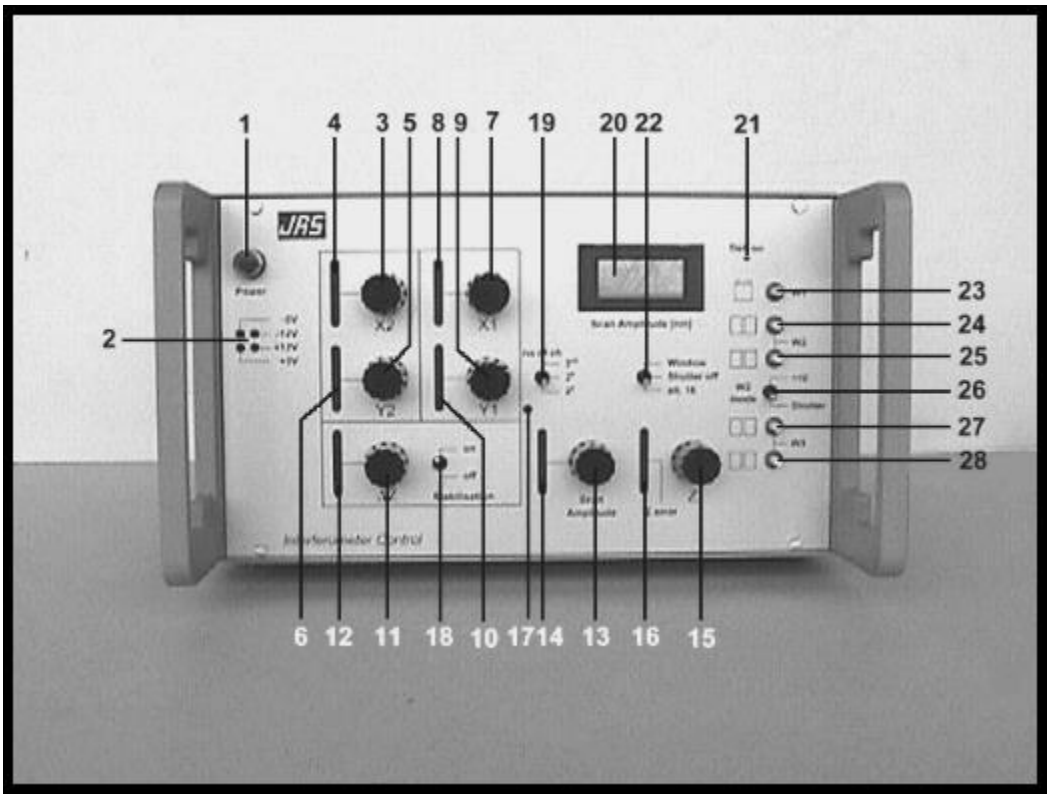
Most of the controls for the instrument are located on the interferometer control unit, which also provides electric supply to the instrument and (excluding a few exceptions) to the detector.

The control unit allows one to:

- Align both the mirrors pairs manually, using the piezoelectric transducers until the tandem condition is reached
- Maintain alignment on a long time period, automatically compensating any perturbation
- Scan the mirror on the nanometric range, maintaining alignment, and dividing the scan in a fixed number of subdivisions
- Activate the input shutter according to the experimental situation and requirements
- Provide analogue and digital output lines for measurement data gathering
- Remotely access a subset of these functions by means of rear input connectors

The front panel of the control is shown in the following figure:

Figure 4-2 TFP control unit front panel



The description of the control unit front panel controls follows:

1. Main power switch
2. Internal supply availability indicators (supply is ok when all are lit)
3. X2 piezoelectric tilt control
4. X2 piezoelectric tilt position indicator
5. Y2 piezoelectric tilt control
6. Y2 piezoelectric tilt position indicator
7. X1 piezoelectric tilt control
8. X1 piezoelectric tilt position indicator
9. Y1 piezoelectric tilt control
10. Y1 piezoelectric tilt position indicator

11. ΔZ shift control
12. ΔZ shift position indicator
13. Scan amplitude control
14. Scan position indicator
15. Z shift control
16. Z shift + stabilisation centring position indicator
17. Scan amplitude LCD display indicator calibration screw
18. Stabiliser feedback switch
19. Number of channel selector
20. Scan amplitude LCD display indicator
21. Detector supply indicator LED
22. Shutter mode selector
23. Main shutter window width control
24. Secondary shutter window start position control
25. Secondary shutter window width control
26. Secondary shutter window mode selector
27. Tertiary shutter window start position control
28. Tertiary shutter window width control

The meaning of many of these controls may be immediately clear to the reader; the main functions of the control unit will be described in detail in this chapter.

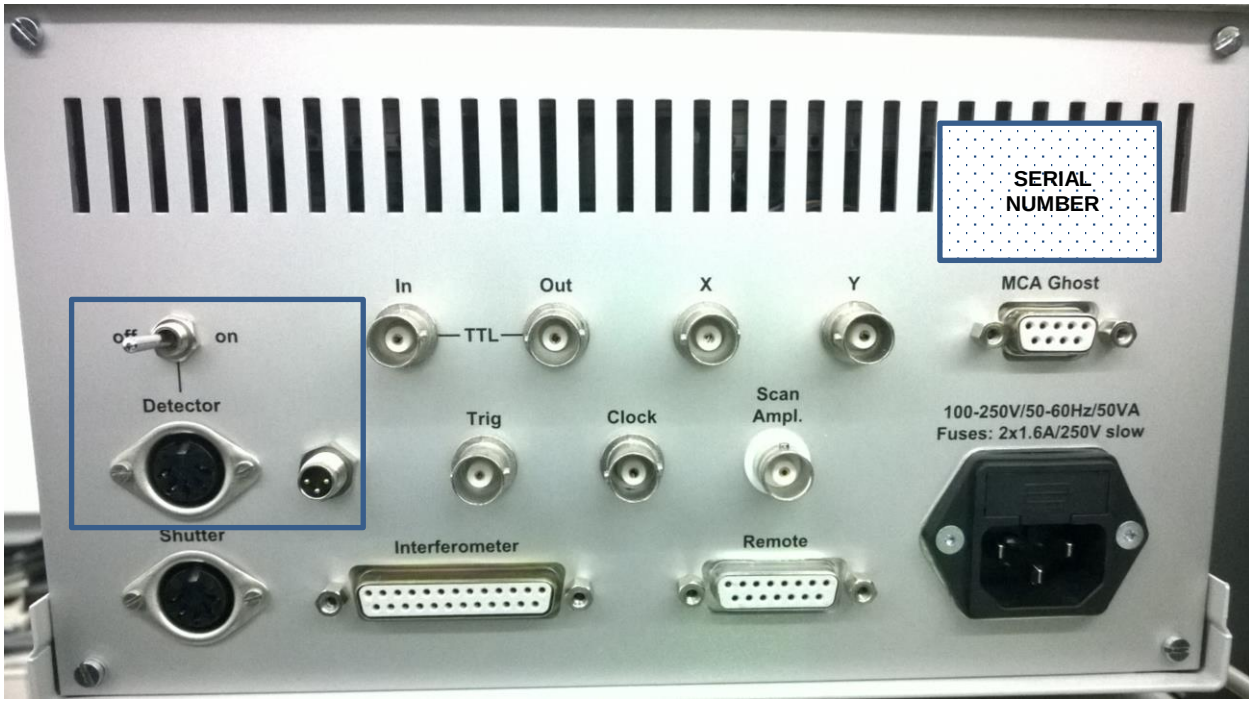
The LED indicator 21 on the front panel shows the position of the switch on the rear panel of the control unit. It is important to note that it will be meaningful only when the instrument detector is powered through the control unit: if your detector is powered by means of a separate power supply, the LED information will have no relationship with the status of the detector.

The LED strip 16 is a multiplexed indicator, which **alternates 2 different outputs**. During the longer interval, It shows the current voltage offset applied to the Z transducer, while during the shorter interval, it show the position of the main tandem mode peak with respect to the scan centre.

4.1.2 Spectrometer control unit rear panel connectors

The rear panel of the interferometer control units is depicted in Figure 4-3, their meaning is as follows:

Figure 4-3 TFP control unit rear panel

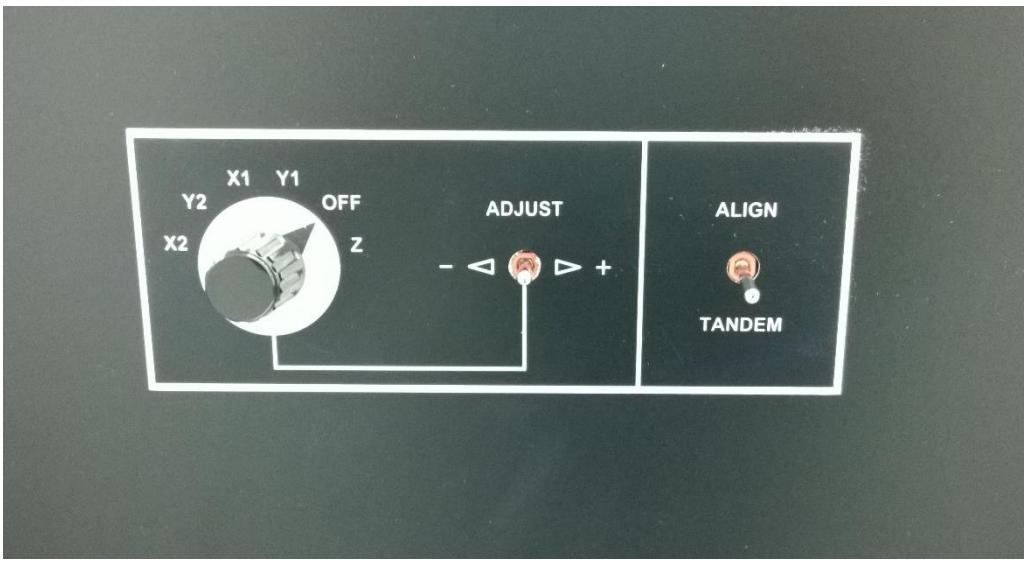


- **Detector connectors and switch** (blue box in picture above): these connectors provide supply to the interferometer detector. The small M8 connector can be missing on older control units and it is used only with detectors requiring +12V supply.
- **Shutter**: output for the input shutter. It must be connected to the socket on the left side of the interferometer input turret (cable provided).
- **Interferometer** DB-25: connector used to drive the instrument: it must be connected to the right side of the interferometer housing box (cable provided). See section 8.1 of this manual for a detailed pin description.
- **Remote** DB-15: can be used to remotely access many of the internal control unit functions. Normally disconnected. See section 8.1 of this manual for a detailed pin description.
- **TRIG** and **CLOCK** BNCs: output two internal timing signals related with the scanning operation, and can be used to synchronize external device with the interferometer, or for diagnostic purposes. These signals are described in section 8.1.
- **Scan amplitude** BNC: provides a positive voltage proportional to the scan amplitude value reported on the front LCD display (0.1 V for each μm in scan amplitude).
- **IN TTL** and **OUT TTL** BNCs: the input socket is used to get TTL pulses from the detector. The TTL pulses entering the input connector are stretched on the OUT TTL one, thus allowing easier counting by means of external counting devices.
- **X** and **Y** BNCs: represent every scan in terms of a timed voltage ramp (X) and a logarithmic voltage signal (Y) proportional to the number of counts recorded by the detector during the scan. They are suitable to graph the interferometer signal on an oscilloscope configured in the XY mode. Refer to section 8.1 for additional information.
- **MCA GHOST** DB-9: standard RS-232 serial port used to connect the control unit to a PC. The serial signal contains information readable using the JRS GHOST software (freely downloadable). The signal is absent if the “GHOST” option was not purchased together with the control unit.

4.1.3 Controls available on the spectrometer enclosure

Some of the operations can be performed only using knobs and controls available on the interferometer enclosure.
The most evident controls are on the left of the instrument front panel (detail in Figure 4-4). The large rotating selector at left allows one to choose among five mirror motors available: X1, Y1, X2 and Y2 motors are used for large alignment corrections on the corresponding axes of the two mirrors pairs, while the Z motor is used to change the mirror spacing. In order to activate each of the motors, the middle lever (ADJUST) is used in either direction. If the adjust lever is pressed for a short time, a small motion will occur; if the pressure on the lever is maintained, the motion will accelerate up to a maximum speed; this is usually useful only for changing quickly the mirror spacing. Using the Z motors, the mirror spacing is increased by pushing to right, decreased pushing to left.
The round removable cap in the front panel allows access to the mirror spacing measurement gauge without opening the instrument lid. You will need to remove the cap and look at the gauge every time a change of mirror spacing is required; the cap must then be placed again in position.
The last control visible in figure 2-3 is the ALIGN/TANDEM switch, for changing the configuration of the internal optics.
All the motors are accessible from the front panel and operate independently from the control unit controls, but they work only if the control unit is switched on.

Figure 4-4 Front control panel on the spectrometer box



The input and output pinhole turrets each provide a choice of 6 different pinhole sizes. The input wheel is directly turned, the output turret is controlled remotely by means of a mechanical system whose controls are accessible on the right side of the black box. A good method to completely close the experimental light input or the detector output is putting the corresponding pinhole wheel mid-way between two different pinhole positions.

Two additional controls appear on the left side of the TFP-1 and TFP-2 box, close to the rear side, in the form of two black knobs. These two knobs are a remote control for the tilt of the last mirror before the output pinhole (M6, see Figure 2-2 for TFP-1 and Figure 2-5 for TFP-2 HC).
These knobs have a dramatic effect on the signal intensity and must be adjusted **only** in the context of the alignment procedure described in this manual section 5.4.

Do not adjust M6 knobs in the context of your everyday experimental work, for example in order to increase the signal coming from a particular experiment. Doing so is a guaranteed source of misalignment that is going to create troubles sooner or later.

4.2 Basic optical requirements

In order to perform a Brillouin light scattering measurement, TFP spectrometers need two beams of light: the *input beam* and the *reference beam*. Almost always, both these beam come from a single laser source; the reference beam is a small fraction of the original laser beam, usually generated by means of a beam splitter, while the input beam comes as output from a scattering setup, where a relevant portion of the laser light hits a sample.

The optical plates of TFP-1 and TFP-2 HC are assembled using mirrors, lenses and prisms whose optical performance is acceptable in most of the visible range (400-700 nm). Recent TFP-2 HC optical plates support an even broader band extending to the very near infrared (400-1000 nm). Each FP mirror set will work, conversely, only inside a defined wavelength band, or inside a small number of bands. **The usable band of the spectrometer is thus limited mainly by the FP mirrors coating.**

The input beam, entering from the main pinhole, contains the light that will be analysed and that carries in its spectrum interesting information about the sample under study. This beam should in principle hit the input pinhole in the centre and be directed as orthogonal as possible to the pinhole wheel plane. The input beam must be focused to the pinhole and **have an aperture not larger than f/18**, i.e. the focus length of the input lens must not be smaller than 18 times the diameter of the beam before the lens. The TFP-2 HC will analyse only the part of the input beam which is vertically polarised, while the TFP-1 optical system is not particularly polarisation selective.

The laser light coming from the input pinhole can travel through the instrument with a relatively small attenuation and reach the detector, potentially damaging it: it is thus **very important** to avoid that, whenever the TFP detector is ON, a big quantity of light could accidentally hit the detector; this is typically obtained by switching OFF and protect the detector in all the moments when it is not needed for measurements, as for example when rearranging or setting up the experimental scattering device.

The reference beam enters the spectrometers though a grey plastic diffuser, that in turn also works as a strong attenuator. The only requirement for the reference beam is to hit the diffuser and to have a power in the range 1-10 mW (depending on the sensitivity of the detector). The quantity of light actually entering the instrument may be tuned at any time by moving the reference beam in or out of the diffuser. The reference beam does **not** need to be focused (but can be if necessary for particular reasons), and does **not** need to have a specific incidence angle and polarisation. The attenuation on the reference beam is so high that the reference light can never represent a danger for the detector.

4.3 Example setup: optics for backscattering

Figure 4-5 shows the basic optical components which are needed for a backscattering experiment. The backscattering configuration is the simpler and most known arrangement for scattering experiments, and is intended here to be an application example, illustrating how to comply with the optical requirements of the TFP spectrometers.

The original laser beam coming from the laser (top in figure) hits a small profile mirror or beam splitter, which directs it to the sample though a focussing lens LC2. The choice of this lens is not critical from the point of view of the spectrometer, and has minor effects on the spectrum. The sample in study is placed in the focus of LC2. A portion of the light scattered from the focus volume inside the sample will be then gathered again by LC2 and sent toward LC1 in the form of a parallel beam. LC1 is coaxial with LC2 and has the same diameter D.

With the exception of the light hitting the small mirror, LC1 will receive the light from the scattering setup and will focus it in a point, which has to coincide with the centre of the spectrometer's input pinhole P1, whose height with respect to the optical workbench is 205 mm.

In order to respect the f/18 aperture constraint of the TFP spectrometer, and assuming that the usable diameter D is between 20 and 25 mm, the optimal focal length of LC1 will need to be in the corresponding range 360 - 450 mm. Figure 4-5 takes into consideration the full diameter of the lenses in use, and considers that the effective area in use is slightly smaller.

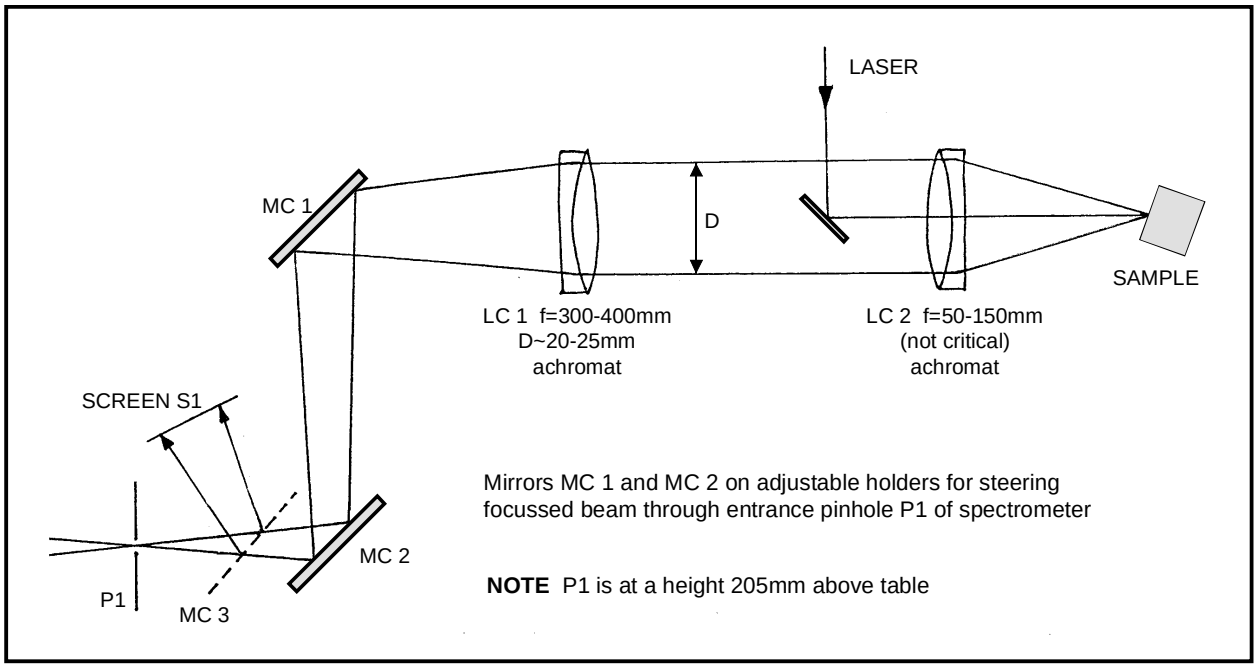
The two adjustable mirrors MC1 and MC2 are used for compensating any direction and/or height difference between the experiment and the entrance aperture.

Do not be tempted to omit these two mirrors from your scattering optics - without them it is difficult to direct the scattered light through the input pinhole P1 and simultaneously through the mask A1 (see TFP optical schemes in the previous chapters).

The beam splitter MC3 and virtual screen S1 are not part of the experimental setup and may be used, when necessary, to verify the orthogonality of the beam to the first pass of the instrument. This aspect will be clarified at a later stage in the manual (section 7.2.2).

All the lenses in this example are achromatic lenses: it is advisable to **always** adopt achromatic doublets in Brillouin scattering setups, in comparison to single lenses, in order to minimise the spherical aberration. In order to obtain the desired results, pay also attention to the direction of mounting of doublets, as shown in Figure 4-5the following figure.

Figure 4-5 Optics for back scattering



4.4 Detector safety

Notwithstanding their complexity, the TFP spectrometers are quite rugged devices, expected to resist time and use quite well.

This has a notable exception for what concerns the detector. Independently by the specific brand and model of detector mounted inside your TFP, the detector will always be a very high sensitivity device, capable of counting almost every single photon hitting the active area.
This component is very often subject to aging, in the form of a gradual loss of efficiency and increase of dark count rate, and will need to be handled with the greatest possible care in order to obtain the best possible performance.

The most common cause of premature failure of a detector is exposure to strong light. It is not easy at all to say “how strong” must be the light to produce an irreversible damage in such a device, even because the duration of the exposure is also an important factor. Common wisdom says that the normal illumination of a room is usually sufficient to create problems, and that the direct hit of a laser intensity visible by human eye will destroy the detector.

In cases where it is absolutely necessary to work with active detector and TFP box open (i.e. when adjusting detector focus), it is quite safe to work with dimmed and indirect room lighting, checking that the count rate provided by the detector does not grow too much.

The following suggestions will help you to preserve the detector from damage:

- If possible, switch off the detector when not in use; remember to switch it always off before deactivating the TFP control unit. After switching on the TFP control unit, always check that the detector is off by looking at the red LED lamp on the front panel.

- Even when the detector is off, it is always a good practice to block the optical path between the TFP input and the detector. This is easily done by placing the input pinhole wheel and/or the output pinhole wheel in a position in between two different pinhole choices.

- The previous recommendation holds particularly true in cases when the optical setup is being rearranged and thus mirrors and lenses are moved in the external setup. In these cases, always remember to switch off the detector or, at least, to close carefully the input pinhole.

- Shutters are built into the spectrometer to protect the detector from strong elastic light entering through the main input pinhole. Be sure to understand the shutter function operation (described later in this chapter) before using the detector and experimental light. In most cases, the shutters should be already operating before letting the experimental light in, and should be switched off only after stopping the experimental light.

- The intensity provided by the reference input, on the other hand, is highly attenuated inside the TFP box and is safe for the detector.

4.5 Start-up sequence and basic checks on normal operation of the instrument

In this section we suppose that the TFP control unit and the vibration isolation control unit are both switched off, and that the user wants to start up the system.

- ***Anti-vibration system start up***

  Switch on the main switch on the vibration isolation control unit and look at the red LEDs: they should light up and remain on for about half a minute, then going off and flicker occasionally only in presence of stronger vibrations. Press the black enable button: the yellow activity LED should light up, while the red ones should remain all off. The system is now active. In case something seems not correct, refer to previously mentioned section 3.2 and/or to the isolation system manual for more information.

- ***Check of spectrometer's pinholes status***

  As said in previous section, it is important to protect the detector from excessive light and from unexpected exposure, and this is often made by closing the input and/or output pinholes. Besides this, it is important to be aware of the status of the optical system before starting the electronic control unit. It is a good idea to check the current settings of the input and output pinholes of the spectrometer: they could be selected to a position or otherwise set in between two valid positions in order to close the pinhole and block the light. **For a detector safe start-up, *at least* the input pinhole must be set to block the light**.

- ***Spectrometer control unit activation***

  Switch on the control unit and ensure that the four red LED lamps, n.2 in Figure 4-2, light up together. Make sure that the "stabiliser" switch (n.18) is in the "off" position and that the shutter switch (n.22) is also on "off". Have a look to the detector LED lamp (n.21), to understand if the detector is currently switched on. It is advisable to switch off the detector before switching off the control unit, so the detector LED is expected to be off at this stage.

  An estimate of the current scanning range is reported in the LCD panel; turn the "scan amplitude" control knob (n.13) fully counter-clockwise to reduce the value to 0 (not scanning). Look at the position of the scanning range LED indicator (n.14): the indicator should be steady and close to midrange; if this does not happen refer to the procedure in section 5.1 to bring it back to centre.
  Increase again the scan amplitude to some safe value. A good starting choice is about 90% of the actual laser wavelength (i.e. about 480 nm scanning for a 532 nm laser wavelength). While scanning, indicator 14 is expected to oscillate around the centre, proportionally to the selected scan amplitude.

- ***Check of the detector signal***

  In order to check the detector signal, the input pinhole must remain closed and/or a screen must be blocking the experimental path to the input pinhole, so that no laser light can enter. In this condition, it is safe to switch on the laser source, allowing also the necessary time for warm-up.
  Most of the TFP-1 and TFP-2 HC systems include the Tablestable GHOST firmware to visualise the signal coming from the spectrometer. Refer to the software manual for information about the application and how to perform the operation here mentioned. In case a different software/hardware system is employed to observe signal, refer to the respective manufacturer's manual.

  Check that the optical system is configured to "ALIGN" mode (Figure 4-4). If not, switch the system to this configuration and allow some seconds to reach the position. Configure the

software to observe and visualise the signal coming from the spectrometer and ensure that the output pinhole is selected to a valid position.
Switch on the detector by means of the switch located on the control unit rear panel. Depending on the kind of detector in use, a signal could be visible immediately or could show up after some waiting time.
If necessary, it is possible to check the dark count of the detector by closing the output pinhole (i.e. setting it in between two positions) and looking at the signal.
The spectrometer is now active and can be prepared for a measurement.

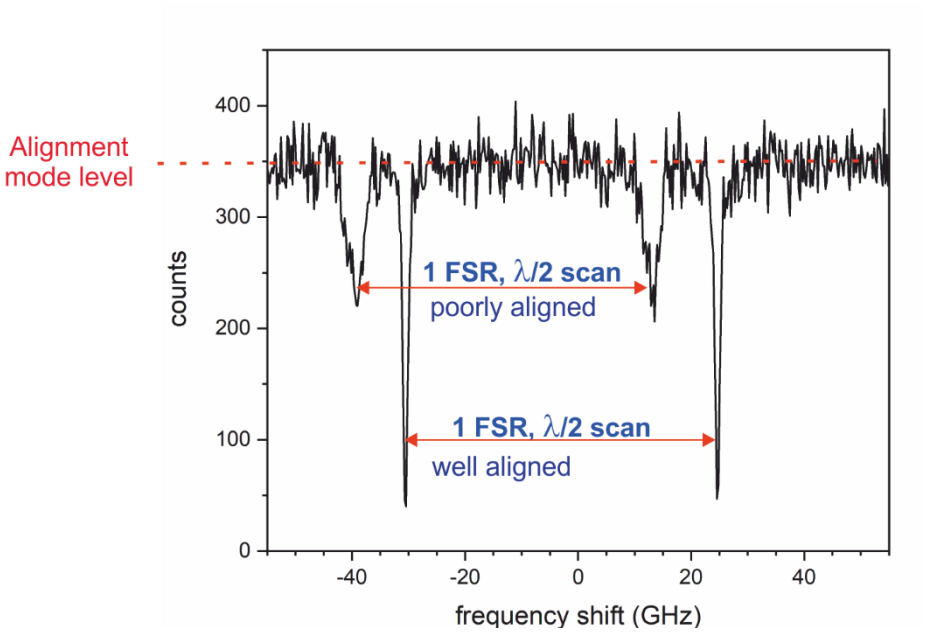
4.6 Use of the TFP control unit with TFP in alignment configuration

The TFP control unit and the TFP control panel on the black box allow the user to control the tilt of the two left side FP mirrors, by means of piezoelectric transducers and mechanical motors respectively. This is done at beginning in alignment configuration, in order to obtain a pre-alignment of the FP mirrors (as described in section 1.7), before bringing the spectrometer to tandem configuration and perform measurements.

Figure 4-6 shows a typical output from the instrument while scanning the mirrors in alignment configuration. The signal shows a maximum level and a certain number of dips created by the two scanning FP resonators. While operating in alignment mode the input pinhole **must** remain closed so that the signal comes entirely from the reference input.
The maximum level of intensity is related to the reference beam intensity and can be increased or decrease by altering the reference beam position on the reference input and/or by changing the reference beam power.

The number of the visible dips depends on the scan amplitude and on the laser wavelength λ: each FP will generate a dip (order of interference) every time λ/2 is scanned. A well aligned (parallel) FP pair provides a sharp and deep variation, a poorly aligned one provides a broad dip. By turning the (X1+Y1) knobs on the control unit, it is possible to improve the alignment of FP1, while the (X2+Y2) knobs do the same on FP2. This also allows one to understand which FP is responsible for a certain dip.

Figure 4-6 Typical signal in alignment mode configuration



Two additional axes are available on the TFP control unit: Z and ΔZ. The Z control affects the scanning transducer and changes the two FP cavities spacing: moving the Z knobs will shift the

dips positions sideways. The ΔZ control changes the FP2 spacing selectively, so will move the position of the FP2 dips with respect to FP1 ones.

The LED strip indicators close to each control unit knob represent the current voltage output provided to the related transducer with respect to the available range. It is a good idea to start a measurement with the axes (X1, Y1, X2 and Y2) indicators close to midrange. If one or more of the LED is close to the limit, they may be centred by means of the axes mechanical motors (see section 5.3). Since the signal is periodic in Z and ΔZ, these can be easily centred by rotating the related knobs by one order towards the centre position.

The control unit GHOST firmware is able to measure up to 2^{12} = 4096 counts per channel. If the number of counts received is higher than this, the counter inside the control unit will "roll off" to zero and a distortion of the signal gathered could be seen. This is not an indication of failure and can happen when the signal is still too weak to provide any damage to the detector, but such a large value of counts could prevent the control unit from stabilising correctly and should be avoided.

The maximum intensity of the signal in alignment mode should be kept in a range of about 250-450 counts/channel when the channel number is selected to 2^{10} = 512. If necessary, the count in alignment mode can be changed by moving the position of the reference beam on the reference input, or by changing the power of the reference beam.

The scanning ramp generated in the spectrometer is such that, when scanning, the mirror spacing goes from larger to smaller, and thus the frequency shift goes from frequencies lower to higher than the elastic line.

4.7 How to configure the spectrometer for a measurement

Depending on the kind of measurement to perform, the spectrometer must be prepared by setting up correctly the hardware and electronics. The choice of the working parameters depends on the experimental needs and is partially constrained by instrumental requirements, too.
The main decisions to take before starting a measurement concern:

- The FP mirror spacing
- The scanning range of the FP mirrors
- The diameter of the input pinhole
- The diameter of the output pinhole
- The timing of the shutter subsystem
- Additional settings of the control units

The following sections will describe the relevance of these parameters and how to set them properly.

4.7.1 The FP mirror spacing and the instrumental FSR

The mirror spacing is the first and most important parameter of a measurement. The current mirror spacing is measured by a mechanical distance gauge installed inside the instrument and visible by removing the round cap on the front side of the spectrometer enclosure. The gauge MPE (maximum permissible error) in the operating range of the spectrometer is ±10 μm.
The distance measured by this instrument is the one between the two FP1 mirrors.

Once the mirror spacing L is known, it is immediately possible to calculate the *free spectral range* FSR of the instrument, according to the formula:

$$FSR = \frac{c}{2L}$$

where *c* is the speed of light.
The FSR corresponds to the frequency scanned by the mirrors when they move by λ/2, λ being the wavelength of the laser source, or otherwise the distance in frequency lying between two consecutive orders of interference. This is in turn useful in order to understand how much space in the frequency realm corresponds to a physical scan.

Notwithstanding the tandem effect, which greatly suppress the higher orders in the TFP response function, during a measurement the elastic laser radiation fraction still generates unwanted resonance peaks in positions corresponding to ± N·FSR, where N is the number of half wavelengths scanned. These peaks render the corresponding frequency regions not usable for measurements, so the mirror spacing must be chosen in order to avoid that the additional orders peaks coincide with some frequency of interest in the specific application.

The control unit is able to select a scanning range between a few tens of nanometres up to slightly more than 2 μm. Given a frequency of interest, like for example the one of a peak, it is thus generally possible to select a FSR smaller than the frequency of interest and scan more than one order, or choose a FSR larger than the frequency of interest and scan less than one order. These two choices are not equivalent and the difference is related to resolution.

The instrumental resolution (i.e. the width of the instrumental response peak) is proportional to the FSR through the *finesse* parameter, as described in section 1.1. This means that in order to make high resolution measurements and be able to estimate linewidths with accuracy, one should choose a small FSR and a large mirror spacing, if possible, and then increase the scan amplitude as necessary to access the frequency region where the spectral feature of interest appears. Conversely, in case a measurement of linewidth is not necessary or if the features of interest are broad and high resolution is not required, the use of a larger FSR and single order scanning is the simplest one. The effective finesse of a TFP spectrometer depends on the FP mirrors and is expected to be between 100 and 120.

4.7.2 How to change the FP mirror spacing

In case a change of mirror spacing is required, ensure the stabiliser is off and switch the optics to the alignment mode. The dips related to the two FP pairs should be seen on the GHOST MCA. Proceed as follows:

1. Turn the axis-switch on the front panel of the spectrometer housing to Z. With the adjacent switch a movement to the left or right will decrease or increase the spacing respectively. Follow the spacing change on the dial gauge and at first do not change the spacing by more than 2-3 mm. You should still be able to see the dips in the signal but they will not be so sharp. Optimize using the X1, Y1 and X2, Y2 controls. Change by a further 2-3 mm as above until the required spacing has been reached.

2. Having optimized the alignment dips check the voltages displayed for X1, Y1 and X2, Y2. For good long term stability these voltages should not lie too near to the extremes. If any of these signals is out of range, refer to the centring procedure in section 5.3.

4.7.3 Choice of input and output pinhole size

The correct size of the input pinhole for a particular measurement depends on the resolution of the interferometer and may be determined using the standard formula:

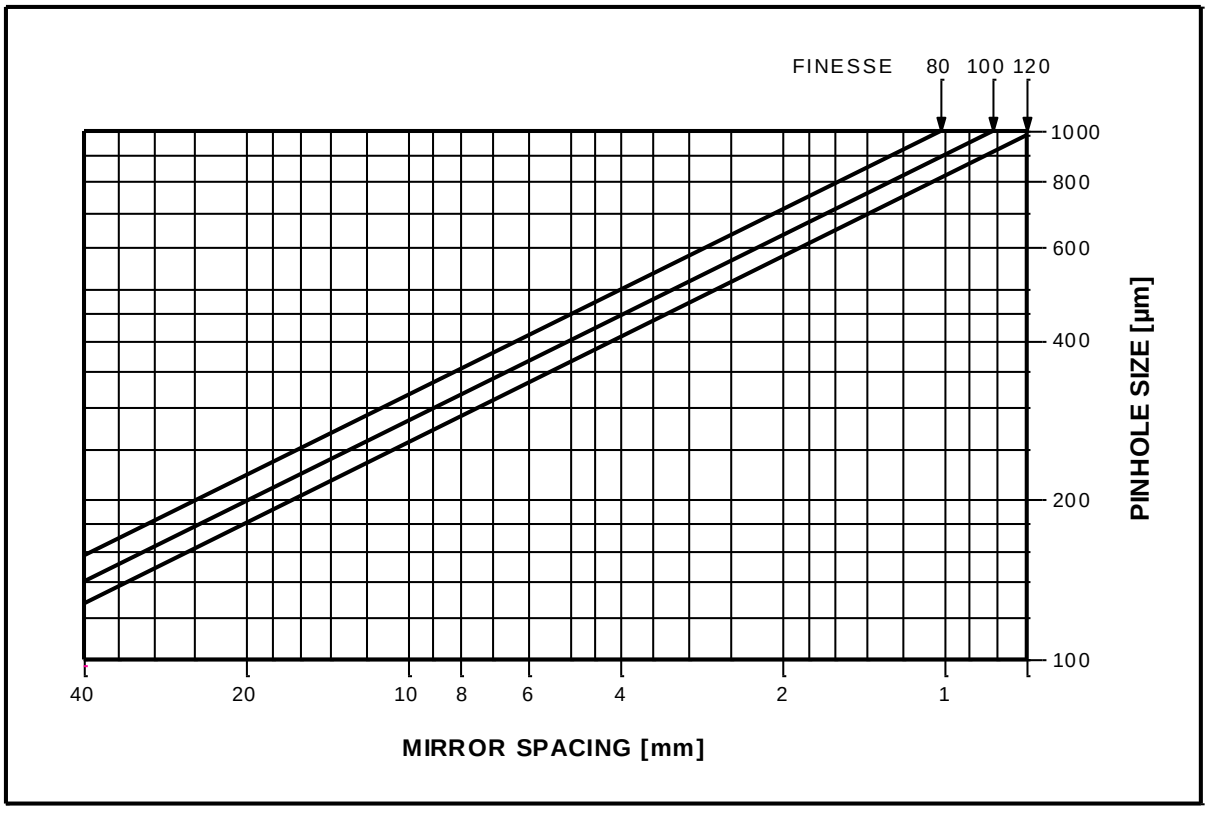
$$\Omega \cdot R = 2\pi$$

, where Ω is the solid angle subtended by the pinhole at the plane of the input lens, and R is the resolution given in terms of the *finesse* F and mirror spacing L by:

$$R = \frac{2FL}{\lambda}$$

In the actual devices, the input pinholes may be varied in size from 150 μm to 1300 μm. The lines drawn in Figure 4-7 correspond to different values of instrumental finesse, which could be found in a specific spectrometer, and to a wavelength of 532 nm. These curves may be used to obtain the best pinhole size.

Figure 4-7 Advisable pinhole size



The output pinhole sizes are adjustable from outside the spectrometer and range from 200 μm to 1300 μm. The output pinhole should in general be set to a value about 1.5 times the input pinhole size.

The use of an input pinhole which is too large will lead to an asymmetry at the base of the elastic peak. The use of too small a pinhole will result in an unnecessary loss of signal.

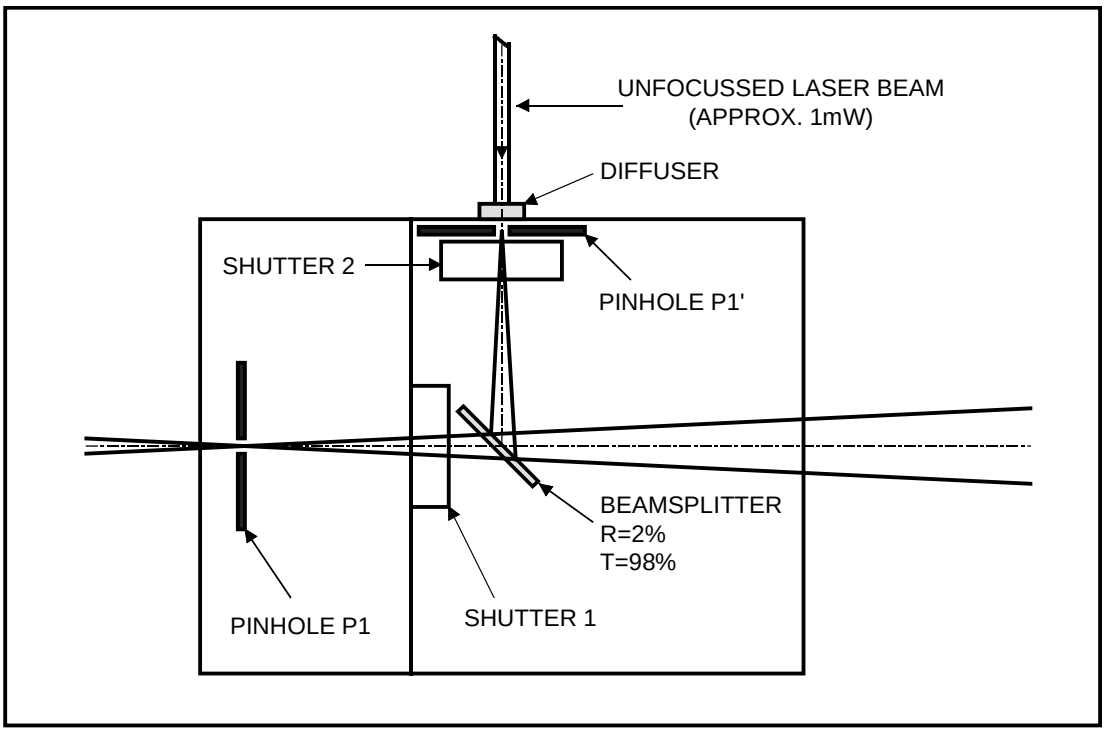
4.7.4 Timing of the shutter subsystem

The shutter subsystem is integrated in the TFP control unit and in the input assembly of the spectrometer, and is one of the most vital parts of the instrument. The system is composed of an electronic and adjustable timing generator, which provides signals synchronous with the scanning process, and of a couple of shutters mounted inside the input turret.

A schematic top view of the spectrometer's input assembly, including the shutter motors, is shown in Figure 4-8. The figure shows the optical paths of the input light beam, coming from left, and of the reference beam, coming from top and reflected by a small beam splitter in order to enter the interferometer on the same optical axis as the input beam.
One of the two independent shutter units is placed along the path of each beam; each unit contains a metal blade that can be quickly moved in or out of the beam path. When inactive, both the units will let the light pass through. When active, the two motors are always in opposite position, i.e. only one of the two light beams is allowed to enter the spectrometer.

In order to operate the shutters a trigger signal is required. This is known as the "window" signal and is generated in the control unit. The shutters are controlled by three independent windows W1 - W3, set by the white knobs on the right side of the control unit front panel (23-25 and 27-28 in Figure 4-2). Outside of these windows shutter 1 is open and shutter 2 closed. Within any of the windows shutter 1 closes and shutter 2 opens, allowing the reference beam to pass through the spectrometer.

Figure 4-8 Schematic top view of the shutter LM2 assembly



Shutter specifications LM2:

Open/close time:	2.5 ms
Timing jitter (max.):	0.5 ms
Lifetime:	> 10^8 operations

In most Brillouin scattering experiments it is essential to be able to modulate the laser intensity reaching the photomultiplier. In back-scattering experiments there is often so much elastic light that the photon counting system could be damaged: in this case it is necessary to block the input beam while scanning through the elastic peak and use the reference beam to stabilise the spectrometer. This is the task carried out by shutter window W1, which is always located at half of the scan and whose width is set by turning knob (23). Window W1 cannot be disabled if the shutter system is active.

When a large elastic intensity is present on the input pinhole and more than one wavelength is scanned, the spectrometer will produce additional peaks (neighbouring orders) in symmetric positions around the elastic line (see Figure 1-3); these can be blocked as necessary by positioning shutter windows W2 and W3 over the regions affected by the neighbouring interference orders. Knobs (24) and (25) in Figure 4-2 affect the starting position and width of W2 respectively, while (27) and (28) affect the starting position and width of W3. Windows W2 and W3 can be disabled by setting their width to zero (i.e. rotating the corresponding knobs fully counter-clockwise).

The windows W2 and W3 can be simply adjusted, whenever necessary, as described in the following section.

4.7.5 Spectrometer pre-alignment for TANDEM configuration

The main purpose of the alignment configuration is to ease the alignment of the spectrometer for tandem mode.
In order to pre-align for tandem mode, use the X1 and Y1 knobs on the control unit to render the dips related to FP1 as sharp and deep as possible. The FP1 peak positions can be used to determine the effective frequency range of the scan: this operation is usually called calibration of the X axis; refer to the GHOST software manual for instruction about this.
Optimise FP2 dips using X2 and Y2 knobs, to make them deep and sharp too.

If, during the dips optimisation process, one of more of the LED indicator for these axes get too close to their range limit, refer to section 5.3 to centre them by means of the corresponding mechanical motors.

Once all the dips look sharp, use the Z knob on the control unit to bring *one* of the FP1 interference dips in the scan centre. After doing this, make sure that the LED indicator corresponding to Z axis is around midrange – in opposite case move again the knob toward midrange and switch to another order.
Use the ΔZ knob to similarly drag one of the FP2 interference orders to the centre, in such a way that it superimposes with the previous one. Also in this case, if the ΔZ LED indicator is not close to midrange, it is possible to switch to another order.

In case the scanning range must be set to values larger than λ, additional interference orders will be visible at right and at left of the main one, and a fine positioning of shutter windows might be useful. In this case, do as described hereafter.

Fine adjustment of shutter windows W2 and W3

Referring to Figure 4-2, set the front panel switch (22) to "window" and the mode switch (26) to “shutter” (top position). The position of the windows is shown by a colour change in the GHOST software, and will also be testified by a drop of the alignment mode signal, whenever the shutters are blocking the reference light beam.

The central window cannot be turned off. The width is adjusted by potentiometer (23).

The width of the second window pair W2 is determined by (25) and if not required can be adjusted to zero. The position of the window is adjusted by potentiometer (24). Make sure that W2 includes the regions of the first neighbouring interference orders.

If required a third window pair W3 may be set using potentiometers (27) and (28), to include the regions corresponding to the second neighbouring interference orders.
In case of very large scan amplitude, when more than two neighbouring orders are visible, the use of additional windows is not required to protect the detector, due the strong attenuation provided by the tandem effect. The measurement spectrum could anyway contain spurious and malformed peaks in these positions.

4.7.6 How to bring the instrument to Tandem configuration and stabilise

In order to bring the instrument to Tandem configuration, use the corresponding switch located on the front panel of the spectrometer box (Figure 4-4).
After a few seconds, a small tandem signal peak should appear at the scanning centre. This peak must be optimised manually by means of the knobs on the control unit, using preferentially the sequence $\Delta Z \rightarrow$ (X2 and Y2) $\rightarrow$ (X1 and Y2) and iterating the process as necessary. The peak can be eventually centred by means of the Z knob.
Once the peak is larger than about 700 counts per channel, the stabiliser circuit of the control unit can be activated (switch 18 in Figure 4-2 to the upper position).

The maximum intensity of the tandem configuration peak should be larger than the maximum level of the alignment mode signal, and the ratio between these is normally expected to lie between 3 and 5 (measured using an output pinhole larger than 450 μm). If a larger or smaller ratio is found, the procedure described in section 5.4 may be used to bring it back to normal values. This must be done in case the ratio looks low and also in case it looks high: a high ratio does not indicate, in fact, that the tandem mode is improved, but rather that the alignment mode is providing a signal lower than normal.

The stabiliser should optimise the tandem peak to its maximum possible intensity, and keep it at maximum. **While the stabiliser is active, all the axes knobs on the control unit, with exception of the *scan amplitude* one, are disabled and do not provide any effect.**

Observe the Z-error display (n.16 in Figure 4-2) while the stabiliser is active. This is **a dual display showing both the Z-correction signal and also the drift of the peak from the scan centre**. The longer flash shows the Z-correction signal, the shorter one the peak drift. Once the stabiliser has been switched on for a few scans the latter should be in the centre of the display. Of course if the Z-correction also happens to be zero the two signals will be coincident and so the display will not flash.

The control unit stabiliser system is expected to maintain correct alignment of the system for an indefinite time, or as long as the thermal expansions in the system can be electronically compensated. Assuming that the Z transducer is close to midrange at zero scanning at beginning of a measurement, as described in the previous section 4.5, the thermal drift should be compensated up to a variation of ±2 °C. Beyond this limit, the changes will need to be compensated manually by suspending the measurements and repeating the procedures described in this chapter.

In almost all the experimental cases, the shutter system must be activated before opening the input pinhole, in order to protect the system from excessive elastic light. Once the shutters are correctly operating, the spectrometer is ready for measurements. When the experimental light is entering the system, a fine adjustment of shutter windows W1, W2 and W3 might be required to remove unwanted parts of the signal.

4.8 How to go back to alignment mode for parameter change or to switch off

It is very easy to revert the system to alignment configuration. The basic procedure is the following:

- close the input pinhole in the usual way, and/or stop the input light beam
- switch off the shutter subsystem and the stabiliser on the TFP control unit
- switch the configuration from tandem to alignment (switch in Figure 4-4)

at this point, the system can be reconfigured, for example changing the mirror spacing or the scan amplitude as necessary. If it is necessary to switch off the system, one can go on as follows:

- switch off the detector, optionally closing the output pinhole for improved safety
- disable and switch off the vibration isolation system

4.9 Scanning time and number of channels

The switch 19 in Figure 4-2 can be used to select the number of channels in the control unit, among three possible choices of 2^8 = 256, 2^9 = 512 and 2^{10} = 1024 channels. When the ÷10 special function (see following section 4.13) is not active, the scanning time defaults to an effective measurement time of 512 ms per scan. This means that a different setting of number of channels implies only a different time per channel, ranging from a minimum of 0.5 ms to 2 ms per channel.
The number of channels should be a compromise between speed of measurements and quality of the data: a lower channel number setting implies a quicker build-up of the spectrum, but a smaller data point density in the frequency range.

4.10 Normal behaviour of the reference signal intensity with output pinhole size

As previously said, the apparent intensity of the reference beam signal can be set at a desired level by moving the reference beam position on the input diffuser, or changing the intensity of the beam.
Once the input intensity is fixed, a change in the count number will be however visible when changing the output pinhole. This happens because some of the output pinholes are smaller than the size of the signal on the output pinhole plane.
If the output beam alignment is correct, the signal level should be approximately the same for pinhole equal to or larger than 450 mm, while significant decrease should be seen at smaller pinhole sizes. This behaviour affects both the configurations (tandem mode or alignment mode).
In case a significantly different behaviour is seen, the output alignment of the instrument might be in need of adjustment. This can be done by means of a very simple procedure described in section 5.4.

4.11 Photon counting limit, detector linearity and saturation

During operation, the instrument control unit will provide as output the number of counts read by the interferometer detector and, in turn, the intensity of light at a certain frequency shift with respect to the reference beam. The number of counts for each channel is limited by electronics and detector capabilities. In order to avoid distortions in the spectrum, the user must take care that the reference beam and the experimental light are both in the acceptable intensity region.
The number of counts is hardware limited mainly by two factors:

- The range of the digital counter inside the GHOST firmware circuitry: a 12 bit counter is used, so up to 2^{12} = 4096 photons can be counted for each channel before a counter roll-off occurs. When the intensity of signal produces enough counts to go over this limit, the

counter resets and the excess count number is recorded: in a peak, this will lead to very strong apparent changes in the intensity. It will be easy to reach this limit in the reference beam when its intensity is too high.

- The saturation and linearity limits of the installed detector, which are usually provided by the original manufacturer in terms of counts/s, and together with linearity correction formulas when available. These effects may be more subtle and vary from a detector to another. A detailed calibration sheet for the detector is supplied by the detector manufacturer and will provide information of the saturation limit and linearity behaviour for the detector mounted in your instrument. The number of counts at which the instrument will approach detector saturation and nonlinear behaviour also depends on the number of channels selected in the control unit: the time spent on each channel is 0.5 ms when using 1024 channels, 1 ms at 512 channels and 2 ms at 256 channels.

4.12 Polarisation selectivity in the TFP-2 HC

The use of polarisation optics inside the high contrast interferometer TFP-2 means as a consequence that the instrument is highly polarisation selective: the sensitivity to horizontally polarised light entering the input pinhole is much smaller than that for the vertically polarised light. **The light to be analysed must be vertically polarised when entering the input pinhole.**
TFP2-HC can be equipped with a polarising cube beam splitter inside the input turret in order to optimize the use with the CM-1 confocal microscope appendix. In this case, the horizontally polarised light entering the instrument will be suppressed by factor of about 10^3.

4.13 Shutter special modes

In particular experimental situations, it may be useful to use some special modes of the shutter system, in order to improve the signal quality or to make the measurements possible.

Alt.16 special shutter mode, for measurements of the central part of the spectrum

For measurements having almost no intrinsic elastic peak and where it is desirable to measure right through the central portion of the spectrum, it is possible to separate the stabilisation cycles from the measurement cycles so that the reference signal does not appear as part of the spectrum.

In 90° or quasi-forward scattering experiments there is often so little elastic scattered light that the intensity is not dangerous at all for the detector. In these cases, it could be possible and interesting to study the central part of the spectrum. A solution is to separate the stabilisation cycles from the measurement cycles, by introducing reference laser light only during a cycle of 16 stabilisation scans (MCA gated off) followed by 16 scans when the signal alone is recorded

Switch the shutter switch (20) to "Alt. 16". For a period of 16 scans shutter 1 is closed and the interferometer stabilises on the light signal falling on P1'. During this period the MCA TRIG signal is disabled so that no signal is recorded by the MCA. For the next 16 scans shutter 1 opens and shutter 2 closes, TRIG is enabled and the spectrum is recorded even in the complete absence of an elastic peak.

÷10 special shutter mode, to enhance weak spectral features

The function of the window W2 can be changed to enable parts of the spectrum to be selectively scanned at a slower rate thus allowing weak signals to be seen more quickly.

Set the window W2 to the desired part of the spectrum as above and switch the mode switch (26) to "÷10": the channels covered by W2 will have a 10 times longer duration.

Important: the ÷10 switch acts on the scan timing even when the main shutter switch is in the off position, and independently of the fact that the spectrometer is in the tandem or alignment configuration.

4.14 Use of the spectrometer at small mirror spacing

In case a large frequency scan is necessary and consequently a very small mirror spacing (significantly less than 1 mm) is selected, it is important to take into account some considerations about spacing of the two FP cavities. Before attempting to reduce the spacing to the smallest attainable values, it is worth remembering that the instrument is able to scan up to ±3 FSR from the elastic line: increasing the scanning range may allow to access the intended frequency range using a larger mirror spacing.

The simpler consideration when going to small mirror spacing concerns the error on the spacing measurement, as given by the mechanical distance gauge inside the spectrometer. If the gauge calibration has been properly done during the mirror spacing calibration procedure, the accuracy for gauge measurements is 10 μm. This uncertainty must certainly be taken into due account when working at small spacing and might become too large. In case a higher accuracy is required, replacement gauges can be provided by Tablestable.

A second consideration concerns the mathematical relationship between FP1 and FP2 spacing, which need to respect the constraints of the tandem geometry construction (see section 1.5). The two interferometers of the tandem system will only scan synchronously if the relationship $L_2 = L_1 \cdot \cos(\theta)$ is accurately maintained. In general there will be some error ε so that $L_2 = L_1 \cos(\theta) + \varepsilon$. For satisfactory scanning the error ε should be less than $L_1/(500 \cdot N)$, where N is the number of orders scanned. The effective absolute error ε may be perfectly acceptable when the spacing is large, but could become significant at small mirror spacing, bringing distortions in measurements.

In order to minimise the error ε and calibrate the mechanical gauge, an optical procedure can be performed, called “calibration of mirror spacing”. This operation, described in section 6.3 of this manual, is carried out at factory and verified at installation, and can be repeated whenever necessary by the user.

In order to understand if a calibration of mirror spacing is necessary, do as follows. After bringing the spectrometer to the desired mirror spacing and selecting the scanning range you need to use, bring the instrument to tandem configuration and measure the signal provided by an old-style incandescence lamp. The radiation emitted by the hot filament is a good approximation of a black body radiation. The spectrum measured by the spectrometer should look perfectly flat: any asymmetry in the signal indicates the need to repeat the calibration of mirror spacing. In this case, refer to section 6.3 for instructions.

When a correct calibration of the mirror spacing is done, the ε error should be well under 1 μm, corresponding to a maximum of 1 or 2 orders of interference. Clearly if the spacing L_1 is more than 1000 orders or about 0.25 mm, the effect of ε will not be significant.

For smaller spacing it becomes apparent that only certain specific values of L_1 are allowed by the tandem geometry. The spacings of FP1 and FP2 must be in the intended ratio 20:19. Consider for simplicity a wavelength of 0.5 μm and an extremely small spacing L_1 of 25 μm. L_1 would be 100 orders and L_2 95 orders. This would scan synchronously. But if the spacing L_1 were 27.5 μm L_1

would contain 110 orders and L_2 104.5 orders. An error of half an order would have to be introduced into ΔZ and this is greater than the acceptable value of $L_1/500$. The next possible value for L_1 would be 30 μm. Fortunately this limitation only applies at such extremely small values. For L_1 greater than 100 μm this limitation can be ignored. **For this reason we do not recommend measuring at a spacing L_1 of less than 100μm.**

The next problem is how to set a spacing of around 100 μm to a reasonable accuracy. The conical lens used for the calibration (section 6.3) shows coincidence of spot and ring at a spacing L_1 of 38 μm (for 532 nm laser wavelength). The coincidence repeats at multiples of this distance so it is possible to set spacings of 76, 114, 152 μm, etc. to an accuracy better than 1 μm, or proportional spacings for different laser wavelengths.

Finally, how can one tell if the order of interference selected by means of the ΔZ knob has been set correctly? Here the simple solution is again to record a white light spectrum. Having aligned the interferometer, change to tandem mode and shine a torch with a filament bulb onto the entrance pinhole. If ΔZ is correct the spectrum should be a flat line. If not, return to the alignment mode and shift ΔZ by ±1 order.

If due care is taken as described above it is possible to take reliable spectra with a FSR close to about 1 THz.

When the frequency scanning range reaches these large values, the effect of the TFP-2 HC final band pass filter on the spectrum could be visible in the white light spectrum; the filter can be easily removed to verify this. A similar problem can emerge in the TFP-1 due to the dispersive effect of the PR2 prism on the output pinhole: in this case, select the largest possible output pinhole and ensure that the output beam is centred in it (see section 5.4).

4.15 XY analogue output signals

The two output BNC socket marked “X” and “Y” on the TFP control unit rear panel (Figure 4-3) provide analogue signals useful to visualise the interferometer scan results. The following procedure describes how to operate the control unit for a basic scanning using the XY output BNC connectors to bring the instrument from the pre-alignment phase to tandem configuration operation.

The X and Y output signals contain the same information digitally represented when using the GHOST application. Since it is quite difficult to observe the slow scan on an oscilloscope, we strongly recommend that you observe the signal using the GHOST multichannel analyser software. This software refreshes the displayed signal each scan and is much easier on the eyes!

1 The Y signal is available only when a detector is connected to the TTL input socket on the rear panel of the control unit. Set the oscilloscope in X-Y mode. Connect the X-output signal from the rear of the control unit to the X-input of an oscilloscope with a sensitivity of 0.5 V per division. Connect the Y-output signal from the control unit to the Y-input of the oscilloscope with a sensitivity of 1 V per division. You will observe there is a baseline to the spectrum with a small square wave marker in the centre (there may be other markers but you can ignore these for the moment).

2 With the optics switched to the alignment mode, adjust the light intensity until a signal of about 2 V is seen on the oscilloscope. This corresponds to a count rate of about 300 kcts/s, or 300 counts/channel when using 512 channels mode. It is easy to observe the changes in intensity (due to the different time spent on each channel) when changing from 512 channels to 1024 or 256, and back.

3 Turn the scan amplitude knob until a reading of about 600 nm is seen on the LCD display. The Y-signal should now show two series of three dips. Change ΔZ and observe that only one of these series moves – the dips that move correspond to FP2. Adjust X2 and Y2 to make the dips as deep as possible. The display is logarithmic so the dips will not go completely to zero. FP2 is now adjusted.

4 Repeat for X1 and Y1 and again make the dips as deep as possible. FP1 is now also aligned.

5 Adjust ΔZ so as to bring two dips near the centre of the scan together. Notice that by adjusting Z all the peaks move together. The axis Z can be used to bring the coincident dips to the centre of the scan, i.e. to the centre of the marker.

6 The interferometer is now prealigned. Switch the optics to the Tandem mode and you should see a single peak in the centre of the scan. By successively adjusting all axes maximize the height of this peak. If you have done everything correctly, the peak height should be at least 1V higher than the alignment mode intensity (corresponding to a factor of 3 or more in intensity).

7 You can now switch on the stabiliser (switch 18 in Figure 4-2). The peak should move to the exact scan centre and after a few scans reach maximum amplitude. The stabilisers should hold this alignment indefinitely provided the room temperature does not change by more than ± 2 °C.

8 The shutter system must be activated before measurements as usual. The position of the windows is shown at the bottom of the spectrum display signal.

Note :
The stabilisers will only work if the peak was placed within the marker before switching on.

4.16 Reference signal from fibre optics

The reference beam illumination may be provided, if desired, by means of a fibre optics. Given the weak requirement on the reference beam, it is sufficient to keep the fibre optics output close to the reference input diffuser, so that the light shines on it.

On most recent TFP units, a small fibre connector accessory (see picture) is provided together with the instrument and the input assembly has been prepared to provide fixing point. The fibre adaptor can be fixed by means of two screws whenever necessary. The fibre adaptor conforms to the FP/PC standard; there aren't constraints on the fibre core diameter.

It is worth to consider that, when the fibre optics input accessory is used, the only way to change the reference input power is to change the quantity of light coupled into the fibre.

4.17 Multi-wavelength systems and change of wavelength

The TFP spectrometers optical usability is mainly limited by the FP mirrors reflectance curve: while the spectrometer optical system works efficiently at least in all the visible spectrum, each set of FP mirror is able to operate within one band or a small number of bands.

When more bands are available on the mirrors, it is possible to switch from one wavelength to the other in a rather simple way. In both the spectrometers, such a change does not normally require a complete re-adjustment of the optical system.

In the **TFP-1**, in cases when there is a deep difference in the wavelength such as when changing from red to the blue part of the spectrum, an adjustment of the final prism (PR2 in Figure 2-2) **might** be needed. If the signal is not visible at all after a change of wavelength, refer to instructions in section 7.1, point 12 and following, for a check of the PR2 position in tandem mode. If unsure, ask for additional help from Tablestable.

In the **TFP-2 HC**, whenever the wavelength is changed, the final narrow-band filter (F1 in Figure 2-5) must be changed to match the new wavelength. A suitable filter could have been provided by Tablestable with the instrument. If it is necessary to buy a new filter, it is important to pay attention to the filter's blocking band, making sure it extends at least to the band where the used detector(s) are sensitive, especially on the long wavelength side: if the blocking band is not sufficiently wide, the optical noise of the instrument could be sensibly increased. It is preferable to use a filter with a suitable blocking band than one having a better optical density or narrower pass band.

In order to change the filter, proceed as follows:

- switch off the detector, open the top lid of the box
- remove the protective screen 3 (see Figure 7-1) by lifting it up
- remove the two nylon nuts that keep the filter holder in position, making sure the two nylon screws do not rotate at the same time
- remove the filter holder and install the new filter, paying attention to the propagation sense (usually indicated by an arrow)
- replace the nuts, reinstall screen 3, close the box

4.18 Rotating notch filter usage (provided with the CM-1 microscope appendix)

When the CM-1 microscope appendix is mounted before the interferometer, the laser beam is focussed on a sample surface and white light from a LED lamp is shed around the beam position to illuminate the working area.

Figure 4-9 Notch filter camera

The CMOS sensor in the USB camera viewer is very sensitive and requires just a small amount of light to work properly. For this reason, the small power of the LED illuminator is already sufficient to produce a clear image of the surface. On the other hand, due to the small efficiency of the Brillouin phenomenon, the laser intensity needed to obtain a reasonable signal through the interferometer is comparatively enormous, and will easily saturate the sensor. This makes it in turn impossible to see the laser spot on the sample surface together with the wideband illumination under operating conditions.

It is indeed possible, and in some cases useful, to place neutral density filters before the microscope input, so that the laser power falls into an acceptable intensity for the sensor: usually an optical density between 4 and 6 will be needed. Microscope alignment can be checked this way, but the sample image will be not available during measurements.

The solution that can be adopted in the case of the CM-1 microscope is to install an OD6 notch filter inside the camera tube. This filter effect is controlled by rotating the knob on the front part of the camera tube. In the normal position (orthogonal to the internal beam) the filter will attenuate selectively the 532 nm laser light and allow the user, under most conditions, to see the position of the laser spot on the surface even during a Brillouin measurement.

When operating with low laser power or when in need of seeing very low laser power through the camera (i.e. when aligning the reference beam through the pinhole viewer) the notch filter can be made ineffective by rotating the control knob. The effective optical density of the filter will decrease quickly when rotating the filter out of position, until the filter will be completely inefficient. The angular dependence can thus be used to tune the notch optical density. The normal (orthogonal) position of the filter is marked by the black line on the control knob, which points upwards in this position.

In order to ensure the imaging signal from the confocal microscope is always available to the camera, a further modification was made on the input turret of the interferometer: the movable mirror usually mounted in order to divert the light to the camera when needed has been replaced by a polarising beam splitter. This one will send the horizontally polarised light towards the camera, while the vertically polarised light will be able to pass straight to the interferometer. The small horizontal component of the light gathered by the microscope is sufficient to form the image**. It is important to notice that, with this modification, any horizontally polarised scattering signal entering the input pinhole will be attenuated and will be not efficiently analysed by the interferometer.**

4.19 Remote control of the spectrometer and scanning customisation

The electronic control unit and the software provided with the spectrometer allow the user to perform a great variety of experiments by configuring the instrumental parameters as described previously in this chapter.

In cases where a detailed control of the instrument's behaviour is needed, the spectrometer control unit provides the ability to customise the main functions of the instrument by means of the rear REMOTE connector, whose pin description is reported in section 8.1 of this manual.

The REMOTE connector allows the following operations:

- Control of X1, X2, Y1, Y2 and DZ piezoelectric transducers of the interferometers. The corresponding pins on the rear port can be used to read (by connecting a high input impedance instrument such as a voltmeter or an oscilloscope) or change (by connecting a suitable voltage source) the force exerted by the transducers. When a voltage source is connected to one of these pins, the corresponding front knob of the control unit will not work anymore. In order to remotely control the FP axes, the control unit stabiliser must be turned off.

- Control of the spectrometer optical configuration: it is possible to operate the tandem/alignment motor and switch from one configuration and the other. In order for this remote control to operate properly, the align/tandem switch on the front panel of the spectrometer enclosure should remain in the TANDEM position.

- Remote control of the shutters subsystem timing. In order to remotely control the shutters, the shutter switch on the control unit front panel must remain in the "window" position.

- Remote control of the scanning ramp and of the Z axis: it is possible to obtain a signal proportional to the voltage applied on the main Z transducer and/or send a modulation ramp that will be translated in a (scanning) movement of the main stage. In order to externally provide a scanning ramp, the scan amplitude on the control unit must be set to zero.

Using the remote inputs it is possible to completely modify the operation of the spectrometer. By counting the pulses output from the detector signal cable synchronously, a spectrum can be built on a custom scanning action.
If you try to configure a custom scan, please be aware of the following important *caveats*:

1) Whenever the TFP is well aligned for transmission and scanned through the elastic light position or nearby interference orders, it is very important to timely operate the shutters in order to protect the detector from strong light that could pass through the optical system. When the control unit timing is overridden and the spectrometer is controlled by means of the remote channels, this responsibility falls entirely on the user.

2) The interferometer stage exhibits mechanical resonances. While feeding a custom voltage ramp for Z scanning, avoid high accelerations and scan speeds strongly different from the ones normally generated by the control unit. Strong accelerations easily trigger oscillations resulting in overload of the scan board and deeply non-linear scanning.

3) The GHOST firmware supports only the ordinary scanning action and timing from the control unit: it will not work with a customer-supplied scanning ramp. In this case, a custom data gathering system is also required.

4.20 Troubleshooting

Some common troubles often reported to us by customers are listed here. The described operations for each section can lead to a quick solution or can be used to rule out the simplest causes of trouble before calling Tablestable for support.

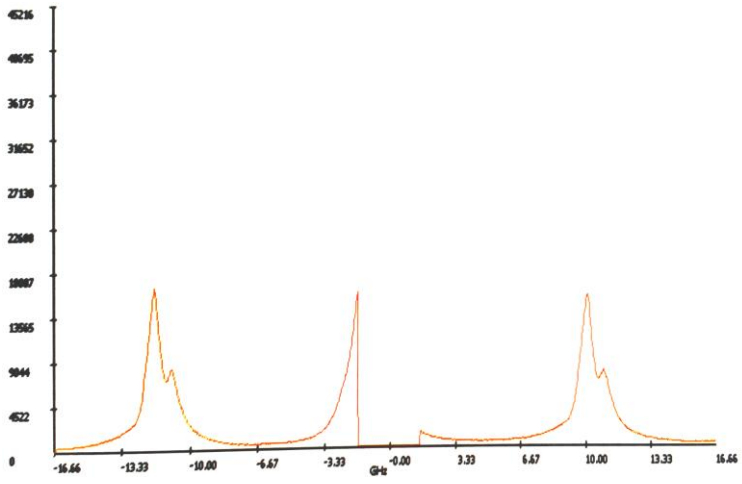
- ***FP2 low quality dip in alignment mode at a large mirror spacing***

When operating the spectrometer at a large mirror spacing, the depth of FP2 dip in alignment mode can sometimes decrease significantly with respect to the FP1 one.
This phenomenon is often due to an imperfect incidence angle of the alignment beam on FP2. This angle is set as close as possible to 90° tilting the second beam splitter BS2. When the mirror spacing increases, the sensitivity of the Fabry-Peròt transmission function to angle becomes larger and even a small deviation from a normal incidence could lead to a visible decrease in the dip. FP1 does not exhibit this anomaly.
Before talking about the solution for this anomaly it is worth pointing out that, since the tandem mode light path is independent from the alignment mode one, a bad shape of the FP2 dip is not necessarily indication of a bad performance while measuring in tandem mode.
In order to correct this behaviour, you can adjust either BS1 or BS2, trying to maximize the quality of the FP2 dip in alignment mode. This will necessitate opening the instrument lid to get access to the BS1 and BS2 tilt knobs, while the alignment mode is selected and the counter is working: it is thus required to work in relative darkness. This operation must be also performed selecting a small output pinhole (the smallest, ideally) so that the angle of incidence on the FP2 left mirror can be corrected without moving the output beam position out of the output pinhole. The necessary corrections are expected to be small.

- ***Double or multiple peaks seen in alignment and/or tandem mode, multiple peaks visible inside the main shutter window region***

Regular and relatively strong repetitions of inelastic features in a Brillouin spectrum can be an indication of a multimode operation of the light source. If the laser source produces more than a single wavelength and the additional modes are strong enough, they will give rise to an inelastic spectrum which will superimpose on the main one, exactly as the additional modes are superimposed to the main one. An example of this situation is shown in Figure 4-10.

Figure 4-10 Double peak spectrum



Different symptoms can generally appear in this case and may be used to diagnose problem with higher confidence:

- Enlarging the main (central) shutter window as much as possible and gathering data for a short time, the secondary peak (or peaks) could appear together with the strongest mode.
- Using a healthy single mode source, only a single peak appears inside the main shutter window.

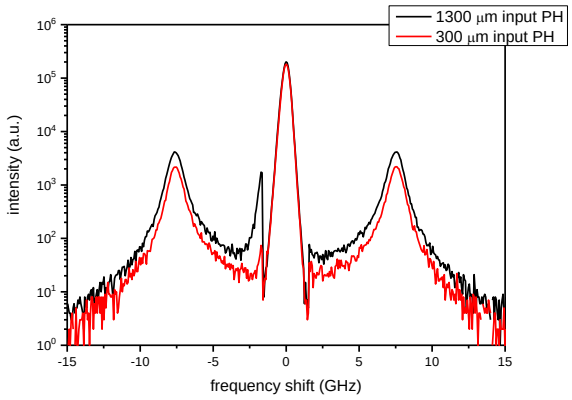
- When working in alignment mode, the dips produced by transmission on the two FPs will be multiple as well (smaller dips will appear regularly close to the larger ones) and the depths of all the dips will be decreased with respect to the normal ones.
- The position, number and intensity of the additional modes can change with time.
- These anomalies can appear and disappear at random, often in connection with the temperature conditions of the laser source or when the source is switched off and then on again. A warm laser source is usually less prone to multi-mode operation than a cold one.

If you experience multi-mode operation in your source, refer to the laser source manufacturer for a repair: a multi-mode operation in a single mode laser is generally a defect covered by the guarantee.

- ***Asymmetric response function and elastic peak tail***

The spectrometer response function becomes asymmetric when too large an input pinhole is selected. The best input pinhole size can be seen in the plot in Figure 4-7 .

Figure 4-11 Shoulder on the elastic peak



An asymmetry in the response function will almost always appear as a stronger tail at the base of the elastic peak on the negative frequency side, whose intensity will depend by the amount of elastic (reflected) light entering the input pinhole. An asymmetric elastic peak will cause the stabiliser to slightly shift the whole spectrum, leading to an apparent asymmetry in the positions of the Brillouin peaks.

An example of this kind of asymmetry is reported in Figure 4-11, where two spectra of a water sample, taken using different input pinholes at a mirror spacing of 3 mm, are compared after normalising to the maximum on the inelastic features. When the largest input pinhole is selected, a strong signal rise is seen at negative frequencies next to the elastic peak.

- ***Spectrometer conditions drifting, instrument in need of frequent corrections***

A series of symptoms have often been found, such as:

- Need of frequent motor corrections for alignment of mirrors, even if the mirror spacing is not changed
- “Scan Amplitude” LED indicator on the control unit drifting with time, often reaching end of range, with consequent need of readjustment of the transducer screw to centre it
- Strong drift of the LED indicators of some axes during stabilisation, leading often to end of range and thus requiring realignment

All of these phenomena can be triggered by too strong temperature changes in the room where the instrument is sitting. The instrument enclosure protects the spectrometer from air currents and quick variations of temperature, so that the instrument thermalizes to the optical workbench where

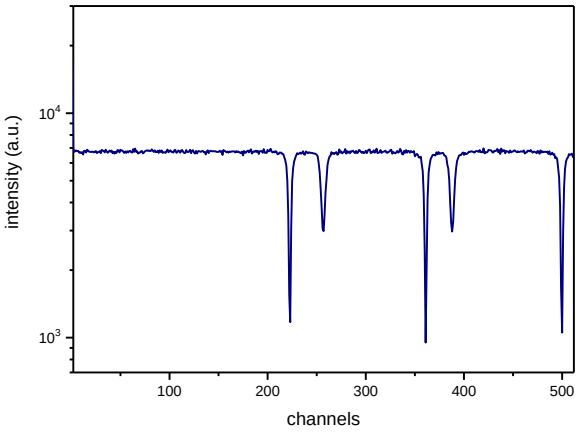
it is sitting. This latter has a quite large mass and its temperature changes only slowly as the room temperature changes.

For best results the temperature of the lab should be maintained to ±1 °C. However this must be maintained day and night. If the air conditioning is switched off at night the optical work bench will cool down overnight and slowly warm up again the next day. This will cause a continuous drift in the temperature of the interferometer and lead to the phenomena described above.
The only way to correct this behaviour is to stabilise the temperature 24/7.

- ***Spectrum scan stops, shape is malformed***

If the spectrum seems to be malformed at the beginning or the end and seems to be stopped at a constant value, the cause can be an out of range condition on the transducer. When the transducer reaches the maximum or minimum output voltage, the scan will stop and the mirrors will not move any further. This is of course more likely to happen when a large scan amplitude is selected, with two orders of interference or more scanned, and is also indicated by the "scan amplitude" LED indicator reaching the red zone while scanning.

Figure 4-12 Scan limit reached



An example of this situation is reported in Figure 4-12, as seen by acquiring a few measurement cycles in alignment mode: the scan is stopped at left.
The solution is to centre the scan amplitude indicator using the transducer adjustment screw. Instructions to perform this procedure are reported in section 5.1.

- ***Setting a strong beam to the pinhole input, no light is seen inside the spectrometer, or the beam shape is cut***

Several of the procedures for alignment and testing of the spectrometer require focussing a laser beam into the input pinhole, so that the light path inside the spectrometer can be easily followed. Such an intense signal could easily damage the photon detector, so this needs to be switched off and protected by some physical barrier (for example moving the output pinhole wheel to a middle position).

If the beam is already apparently well centred on the larger input pinhole, and no light at all is seen inside the interferometer immediately after the input aperture, it is important to ensure that the control unit is switched on and that the shutter connector cable is correctly installed. When the control unit is off, the input shutter can easily go out of position and obstruct the input beam after the pinhole. The shutter positions are only defined when the control unit is switched on.

- ***Moving the control unit front knobs, no change on the LED indicators***

Under normal conditions, the front panel knobs on the control unit directly change the voltages applied to the corresponding piezoelectric transducers for adjusting the mirrors of FP1 and FP2, The LED strip indicators show the actual position with respect to the possible range. When the "stabilisation" feedback loop is activated by means of the front panel switch on the control unit, the

knobs are no longer active and the LED strips indicate the voltage related to the electronic feedback, not by the knob's position.

The most common cause for lack of response when adjusting the knobs is the stabilisation switch being in the wrong position. Check that the stabiliser is off.

- ***Additional and unexplainable inelastic peaks are visible***

The presence of unexpected peaks in the spectrum has many possible causes and, contrary to what is commonly believed, hardly comes from misalignment the spectrometer. In fact, it is not possible to misalign a spectrometer in such a way that an inelastic signal appears.

The first and obvious advice is to check the sample, because in most cases the signal is real. A second possibility is that the signal does not really come from the sample, but is rather generated by the laser source as an additional mode. In this case, if the measurement is made on some elastic source like an interface or a metallic surface, the signal will appear much stronger but at the same frequency. This kind of trouble can be strongly reduced by means of the Tablestable TCF device.

The only peaks which are instrumental in origin are the so-called "ghost" signals, i.e. replicas of a real inelastic peak at a frequency of ±1 FSR. These peaks are an unwanted but unavoidable component of the TFP response function, and are created by the tandem configuration of the interferometer. Ghost peaks become visible only when a very strong inelastic signal from the sample is present; in this case, they are much smaller than their generating signal and not perfectly identical in shape.

It is simple to verify if a spectral feature is a "ghost": it is in fact sufficient to change the mirror spacing, thus altering the FSR, and the feature will appear at a different frequency. Adding or subtracting a FSR to the ghost frequency will lead to the generating peak.

- ***Inelastic signal from sample appears weaker than expected***

If the signal is significantly lower than what was found in the same experimental conditions and on the same sample in the past, users are first of all encouraged to check the external setup alignment before thinking to an instrumental trouble.

Aging or damage of the detector is always a possible origin of such a behaviour, and should be considered.

The only advisable procedure to improve the throughput of the spectrometer is the one described in section 5.4. Additionally, in case the detector in use is mounted on the right side panel of the spectrometer box, it is useful to optimise the detector tilts by looking at the signal in alignment mode through the smallest output pinhole.

If the problem persists, users are strongly advised to get in touch with Tablestable for further and more specific suggestions, and to not undertake any further alignment or correction operation on the instrument.

- ***Signal from sample appears lower than expected, stabilisation loop fails, piezo corrections move alignment mode dips sideways***

The symptoms described in the title can be due, if considered separately, to different causes. A small degree of sideways shift in the alignment mode dips is frequently found in FP2 and is

acceptable even in perfectly aligned spectrometers. This behaviour does not normally appear in dips for FP1 instead. If all the spectrometers signal appear to move sideways when the related X and Y piezoelectric adjustment are used, the resulting coupling may prevent the stabiliser to work.

When the mentioned conditions appear together, and supposing that a detector with focusable lens group is mounted (i.e. a detector mounted on the right side wall of the spectrometer box like the Hamamatsu C11202), all these could be generated by a defocusing of the signal at the detector.

The detector focus is usually set at system installation and should not be changed afterwards, especially never changed in order to obtain a better signal during an experiment. If such a thing is done, these problems can sooner or later emerge.
Optimise the focus and tilts of the detector by following the related instruction manual and using the smallest output pinhole in alignment configuration.

- ***Asymmetry in signal peaks position***

There are many cases, including the most classical applications of Brillouin spectroscopy, where the scattered light is expected to provide a pair of peak at two frequencies exactly symmetric with respect to the elastic line position.

If the measurements exhibit, contrary to the expectations, a consistent and reproducible lateral shift, which is independent by the sample under observation and larger than the frequency step, while the elastic light peak is correctly found in the centre of the scan, the trouble could be due to a small error of adjustment in the reference light beam splitter (represented schematically in Figure 4-8).

The reference beam splitter can be properly adjusted using the pinhole camera viewer: refer to section 5.8 for instruction on the alignment procedure.

- ***Completely missing signal from reference or main input***

If the signal from the reference or from the main input beam disappears completely without a reason, i.e. no signal at all is visible in alignment mode, or no experimental signal is visible at all while the detector is still operating correctly, there is a chance that one of the shutters is not working.
When the motors are not working or stuck, the shutter blades can remain in the “closed” position, thus preventing any signal from reaching the detector. In this case, the detector will not see anything from one of the input, for example no signal is recorded in tandem mode even if a lamp is shining at the input pinhole, or no reference appears even if the reference beam hits the reference input in the centre.

The motors in the shutter system have a very long life, but the possibility that they have stopped working cannot be ruled out without checking. The possibility of a failure in the control electronics is also small but not zero.

The camera viewer is probably the best way to quickly check the shutter operation. Refer to the camera viewer manual for a test. If the shutter blades are working, the spots related to the reference should blink when the shutter system is active, while at the same time the image of the pinhole should blink too (in opposition of phase).

In case the shutter is not working properly, please call Tablestable for help.

5 TFP ORDINARY CHECKS AND BASIC ADJUSTMENTS

The TFP should provide reliable and long lasting operation without any serious requirement for maintenance. Only minor adjustments, described in this chapter, are required or could be performed at choice of the customer from time to time, in order to ensure correct operation and optimised output. If performed following carefully the instructions, these operations are safe and help in diagnosing and solving many small troubles.

5.1 Adjustment of capacitance range and centring of scan amplitude indicator

The scan amplitude LED indicator on the control unit front panel (14 in Figure 4-2) could be occasionally found off centre. This happens usually when the room temperature has changed noticeably and thermal expansion of the system components has modified the scanning stage capacitor spacing, so that the indicator mid-range does not corresponds anymore with the reference mid-range capacity.
A small change in the centring is not harmful, but if the indicator is far from midrange the scan amplitude limit could be temporarily compromised, and the instrument needs to be adjusted by bringing the capacitance into the correct range.
This operation is very quick and easy to do. In order to adjust the spacing of the capacitor and compensate these thermal variations:

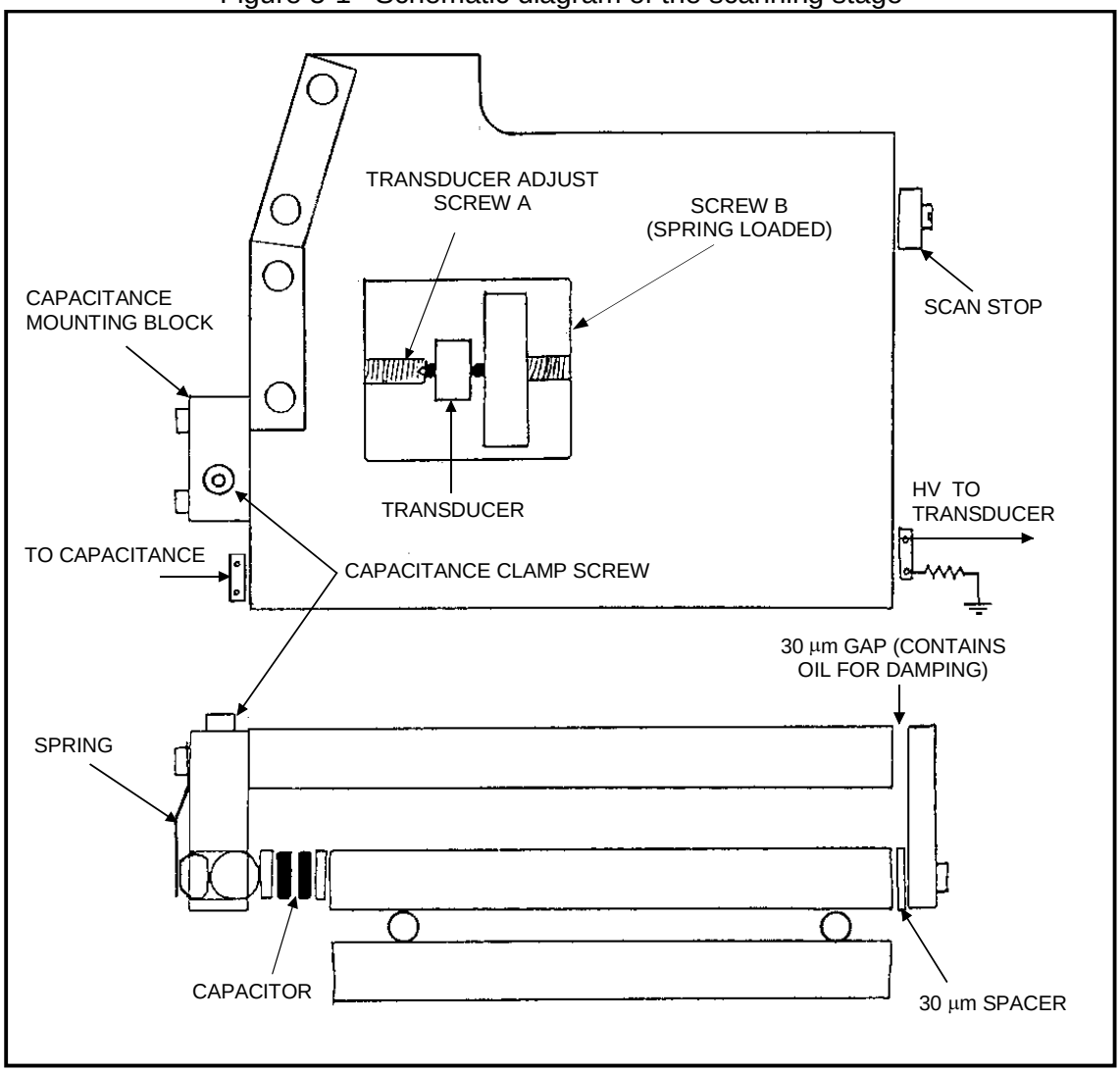
- Set a zero scan amplitude and **switch off** the detector, then open the lid of the instrument. Using a zero scan amplitude, you will see a single LED lit in the scan amplitude indicator.

- Looking at the scan stage and with reference to Figure 5-1, locate the transducer adjust screw A. This screw has a series of small transverse holes that allow one to turn it from the side. On the TFP-2, these holes could be not accessible at large mirror spacing: if this happens, a nut should be accessible at the left end of the screw, in the space between the right and left FP mirror holders. If the operation looks difficult even this way, reduce the mirror spacing as necessary to access screw A.

- Insert the special needle tip tool provided by the spectrometer in one of the holes on screw A and turn the screw gently and by a very small angle until the scan amplitude LED moves to the centre (yellow LED). The sense of motion is such that, if the reported position is higher than the central LED, you must push the tool, and vice versa.

If difficulty has been experienced in setting the scan-amplitude indicator to mid-range or if highly non-linear scanning is suspected, it may be necessary to reset the capacitance and the scanning transducer, as described in the following section 5.2.

Figure 5-1 Schematic diagram of the scanning stage



5.2 Reset of the transducer and of the capacitor range

This procedure of adjustment is performed as a part of the instrument installation, and can be repeated as a normal user-level maintenance operation, when a mechanical reset of the transducer is required.

In case the transducer needs to be reset, it needs to be loosened and then tightened again. Starting from the normal working instrument condition and using Figure 5-1 as a reference, do as follows:

1. Switch off the detector and set scanning range to zero. Open the top lid of the spectrometer box.

2. (only for **TFP-2**) Set the mirror spacing so that the oil gap is visible and accessible.

3. Use the adjustment tool and screw gently A so that the oil gap is large enough to allow insertion of the 20 μm steel shim (provided with instrument). A very small rotation (about a quarter of a turn) should be sufficient. The sense of rotation to obtain this is the one towards the dial gauge.

4. Using a pair of small tweezers, pass the steel shim through the oil gap of the scan stop in order to clean it. Finally leave the shim in the gap.

5. After this, slacken the transducer adjustment screw A by moving the tool toward the back of the instrument, until the parallelogram will rest on the shim. At that point, the adjustment tool will lose tension will tend to fall on the stage, there is no harm if this happens.

6. Slacken the capacitance clamp screw. This automatically brings the capacitance plates into contact. Tighten capacitance clamp screw again.

7. Apply again tension on screw A, similarly to what was previously done on step 3. : screw it just enough that the metal shim can be removed from the oil gap. Then, move screw A very carefully in order to bring the scan amplitude indicator (n.14 in Figure 4-2) in the centre. The procedure is complete.

8. (optional) It might be useful to add one or two small drops of machine oil in the oil gap.

5.3 Motor compensation of PZT drift

In the event that one or more of the voltages X1, Y1 and X2, Y2 displayed on the control unit are out of range, they may be readjusted using the motor controls. The control panel on the spectrometer housing allows fine motor control of the above axes.

For example to correct X2, first of all use the X2 adjustment on the control unit to return the voltage towards mid-range, making sure that the corresponding dip for FP2 is still visible. Now turn the axis-select switch on the control panel to X2 and use the adjacent switch (the same one you used for the spacing change) to optimize the dips. Do not hold the switch for more than a second because the correction begins to speed up and you may end up completely misaligning the axis. Use repetitive short corrections.

You cannot optimize perfectly using the motor controls so return to the control unit and optimize using the X2 and Y2 adjustments. If the voltage for X2 is still not near enough to the centre repeat the procedure.

Repeat for any further axes.

5.4 Optimisation of the output intensity of alignment and tandem configurations

An optimisation of the output alignment of the instrument could be required or useful when one or more of the following behaviours are seen:

- The intensity of the signal in alignment mode or the one of the elastic peak in tandem mode seems to decrease with respect to a constant condition of the reference beam, both in geometry and power.

- The intensity of the alignment mode signal and/or the intensity of the elastic peak in tandem configuration reduces too much, or gets almost to nothing, when reducing the output pinhole diameter to the smaller values.

- The ratio of the elastic peak intensity to the maximum intensity in alignment mode, measured with an output pinhole larger than 450 μm, lies outside the range 3 - 5. The optimised value of the ratio for a specific spectrometer depends on the FP mirrors and

on the optical system components, but should be found in this range, and should not change much in time. **A ratio higher than 5 does not necessarily mean the spectrometer is providing a better signal in tandem mode**, and should also be fixed by means of this procedure.

The execution of this procedure should be required more frequently in a “young” instrument, which is still undergoing mechanical relaxations of the components, but it is however very safe and can be repeated as many times as necessary.

It is worth to note that many times this kind of optimisation is rendered necessary after misuse of the M6 external control knobs. This procedure is the only procedure to adjust the M6 control knobs: **the M6 knobs should never be adjusted outside this procedure, for example in order to increase the signal coming from an experiment, or to optimise the alignment mode signal.**

In order to optimise the output, do as follows:

1) Starting with the system in alignment configuration, and looking at the signal provided by the detector, look at the behaviour of the signal intensity when changing the output pinhole size:
    a. If the signal is visible, both in tandem and in alignment configuration, with all the possible choices of output pinhole, select the smallest output pinhole available and proceed to step 2).

    b. If the signal disappears when a small pinhole is selected, in tandem or in alignment configuration, the misalignment is big and this procedure must be performed more carefully.
    Of course, the only possible thing is to select the smallest pinhole where you still see a signal in both the configurations. It could be a good idea to increase the reference beam intensity in order to improve the count rate. In this situation the corrections on the optics described in the following points must be made by smaller steps, without looking immediately for the absolute maximum but rather aiming for small improvements, until the misalignment is reduced enough to have the signal. Iterating the procedure will lead eventually to a correct optimisation.

2) Always remaining in alignment mode and after dimming as possible the room light, lift partially the box lid and slide it forward, in such a way that you can reach the first 15 cm of the instrument optical plate but without letting too much light inside.
    Locate the first beam splitter in the reference path, identified as BS1 in the instrumental diagrams reported in chapter 2. In a TFP-1, BS1 beam splitter can be adjusted by means of two small black knobs, in a TFP-2 HC there are instead two silvery vertical adjustment knobs.
    Adjust BS1 to improve the alignment mode intensity or to optimise it – depending by the condition at point 1a or 1b previously.

3) Use the ordinary procedure to bring the system to tandem mode configuration, obtaining a visible tandem mode peak. Use the control unit knobs to make the tandem peak as strong as possible, but do **not** start the electronic stabiliser.

4) Using the two remote knobs on the left side of the spectrometer box, try to improve the tandem signal. In doing so, be careful to the following things :

    a. The reference beam may be passing close to the M6 knobs, in which case it is easy to stop it by mistake, thus having apparently no signal.
    b. The M6 knobs have strong effect on the signal: move them by very small steps and changes will be immediately visible on the peak.

c. The spectrometer misaligns spontaneously with time when the stabiliser is disabled. If this happens, the signal will decrease even independently of a motion of the M6 knobs. In this case, re-optimise the peak by means of the control unit knobs.

5) Go back to alignment mode. Whenever a correction is applied on M6, the alignment signal is affected, so it is normal that you find a different, generally smaller, signal in alignment configuration. Repeat point 2) to get a better signal.

6) If the smallest pinhole was selected, the procedure is theoretically finished, and the problems found on the system could be now solved. It is of course possible to iterate point 2) to 5) at will to be sure about the optimisation.

   If, following point 1b), the selected output pinhole is not the smallest one, it should be now be possible to move to a smaller one and see again some signal. At this point the optimisation can be done, still following points 2) to 5), until finally the optimal condition is reached on even the smallest output pinhole.

5.5 Adjustment of LCD display of scan amplitude

The LCD display on the control unit indicates the total scan movement in nanometres. This value, together with the mirror spacing, can be used to guess the current frequency range scanned. The scanning range is obtained by measuring an electrical signal, so the accuracy of this reading degrades with time and it is necessary to adjust it from time to time.

There is a potentiometer adjustment screw for calibration on the front panel (n. 17 in Figure 4-2) just below the switch for changing the number of channels. By turning the adjustment screw, the LCD display may be set to show the correct value of scan amplitude in nanometres.

An accurate calibration can be carried out using the GHOST software, using the value reported after the “calibration” operation to adjust the LCD panel. See the GHOST software manual for additional information about this.

The calibration can be performed also manually: determine the number of channels N between successive dips – this corresponds to a scan amplitude of $N_{ch} \cdot \lambda / (2 \cdot N)$, where N_{ch} is the currently selected channels number.

An approximate check of calibration can quickly be performed when in the alignment mode. Having the interferometers dips in view, detune FP2 so that only the dips of FP1 remain sharp. Centre one dip and adjust the scan amplitude until exactly two orders of FP1 are scanned – this will correspond to a scan amplitude equal to λ (There is a small non-linearity for the first 4 ms at the beginning of the scan which makes the setting somewhat uncertain).

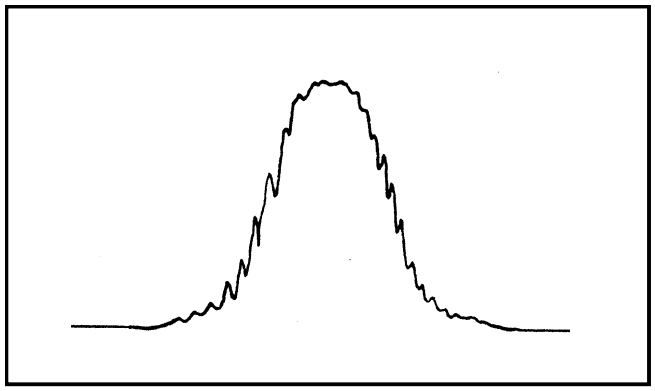
5.6 Damping oil in the oil gap

A small oil gap (represented in Figure 5-1) is used to damp the scan movement and so avoid the onset of oscillations after each retrace. With time this oil may dry out and oscillations can take place, making the leftmost part of the spectrum highly nonlinear. If you see this behaviour, replenish the oil gap using ordinary light machine oil.
The oil gap is always accessible in a TFP-1 spectrometer, while in a TFP-2 HC spectrometer, it could be necessary to temporarily change the mirror spacing in order to access the oil gap through the small aperture at left of G4.
The volume of the oil gap is tiny: in order to fill the oil gap, it is sufficient to drop up to 3 small drops of machine oil using a small metal tip. The oil will fill the gap and remain there due to surface tension and adhesion to metal.
The oil can last many years before a new oil gap filling operation is required.

5.7 A test to check the correct operation of the vibration isolation system

With the scan amplitude set to zero check the position of the scan amplitude display (14 in Figure 4-2). This signal should be near the middle of the indicator. If not refer to previous section 5.1 for adjusting the scan transducer.

Following the normal procedure described previously chapter 4, obtain an elastic peak from reference light in tandem mode. If you now reduce the scan amplitude the width of the elastic peak will increase until the peak appears as below:



Some noise will be present, but should not exceed 5% of peak height. If more noise is observed check the following:

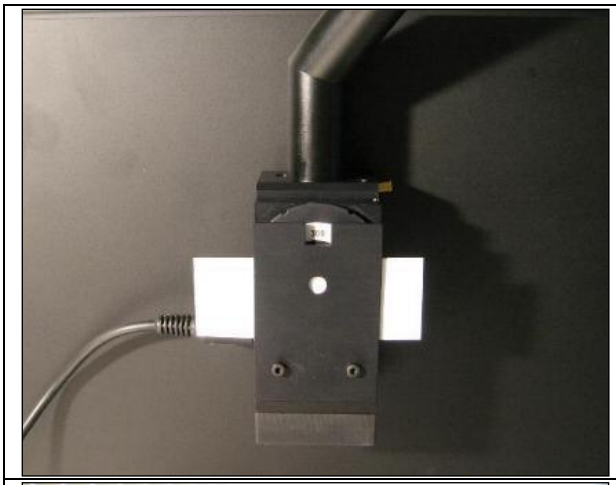
(i) Acoustic noise from surroundings.

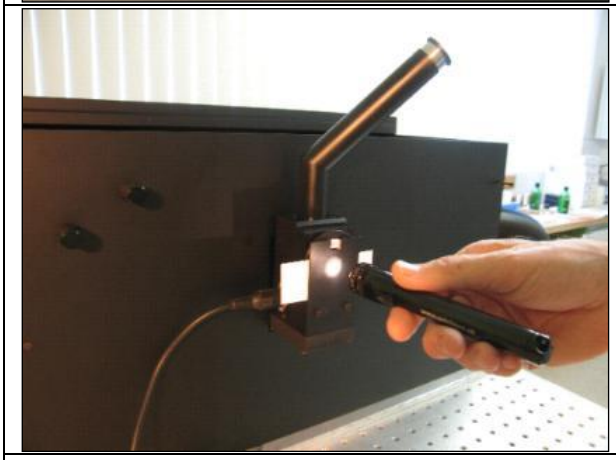
(ii) Vibrations in table - instrument requires an anti-vibration support. Did you remember to turn on the vibration isolation system?

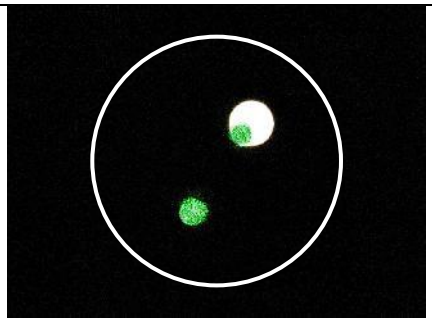
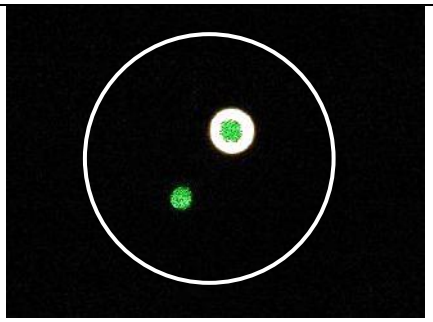
5.8 Alignment of the reference beam splitter

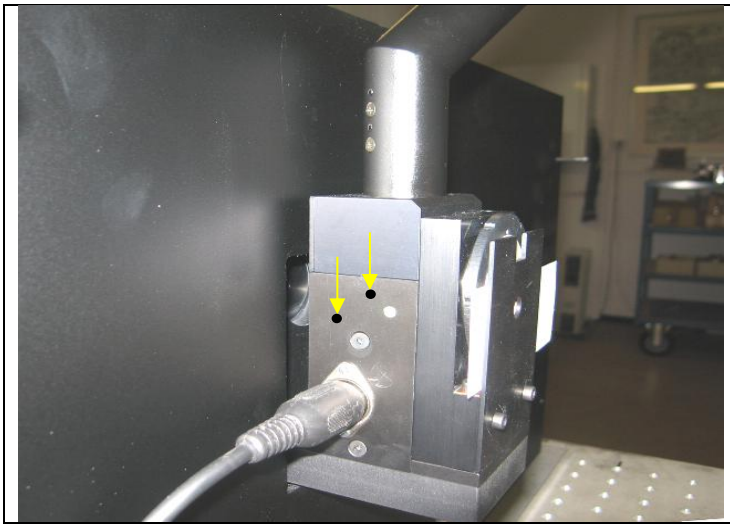
The small reference beam splitter located inside the spectrometer's input assembly (see Figure 4-8) must be correctly aligned, so that the reference beam follows exactly the same path to the photomultiplier as the measurement beam. Failure to achieve good alignment will result in loss of signal and a small frequency shift in the spectrum. The alignment of the beam splitter can be adjusted by means of small tilt screws accessible on the rear side of the input assembly.

The images shown here refers to the alignment of the reference beam **in instruments equipped with the monocular pinhole viewer**. More recent products are equipped with a USB CMOS camera (pinhole viewer PV-1) which allows the pinhole plane to be visualised on a computer screen. The alignment procedure when using the camera is described in the related manual.

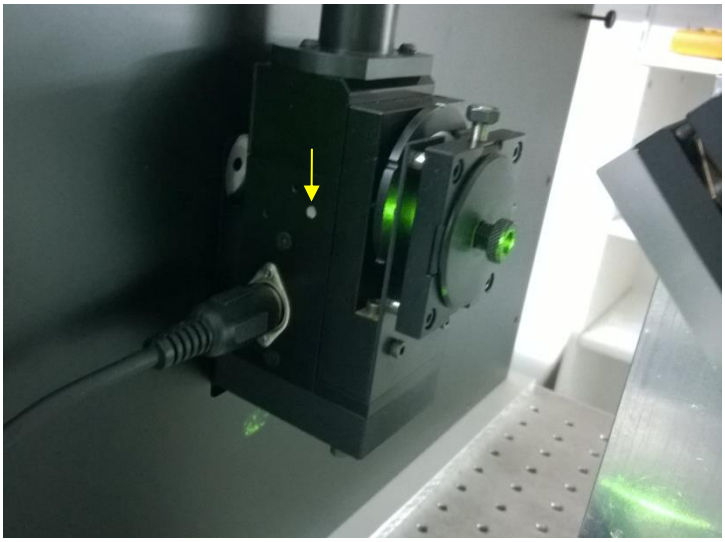
<table>
<tr><td>  </td><td>The reference beam should be directed onto the diffuser on the side of the input shutter unit.

If you look into the pinhole viewer you will see two green spots, corresponding to the beams reflected from the two sides of the beam splitter.</td></tr>
<tr><td>  </td><td>Only one of these beams will be used.

Make the entrance pinhole visible by placing a piece of paper next to it and illuminating with white light. Choose a pinhole size of 300 μm. If you again look into the pinhole viewer you will see one of the green spots (reference beam) superimposed on a white disc (the input pinhole).</td></tr>
<tr><td></td><td></td></tr>
<tr><td>not correctly aligned</td><td>correctly aligned</td></tr>
<tr><td></td><td></td></tr>
<tr><td>  </td><td>  </td></tr>
</table>

	Use a 1.5 mm hex key in the two holes indicated in order to align the beam splitter so that the green spot is nicely centred on the white disc. The reference beam is now correctly aligned.

5.8.1 Alternative alignment procedure

	If no pinhole viewer is available, approximate alignment can be achieved by sending laser light into the input pinhole (150 μm). A direct laser beam can be focussed onto the pinhole by means of the 10 mm focal length lens assembly provided with the instrument, or scattered light can be used. With the optics switched to TANDEM configuration, and the light from reference beam blocked, the light reflected from the first surface of FP1 will be seen as a bright spot on the diffuser. Adjust the beam splitter as above until the spot has maximum intensity. It is important to note that, in order for this to work, the incidence angle on FP1 must be correct, or correctly adjusted following the first steps of the procedure described in the following section 7.2.

5.9 Check of the system efficiency from back scattering in Plexiglas

During the experimental work, it is quite common to have at a certain point the sensation that the signal measured by the spectrometer is not as strong as it “should” be and that some kind of misalignment or adverse condition is decreasing the measurement throughput.

Experience and practice are usually the best starting point to understand whether such an hypothesis is realistic or not: after experimenting for long time on certain classes of samples and using the spectrometer, an experimenter gets a feeling of what level of signal can be expected and which will be the reasonable time base for a measurement campaign.

In case a decrease of the signal is apparent, it is useful to have a way to assess the performance of the experimental setup. In general it is a good idea to choose a standard sample, which turns out to be particularly easy to prepare and to measure, and for which a solid statistic record is present for many experimental parameters; such a sample can be used as a reference to understand if the efficiency of the setup is the same. A test with a standard sample can confirm if the experimental setup is not really at its best.

The spectrometer is assembled in such a way that the internal alignment does not change spontaneously in time. The procedures described in this chapter should be sufficient to compensate the small drifts that are known to be possible in the device. If these are performed, the reason for a decrease of performance is likely to be in the external instrumentation.

In case an assessment of the spectrometer performance is required, because the external experimental setup seems to be ok, we recommend to use a sample of PMMA, commercially known as Plexiglas. PMMA is cheap, simple to find and provides a strong acoustic scattering signal. A sample of PMMA is usually provided with the spectrometer, but the material provided is not different from the one you can find in many hardware shops.

A measurement with PMMA should be done with the simplest and most reproducible setup, in order to have results related to the spectrometer’s efficiency only. If necessary, Tablestable can provide a small self-contained scattering setup that can be useful in this case.

When a PMMA sample is measured in back scattering configuration using a laser wavelength of 532 nm, the longitudinal acoustic waves inside the sample provide a Brillouin doublet signal in around 17 GHz frequency shift. Selecting a mirror spacing of 3 mm (FSR ~ 50 GHz), a scanning range of about ± 0.9 FSR, input pinhole of 450 μm and output pinhole of 700 μm, the number of expected maximum counts number per cycle on each inelastic peak, for every mW of light incident on the sample, should be numerically close to the quantum efficiency percentage of the detector (i.e. roughly 10 counts for a 10% QE detector).

6 ADVANCED AND EXTRAORDINARY MAINTENANCE

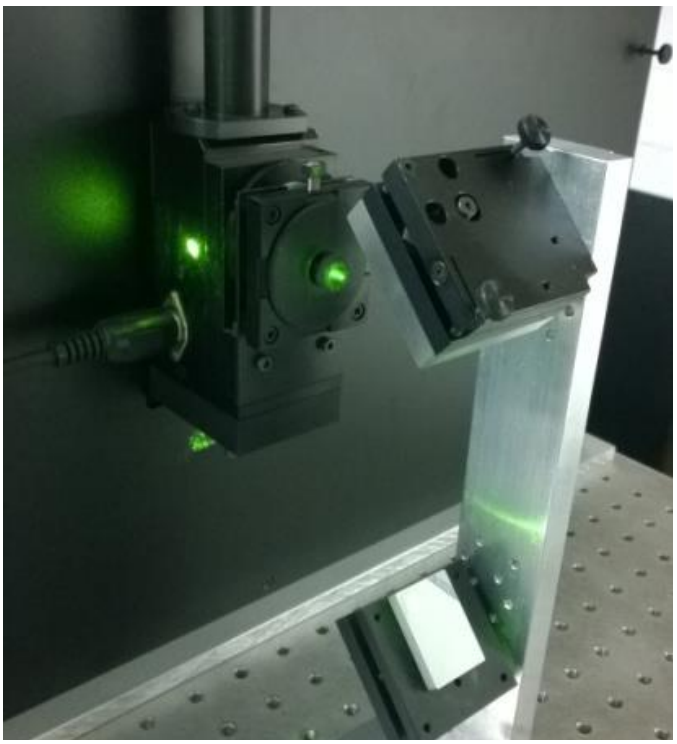
The procedures shown in this chapter should be performed only when a particular need exists in the instrument.
With the exception of the mirror spacing calibration, which could turn out to be necessary from time to time when the reliability of the spectrometer must be improved for small mirror spacing measurements (see section 4.14), these procedures are rarely or never required.

6.1 A light source for alignment and calibration

Many of the maintenance operations can't be performed by looking at the detector's counts, and require instead that the light path inside the spectrometer is directly visible by eye. It will be thus necessary to send light inside the spectrometer from the input pinhole, after switching off and adequately protecting (capping) the detector.

The most convenient light source for aligning the system is an expanded laser beam. The uniform wave front generated this way makes the observation of interference fringes easier. The laser beam should be, in this case, directed straight to the input of the instrument.
In order to input a laser beam to the instrument, we recommend the use of the 10 mm focal length lens provided by Tablestable (see figure), already mounted on a XY stage, which can be directly attached to the front pinhole turret by unscrewing the front cover (M3x6 screws on the bottom).

Make sure the incident beam hits the lens as near as possible in its centre and orthogonally. Moving the XY movements, try to position the beam in the centre of the pinhole, starting from the largest and reducing the size to the smallest. A high precision centring can be made using the pinhole camera viewer, if available.



Check the way the beam passes through the aperture A1 (see Figure 1-1 or Figure 2-5 depending on the type of spectrometer): the aperture should be overfilled and a light halo should be visible around it. On modern instruments, when the beam is orthogonal to the pinhole plane, the light halo should be almost centred with the aperture. If this is not happening, adjust the lens and laser beam alignment until the aperture A1 is symmetrically illuminated.

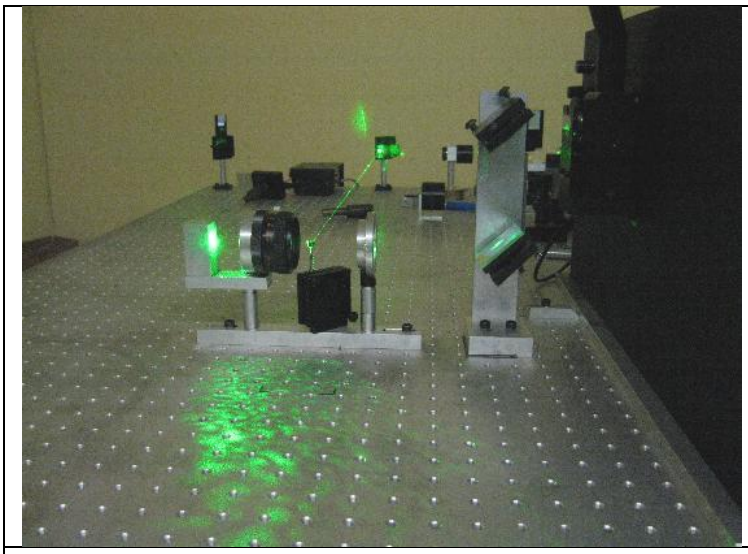
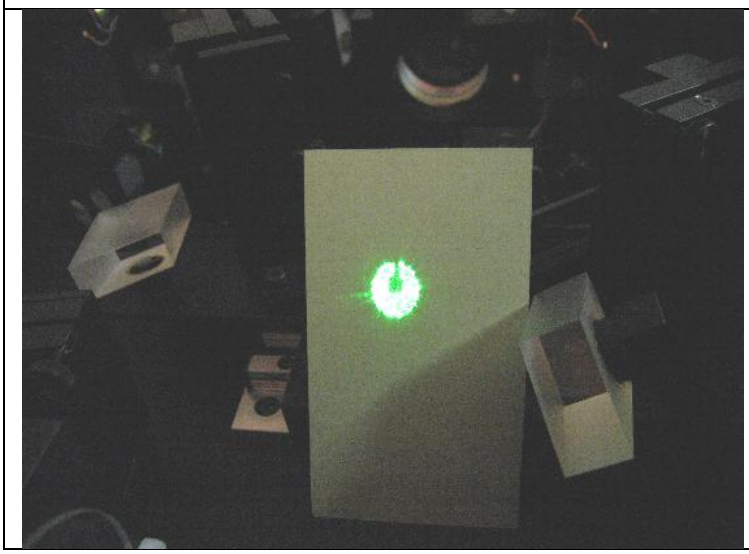
The XY lens focus can be adjusted by advancing or retracting the bolt where the lens is located. The focus can be checked by moving the pinhole wheel sideways and checking if the transition from illumination to darkness: a good focus will give a sharp and sudden transition.

This setup should create a wide and well visible beam going through the system.

6.1.1 An alternative light source

An alternative light source would be the reflected light from your experiment, using a metal block as source instead of a sample. In this case your external focussing lens can be used to direct light to the pinhole.

This second method is not recommended for operation such as calibration or full alignment of the spectrometer, but could be useful for quicker operations, like a quick inspection of the FP mirror's fringes.

	Shown here is a typical back scattering arrangement as described in section 4.3 of the manual. Check that the aperture A1 is uniformly illuminated. Ideally the scattered light should exactly fill the aperture: this condition can however only be obtained with perfect collimation and by choosing an f/18 aperture for the focussing setup.
	If the scattering optics are correctly set up, the image of the scattered light on a piece of card placed in front of FP1 should clearly show the shadow of the small prism used in the back scattering arrangement (or any other device used in the actual setup). If the incident beam is properly aligned, the signal should be visible even with the smallest input pinhole.

6.2 How to optically recover a completely lost FP alignment

It might happen that a FP pair gets so badly misaligned that no signal can be seen in alignment configuration using the detector.

If the simplest case, such a misalignment is only due to a bad position of the piezoelectric transducers, and in this case the problem is solved by scanning the X and Y piezoelectric ranges for the affected pair slowly and systematically, until the dip become visible.

If the piezoelectric correction range is not sufficient, and the loss of signal has happened after a big change in the mirror spacing, it could be useful to go back to the original spacing to recover the signal, and then split the desired change in smaller steps, compensating the misalignment at each step by means of the FP motors.

If nothing works, the most straightforward solution is to look at the spectrometer transmission by means of a direct beam of light. The first operation is thus to disable and protect the detector, and prepare a source of light as described in the previous section 6.1. In this case it is not necessary to have a perfect uniform beam source, so also the alternative source described in section 6.1.1 is sufficient.

Set the shutter off, and selecting the alignment configuration. The input beam of light will hit the alignment mode beam splitters, finally reaching both the FP cavities from left. The transmitted spot or fringe system will be immediately visible at right of FP2, while in order to see the transmitted spot at right of FP1, it will be necessary to temporarily remove the A1 mask. The A1 mask is fixed at right of the FP1 holder by means of two small knurled screws. It is sufficient to loosen the knurled screws and lift the mask to remove it.

A fringe system with 2 or more fringes will be visible after the misaligned cavity. It is usually convenient to set the X and Y piezoelectric controls for the cavity at midrange, and restore alignment by means of the mirror alignment motors. It will be always necessary to use Z axis to keep the fringe in view. The alignment is reached after the fringe system is reduced to a single fringe and then the single fringe is enlarged to provide a spot. The final part of the adjustment, when the fringe starts to be broad, can be carried out by means of the piezoelectric controls.

After the fringe is turned to a spot, it is possible to revert to the normal use condition. Remember to place back the A1 mask at its place and with the same orientation after the operation is complete.

6.3 Calibration of mirror spacing

Calibration of mirrors spacings consists in setting the correct relative spacing between the interferometers and setting the zero point of the dial gauge which measures the mirror spacing of FP1. As described in section 4.14, the error in the mirror spacings must be as small as possible in order to perform good measurements with the mirrors very close to each other.

The calibration procedure requires the use of the two calibration lenses provided with the instrument. Each of these lenses is mounted in a plastic holder that can be inserted into the interferometer mirror holders; the first lens is a positive 40 mm focal length lens, the second is a conical lens, with a hole drilled in the center.

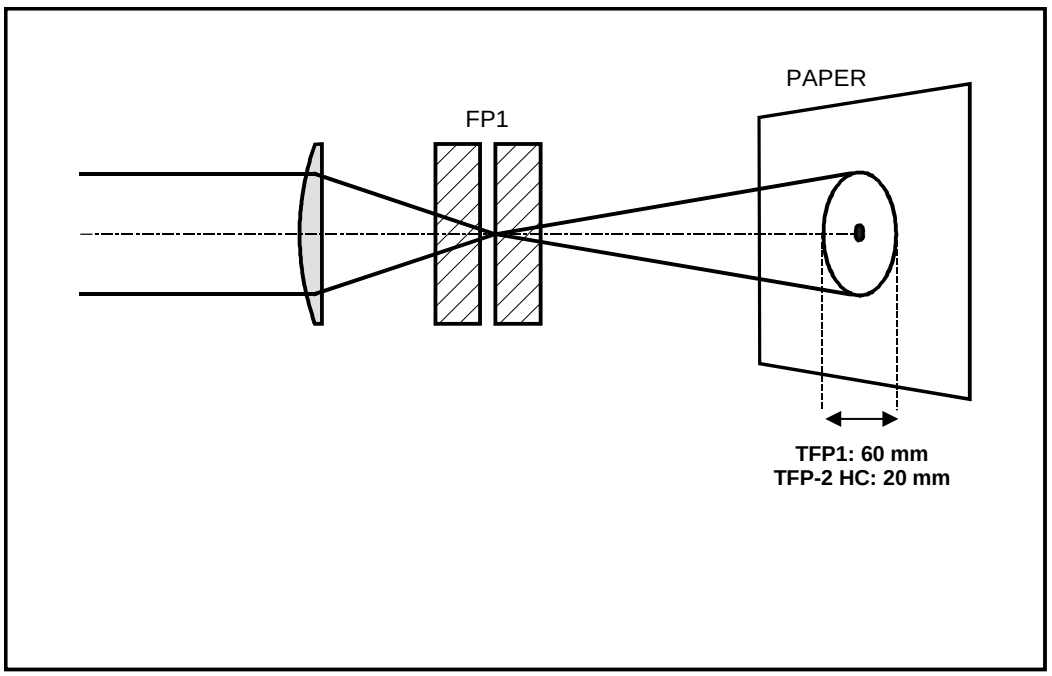
The use of the first lens will get the mirrors close to the calibration condition, the conical lens will then be used for a finer and final adjustment.

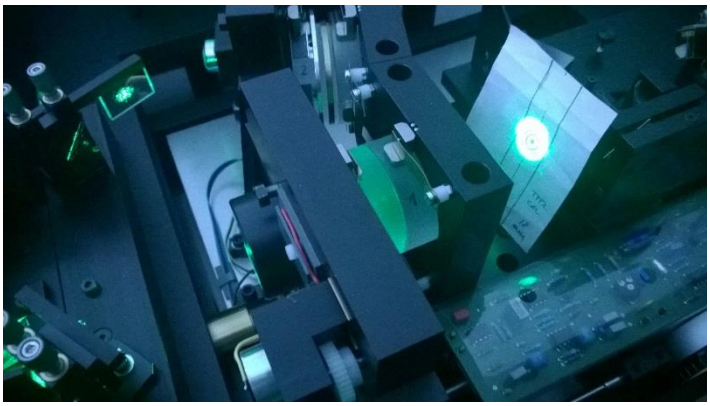
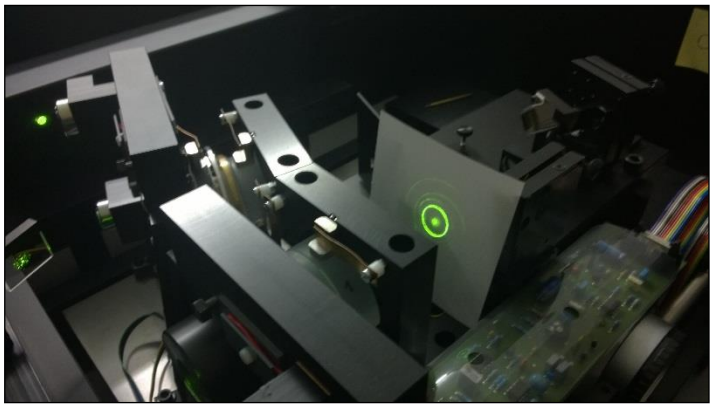
With the special conical lenses a calibration error less than 0.25 μm can be achieved. The calibration condition related to the conical lens is fulfilled when the spacing in FP1 is equal to 144 half-wavelengths. This means that the calibration spacing will be about 38 μm at 532 nm and is used to calibrate the mirrors spacing indicator dial. The spacing obtained by means of the conical lenses when using other wavelengths reduces or enlarges proportionally.

6.3.1 First calibration of mirrors spacing using interference rings (first lens)

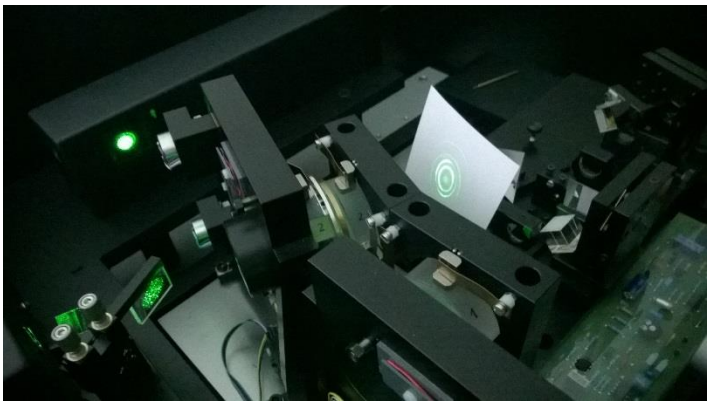
Switch the optics to alignment configuration, and align FP1 using the X1, Y1 and Z controls in order to have a full transmission.
Place the 40 mm focal length calibration lens provided into the entrance of FP1 to a depth of about 15 mm, and remove the mask A2; this one is fixed by means of two screws with black knobs on the right side of FP1 mount. Reduce the mirror spacing to around 100 μm and observe the rings formed by diverging light on a piece of card placed immediately after FP1, as shown in Figure 6-1.

Figure 6-1 First calibration lens image



	In a TFP-2 HC, as shown in the picture at left, the paper target can be positioned only immediately before G2. In a TFP-1 the paper target can be placed at a much larger distance, close to M3, and the fringe pattern will be larger. See Figure 6-1. The number of visible fringes is directly related to the mirror spacing: larger the spacing, the larger the number of fringes in view.
	Observe that the diameter of the ring changes as the Z-control on the control unit is adjusted. Now continue to decrease the spacing step by step by means of the Z motor and observe how the ring number reduces. After each step use the Z knob to reduce the inner ring to a small disc and measure the diameter of the next ring. Stop when this ring reaches a diameter of roughly 20 mm for TFP-2 HC, or roughly 60 mm for TFP-1.

Check that the dial gauge now indicates a spacing of about 40 μm. If this is not the case, the gauge may need to be adjusted. This will be done at the end of the calibration procedure.

	Now check FP2 by placing the same lens into the FP2 holder. A similar size of ring pattern should be observed. You can now change the ring scheme by using the ΔZ knob, in order to reduce the central ring to a dot. If the ring pattern is not identical, your calibration is way out and a correction will be required to the spacing of FP2 by adjusting the 3 black screws on the left side of the holder, as described immediately below.

If the FP2 fringe patter is significantly different from the FP1's one, the correct relative spacing of FP1 and FP2 must now be achieved by *adjusting the position of the non-scanning (left) mirror of FP2*. In order to understand which correction to apply, look at the number of visible rings inside the diameter already visible on the paper. If the number is larger (or equivalently if the first ring is too small when the inner one is reduced to a dot), the spacing of FP2 is too large, and vice versa.

Remove the diverging calibration lens and turn the screws gently as necessary: as a rule of thumb, remember that in order to see the two rings as described, the distance between the mirrors must be 40 μm; if you see three or four rings you have a distance of approximately 80 μm or 120 μm, and so on.

If the mirror spacing is too small, turn screws anti-clockwise, if the spacing is too large turn the three screws clockwise. A complete turn of the screws corresponds to 500 μm.

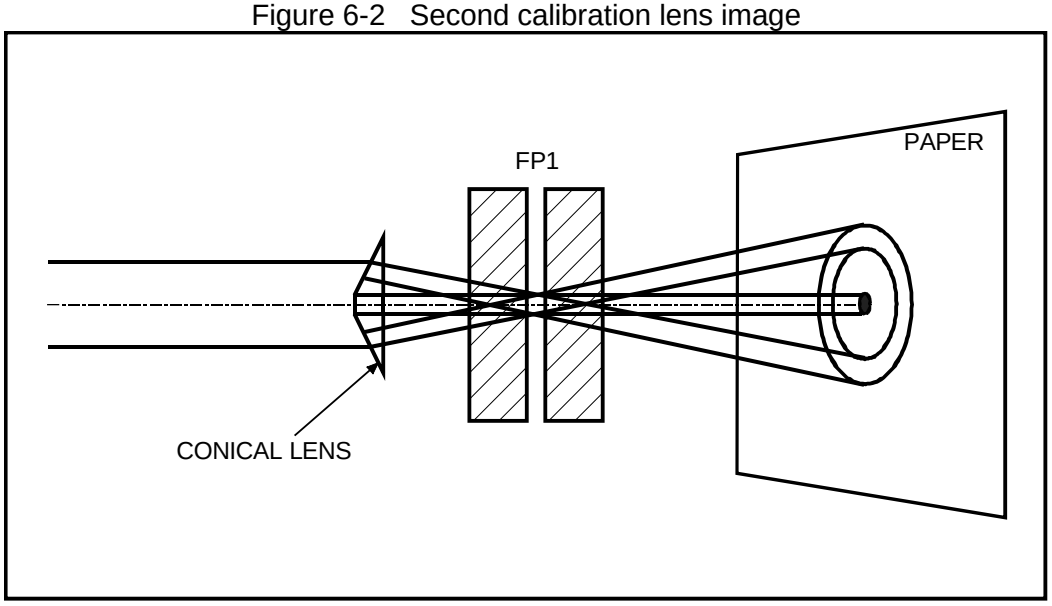
Position the X2 and Y2 knobs on the control unit to midrange. Start from the middle screw and turn it to obtain a desired number of fringes (larger the number, larger the change). Turn one of the other screws in the same sense until you get a 45° degree tilted fringe system: this means the distance travelled is almost the same. Turn the third screw until the mirror is close to parallel again. Use the control unit knobs to obtain full alignment.

Check again the ring pattern using the first calibration lens, if necessary repeat the correction until FP2 is sufficiently close to the calibration distance.

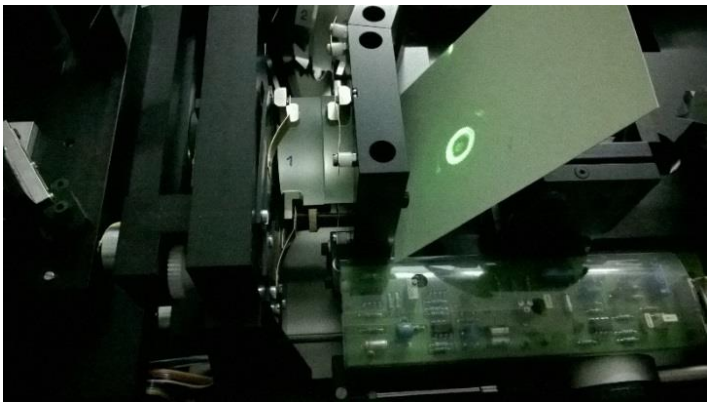
6.3.2 Precise calibration of mirror spacing using conical lens, gauge adjustment

The second part of the method uses a conical lens and allows a much more accurate setting of the absolute spacing. An accuracy in the order the used light's wavelength can be achieved. The principle is shown in the diagram below.

Figure 6-2 Second calibration lens image



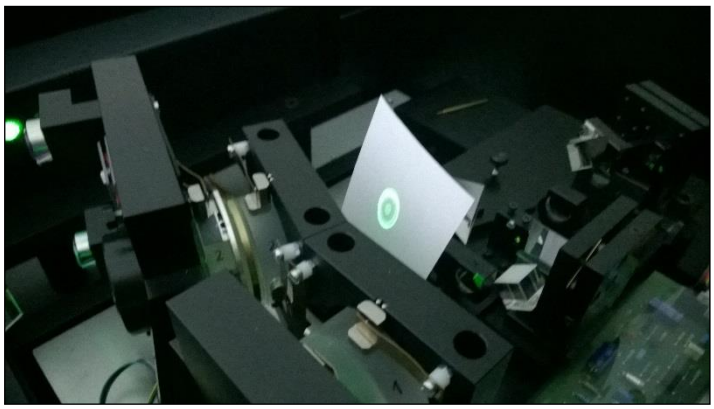
The conical lens is made of quartz glass with a cone angle of 14.5°. There is a hole of diameter 6 mm drilled through the centre. This lens is placed near FP1 with the flat side of the lens towards the mirrors. As shown in Figure 6-2, the light passes through FP1 at only two angles to the interferometer axis – 0° and 6.76°. The central beam produces a spot in transmission on a piece of paper held in front of M3. The other beam produces a ring of about 21 mm external diameter, when observed in the TFP-2 HC position, or about 60 mm when observed before M3 in a TFP-1.



Place the conical lens into the entrance of FP1, with the lettering “FP1” visible. As you change the Z-control you will now see only two rings – a disc in the centre and a ring of light around it.

In most cases, the ring and the disc will not reach maximum brightness at the same position of the Z-control.

Set the Z-control so that the disc is at maximum intensity, then change Z until the ring is maximum. Pay attention to the direction that you turned the Z-control to go from disc to ring. **If the direction was clockwise the spacing of FP1 is slightly too large, and vice versa.** Adjust the mirror spacing by tapping the switch on the motor control – each tap will change the spacing by 0.5 μm or so. Continue until the disc and the ring reach maximum brightness for the same setting of the Z-control.



FP1 is now set at the correct calibration distance. This distance depends on the laser wavelength used and corresponds to about 38 μm when 532 nm light is used, and rescales proportionally to the wavelength. Adjust the dial gauge to read this value.

Now reverse the conical lens and place it into FP2 (the lettering “FP2” must be visible). Adjust the Z-control until the ring or disc are at maximum intensity. If all is well both will reach maximum intensity together. If not, a small adjustment of the spacing of FP2 will be also necessary. The sign of the required change can be again determined by looking at the rotation sense of the Z knob (**not** the ΔZ) as seen previously.

If an adjustment of FP2 is necessary, you will need to remove the conical lens and to change the mirror spacing by a few microns. This is done as described in the previous section. Such small changes can be obtained turning only the middle screw in the required sense until a few vertical

fringes are seen on a piece of paper held near FP2. The number of fringes can be used to judge how big the correction is.

A fringe spacing of 1 mm corresponds to a screw movement of about 9 μm.

Set up the desired fringe spacing and then realign FP2 using only the other two screws. X2 and Y2 motors can also be used if necessary, together with knobs. After returning to full alignment, check again the calibration with the conical lens and iterate the correction if necessary.

When this procedure is complete, the interferometer is fully calibrated for tandem operation at mirror spacing greater than about 100 μm.
You may adjust the translation stop, see Figure 3-1, so that the minimum attainable mirror spacing is equal to the calibration spacing.

Do not forget to replace the aperture mask A2 on the right of FP1 after completing the calibration.

6.4 Alignment of optical system and occasional checks

The full procedure for a thorough check of alignment is described at end of this manual, in chapter 8. While there is rarely a need for such a check, the user could want to perform some very quick and basic check on the system efficiency, while assuming that the internal alignment of the instrument is still optimal.

These are a check of the input and output alignment of the instrument, performed using the laser light beam set up as described in section 6.1, and obviously with the **detector off** and capped whenever possible:

1. Check that the reflected light from FP1 passes cleanly back through the pinhole. The necessary steps are described in the first part of the procedure reported in section 7.2.2.

2. In 6-pass tandem mode, keeping the electronic stabiliser of the CU **disabled** and the scan amplitude to zero, working with the top lid open and selecting a small output pinhole, align manually the spectrometer and check the correct alignment of the output mirror M6, so that the light passes cleanly through the pinhole. Optimize the alignment on the smallest output pinhole. In alignment mode, with the same pinhole, check the correct alignment of BS1 and optimise to the smallest output pinhole, too. This procedure has the same purpose as the one described in section 5.4, which is based on the detector signal.

6.5 Range re-centring of the mirror motors

Each FP mirror holder is equipped with 2 motors, that change the X and Y tilt of the corresponding mirror by rotating a gear, connected to a threaded bar and a pivot point. The two motors of each FP, controlled by the front panel of the spectrometer, work together to provide the desired tilt. When rotating, each motor gear moves sideways between two end positions, having full range of motion about 4 mm (see following figure).

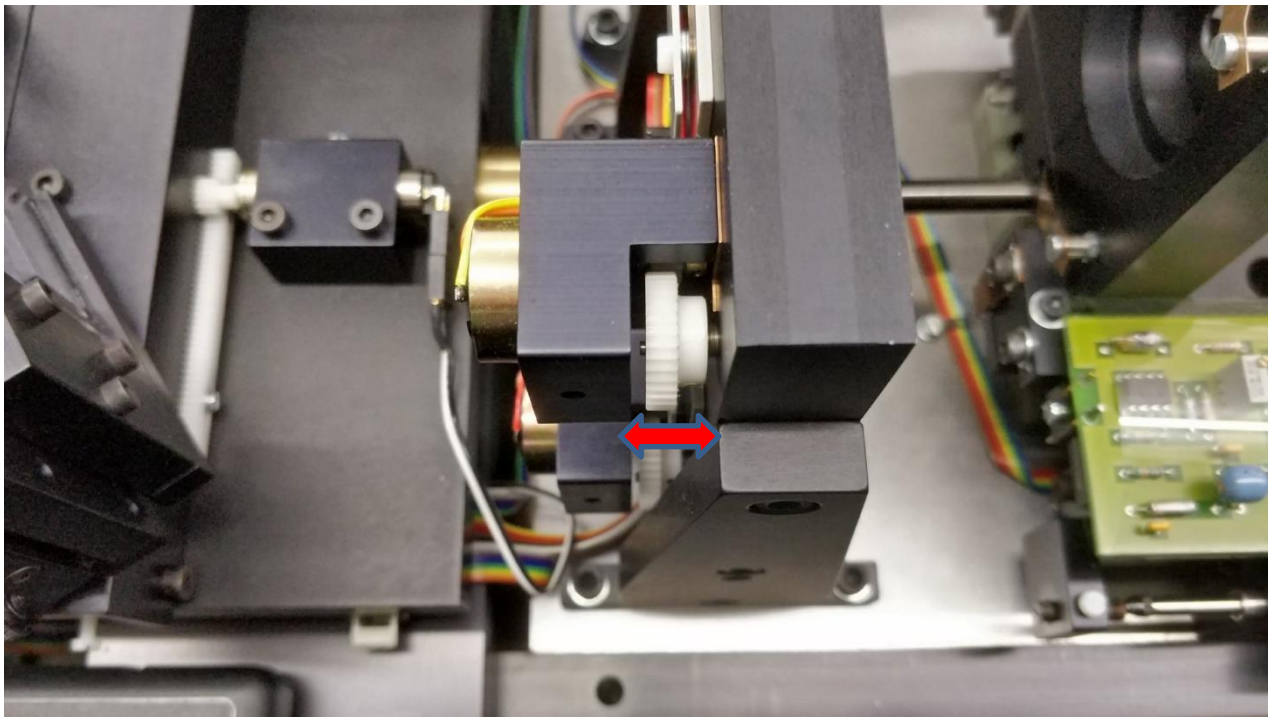
After using the system for a long time, it might happen that one of the gears of the motors reaches the end of its allowable range, and is thus unable to move further in that direction. When this happens, the gear cannot further rotate and stops but no damage is caused to the motor or to any other component of the system. In the meantime the motor correction system becomes not usable, and can be difficult or impossible to use the spectrometer.

In such a case, the motors gears must be recentred, bringing them to about midrange and restoring the parallel condition in the mirror pair.

In order to do so, the first thing to do is to observe the direct light transmission through the affected mirror pair, by preparing a source of light as described in the previous section 6.1.

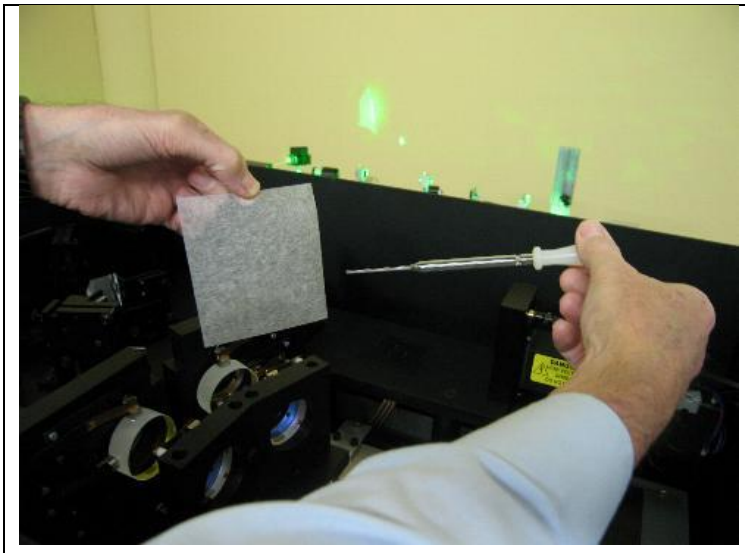
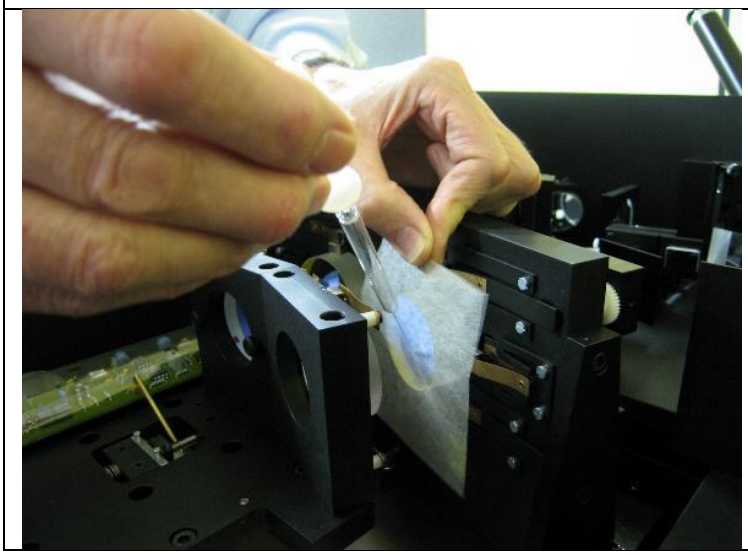
Once a light pattern is visible, bring the two piezoelectric knobs related to the affected FP to midrange, and use the Y motor control of the motor to bring **both** the gears to opposite end positions. This will create a number of vertical fringes after the mirror.

After both the gears reach a stop position, move the Y motor control in the opposite way to get back towards middle of the motion range. Finally, restore the normal parallelness condition using the top and bottom coarse screws on the mirror holder, and the piezoelectric adjustments of the control unit. Do not move the middle coarse screw, otherwise you could alter the instrument mirror spacing calibration.



6.6 Cleaning the FP mirrors

In a normal environment the interferometer mirrors do not need to be cleaned very frequently. After a period of 2 or 3 years the front surface of the mirrors may however begin to show excessive scatter loss.

	The mirrors can easily be cleaned *in situ* as shown here using a lens tissue and a fine pipette. Open the mirror gap to near maximum spacing (30 mm is fine).
	Apply clean alcohol or acetone via a fine pipette to a lens tissue held as low as possible and touching the mirror. The fluid should wet the tissue so that it adheres to the whole mirror area. No excess fluid should be allowed to drip down. Now draw the tissue upwards, making sure that it stays in contact with the mirror. The tissue must remove all the fluid from the mirror surface – if not start again. A little practice makes perfect.

6.7 Adjustments to electronics

The adjustments in this section are made by acting on electronic trimmers installed on the TFP scan board or on the second board inside the TFP control unit. Both these procedures are performed at factory before shipping the instrument; in most cases these procedures are not necessary anymore in the life of the spectrometer.
In the event that it appears that the electronics is not functioning correctly it is advisable to call in for instructions. If you are competent in the field of electronics you may undertake the following alignment checks yourself.

The procedure described in section 6.7.1 is useful if the instrumental scan seems not linear. A software assisted procedure is also available in the GHOST application. Please make sure that enough damping oil is available in the oil gap before thinking that the scan needs correction.

The procedure in section 6.7.2 could be required when the FP2 dip, as seen in alignment mode, becomes broader when moving the ΔZ control unit knob. If this behaviour is particularly strong, the stabiliser could also not be working correctly.

6.7.1 Adjustment of scan linearity on the scan board

The linearity of the scan is controlled by the scan board (Figure 6-3), which is installed inside the spectrometer box, on top of the interferometer stage. With reference to Figure 1-2 and Figure 6-3 it is seen that two adjustments are available for optimum operation of the scanning stage, namely a gain and a linearity adjustment.

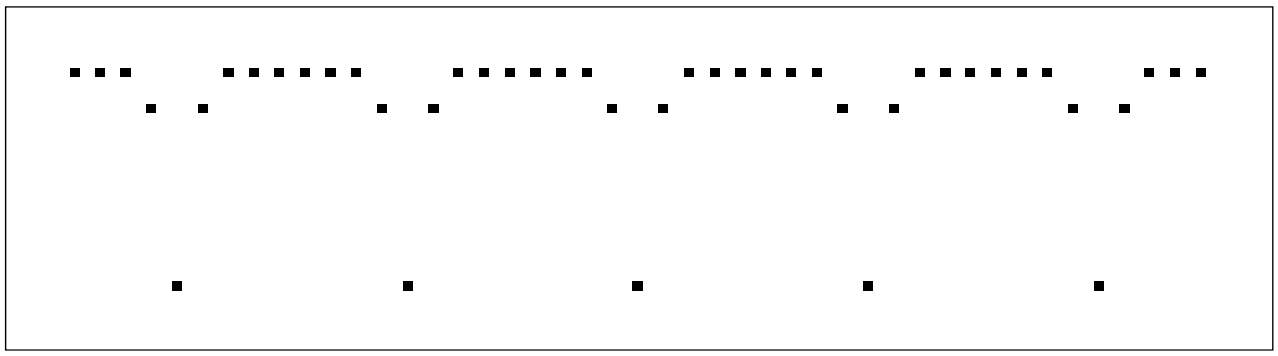
The object is to set the gain in the feedback loop of the scanning circuitry as high as possible without inducing oscillations, and set the linearity adjustment so that the scan is as linear and symmetric as possible. **The presence of oil in the interferometer's oil gap must be always checked before attempting any correction on the scan board potentiometers**: see section 5.6 for instructions.

1. Set up the interferometer in the ALIGNMENT mode with FP1 aligned and FP2 intentionally misaligned. Set ΔZ so that the misaligned FP2 dips are well apart from the FP1 ones.

2. Set the scan amplitude so that about 5 orders are scanned (scan amplitude about 1300 nm), leaving about 1/10 of the scanned channels by side. Align one order in the centre of the scan range and maintain it there with occasional adjustments of Z.

3. An assisted procedure for real-time linearity check is available in the GHOST software; this could be useful to understand if a correction is needed and to realise the effect of variations of linearity or gain on the scan linearity. The gain is increased when rotating counter-clockwise; the adjustment direction of the linearity potentiometer is such that if the peaks at the start of the scan are too close together, the potentiometer should be rotated clockwise.

4. Once the best possible linearity has been obtained on the GHOST MCA software, select 256 channels and display dots for a final verification. Adjust the scan amplitude so that as nearly as possible each dip occurs with a dot at its lowest point. Record this spectrum for maybe 5 scans. If the linearity is good the spectrum will appear as below where it is seen that the two channels higher up the dips are at the same height. (For clarity fewer than 256 channels have been shown).



5. If these channels are not at the same height the linearity potentiometer on the scan board must be adjusted, see Figure 6-3, in order to obtain perfect linearity; readjustment of scan amplitude will also be necessary. The procedure can be iterated at will until the best possible result is obtained.

At the end of this procedure, a linearity error of 0.2% or less should be obtained in the mentioned region. In most cases, the linearity can be further improved and the linear scan can be extended to a larger region.

If you don't manage to obtain this performance, get in touch with Tablestable for help.

Having obtained the above linear spectrum the scan amplitude indicator must be recalibrated. If the linearity and gain settings of the scan board have been changed, the LCD display will also need adjustment: see section 5.5 for instructions. The expected value for the LCD indicator can be also obtained from GHOST in the linearity assessment window.

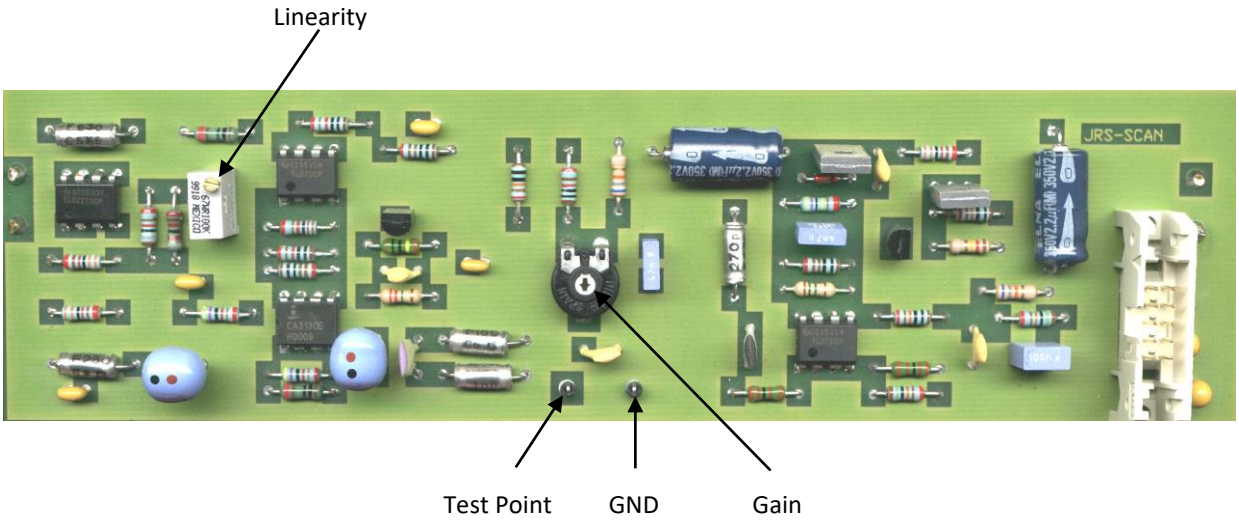
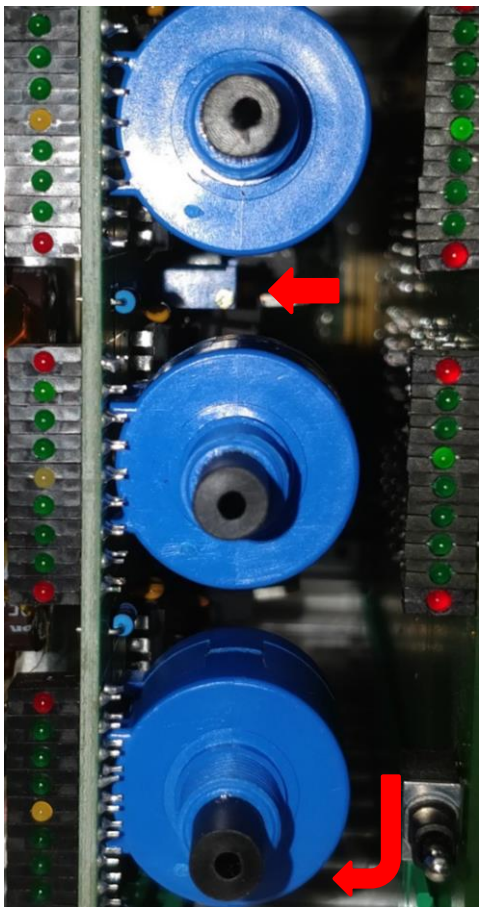


Figure 6-3

6.7.2 Adjustment of the ΔZ scan movement

When adjusting the alignment of the interferometer in the alignment mode, an adjustment of ΔZ is used to move the dips to coincidence. During this movement it is of course desirable that FP2 stays in alignment. In other words the movement of the FP2 mirror must be tilt-free. Unlike the Z-scan movement which is determined by the movement of the parallelogram, the ΔZ movement is achieved by movements of the three PZTs supporting the non-scanning mirror of FP2.

In order to make the movement tilt-free the fractions of the ΔZ voltage applied to each of the PZTs must be adjusted to allow for the differing characteristics of the PZTs. This adjustment has been performed at the factory and it is unlikely that you will need to change it. Should it however become necessary, the procedure is relatively straightforward.



1. Remove the 7 knobs from the front panel controls of the control unit and remove the front panel.

2. Locate board no. 2 of the control unit, the second from the left. Looking from the front side, you will see two small potentiometers for adjustment: one is immediately over the Y2 knob (see figure), the other (not visible in figure but indicated by the lower arrow) is under the ΔZ knob. In the alignment mode observe the dips due to FP2 and set the scan amplitude to at least 1300 nm so that 5 or more FSR are scanned.

3. Adjust the ΔZ control so that the ΔZ display is mid-range. Optimize the alignment of FP2 using the motor controls with the PZT controls set to mid-range (section 5.3).

4. Adjust Z if necessary to bring the dip to mid scan. Now turn the ΔZ control so that ΔZ is scanned by one order. If the scan is tilt-free the alignment of FP2 should remain optimum – if not, adjust the two potentiometers on board 2 until full alignment is achieved again.

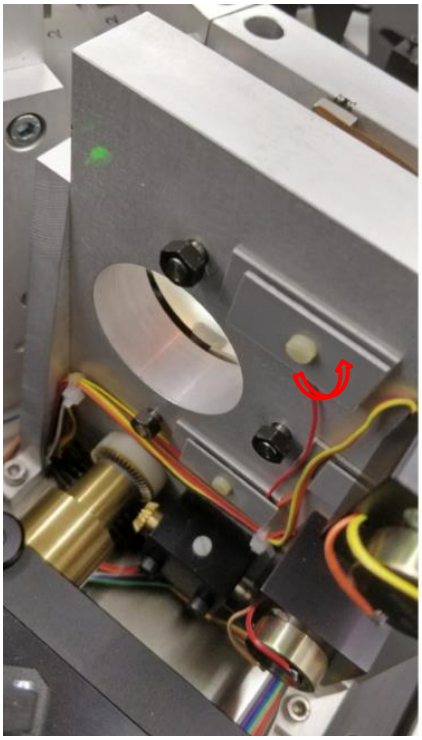
5. Scan ΔZ over the whole range and check for good alignment. Repeat the above procedure if necessary.

6.8 Inspection of the piezoelectric transducers voltages

The FP mirrors tilts are set by means of piezoelectric transducers, power with high voltage and controlled by means of the control unit's knobs. When an axis is not operating correctly, so that it is very difficult or impossible to reach a parallel configuration for one of the FP cavities, it might be required to check that the piezoelectric voltages reach correctly the transducers.

A first test consists in checking the output of the control unit, and namely the presence and the value of the piezoelectric voltage on the "interferometer" port: in this case, refer to section 8.1 for port pin description and expected voltage range of every transducer.

A second step is to check the voltage at the transducer's place. There are three transducers on each mirror pair: two working on the Y axis and one on the X axis. The transducers are located close to the mirrors anti-reflective surface, and are not easily accessible, but their contact leads are soldered on the left side of the FP mirror holders. It is easy to check the voltage at this position.



Each contact is protected by a plastic cover, mounted by means of a plastic nylon screw. In order to expose a contact, slacken the nylon screw and rotate the cover by 90°. The contacts are realised on a metal tag, soldered to a lead coming from the transducers.

7 ALIGNMENT OF THE OPTICAL SYSTEM

The full alignment of the optical system is a complex procedure, which should be performed only by experienced operators. These adjustments are normally not required, except that in the case one of the internal alignment controls has been moved by mistake, or after an optical part is replaced. The instructions provided here are intended for these specific and particular cases.

In case the instrument is not behaving correctly and none of the simpler procedures and information described in the previous chapter seems to apply or looks useful, **users are strongly advised to get in touch with Tablestable and ask for support before attempting to perform a full alignment.**

In case the internal alignment sequence of the instrument is used as a way to familiarise a new user with the instrument, this should be always done under the supervision of an expert operator.

7.1 Alignment of the TFP-1 optical system

The following description provides a detailed procedure for achieving correct alignment of the optical system. Refer to Figure 2-2 and Figure 2-1 for components name and light path diagrams in the two possible configurations.

Before proceeding a source of light will be required. Set it up using a laser beam directed through the input pinhole, as described previously in section 6.1. Use small pieces of paper to follow the beam through the system.

A beam splitter consisting of a simple thin glass plate will be required in front of the entrance pinhole P1. If a direct laser beam is being used place the beam splitter before the focussing lens. Otherwise place as indicated in Figure 4-5**.**
The first aim is to make sure that the beam falling on FP1 is collimated, perpendicular to the mirror surface, and at the right location.

1. Adjust M1 so that the right hand edge of the mirror is about 41 mm from the aperture A1 and at the same time slide the base of M1 so that the input beam strikes M1 about 1mm from its right hand edge. Orient M1 so that the beam now passes through lens L1 - the vertical diameter of L1 should touch the right hand edge of the beam.

2. Use a mirror to reflect the beam after L1 onto a distant wall. Adjust the focus of L1 for parallel light. Temporarily place a corner-cube just after L1. Adjust the orientation of M1 so as to centre the reflected beam on the catseye. Remove the corner-cube.

3. Slide the base of M2 so that the beam passes through the appropriate aperture of A2, and so that at the same time the reflected beam from FP1 approximately folds back on itself. It will be necessary to keep FP1 aligned - use the Z-control to obtain transmission.

4. The front end optics is now crudely pre-aligned. Precise adjustment is obtained as follows:

5. Hold the piece of paper just after FP1 and adjust M1 so that the beam cleanly fills the aperture A2.

6. Look for the beam reflected from FP1. It should strike the rear surface of A1 as a bright spot with two weaker satellites. Ignore the satellites and use M2 to send the bright spot back through A1. Repeat 4 and 5 as necessary.

7. The reflected beam should now pass back out through the pinhole and be observable on a piece of card after striking the glass plate beam splitter. Optimise the focus of L1 and adjust M2 as required. Repeat steps 4 to 6 as required.

8. The multiple passes through the interferometers must be adjusted as follows.

9. With FP1 aligned and adjusted for steady transmission (zero scan amplitude) use M3 to direct the beam 1 onto FP2 so that the reflected beam returns through the aperture 1 of A2. Use for example a fine slit cut in a piece of card placed over A2 to assist in the correct alignment. An accuracy of about 0.1 mm is required. Finally look for fringes on the surface of M3, or on the ghost beam on A2, or after transmission through FP2, and adjust M3 to give about 5 fringes.

10. Align FP2 and, using the ΔZ control, adjust for steady transmission. Beam 3 should now be visible. Check that it falls cleanly on the aperture 2 of A2. If necessary translate the prism PR1 vertically. The prism should be rotated slightly about the horizontal axis so that the front surface reflections do not return to FP2. Finally use the fine adjustment to rotate the prism about the vertical axis so that fringes are seen similar to those in paragraph 9 above.

11. Adjust the interferometer alignment controls to achieve good transmission of beam 4. This should strike M4. Rotate M4 so that beam 5 becomes visible after aperture 3 of A2. Translate M4 so that the bright spot seen on its surface is as small as possible. Check beam 5 again and if necessary re-orient M4.

12. Realign the interferometers so that beam 6 is clearly visible. Rotate mirror M5 so that the beam strikes the middle of the side of the prism PR2. Slide M5 so that beam 6 strikes the mirror near its right hand edge. Rotate PR2 to the minimum deviation position - the transmitted beam will then be circular in cross-section.

13. Orient mirror M6 so that the beam passes through the output pinhole P2. If the beam is not centred on A3, correct by adjusting M5 and realigning M6. Check focus of L2 and adjust if necessary.

14. The tandem-multipass optical system is now correctly aligned. The alignment mode optics must finally be adjusted following the procedure below.

15. Switch the optics to the ALIGN position. The glass block G1 deflects the beam to the axis of FP1. Observe the light transmitted by FP2 - a small amount leaks past the aperture A2. Rotate G1 to centre the beam.

16. Adjust the beam splitter BS1 so that the return beam strikes BS2 in the middle.

17. Adjust BS2 so that the beam reflected from FP2 passes via G2 and M5 to the output pinhole P2. It may be clipped but do not worry yet.

18. Adjust Z so that FP2 transmits. The transmitted beam should strike A2 in the centre. If a correction is needed walk the beam using BS1 and BS2 and repeat step 14.

19. Adjust Z so that neither FP1 nor FP2 transmits. Rotate the glass block G2 (friction held) until the outputted beam passes cleanly through A3. If some clipping still occurs then it is probably because the beam is not passing symmetrically through G2. Adjust the stop on the translation stage - slide the motor out of contact to do this. It may then be necessary to slide the angle piece supporting G1 to compensate. Return to step 13.

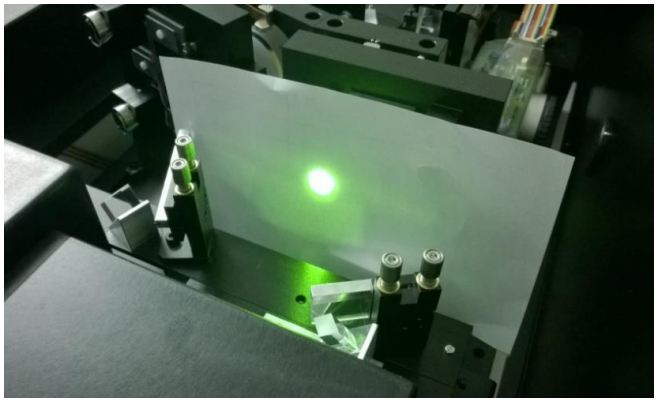
NOTE Do not touch M6 when adjusting the alignment mode optics!

7.2 Alignment check of the TFP-2 HC optical system

Despite the higher contrast reached by means of the TFP-2 HC optical system, the procedure to check its alignment is simpler to perform and quicker, with a lower number of adjustment knobs to use and of required tools, in comparison to the TFP-1.

The most important condition to fulfil in order to obtain a perfectly aligned TFP-2 HC is to make sure that, while in tandem configuration, the signal beam goes from the input pinhole to the output pinhole, being correctly centred on these, and hits orthogonally the FP1 and FP2 surface at each one of the six passes inside the instrument. Once this is obtained, the alignment configuration optical path must be matched to the tandem configuration.

Before proceeding a source of light will be required. Prepare a beam of light entering the input pinhole of the instrument, as described in section 6.1. Check that a nice uniform wave front is seen inside the spectrometer, as shown in the picture at right.



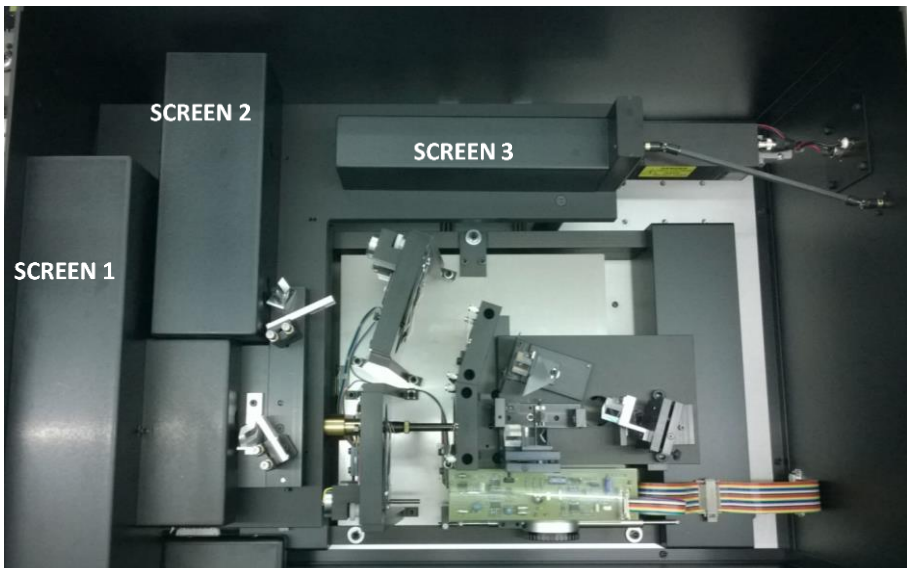
Refer to Figure 2-5 and Figure 2-6 for optical components naming and location.

The alignment procedure is easier to perform at small mirror spacing (≤1.5 mm); reduce the spacing as necessary before beginning.

7.2.1 Removal of the internal screens

The three internal screens of the instrument must be temporarily removed when performing the alignment procedure. The three internal screens, shown in Figure 7-3, are just sitting on the top plate of the instrument, so in order to remove them it is sufficient to lift them. The only important attention to be paid is to ensure that they are pulled vertically and not tilted or moved while lifting. This will avoid damaging internal components or moving any adjustment knob with the edge of a screen.

Figure 7-1 Screens inside TFP-2 HC



7.2.2 Orthogonality of the 1st pass

The first step is to make sure that the light falling on FP1 is orthogonal, and this is done by checking that it is reflected back out of the input pinhole. Choose the largest input pinhole and set the optics to tandem configuration.

If you are using an expanded laser beam you should see the reflected beam going back towards the laser. If the position is not correct, move the G1 tilt knobs to bring the beam back to itself. On older layouts of the TFP-2 HC, these knobs are located on the left size of G1, while on most recent versions these coincide with the G1's mirror tilt knobs.
Reduce progressively the input pinhole size to ensure the back reflected beam passes even through the smallest pinhole.

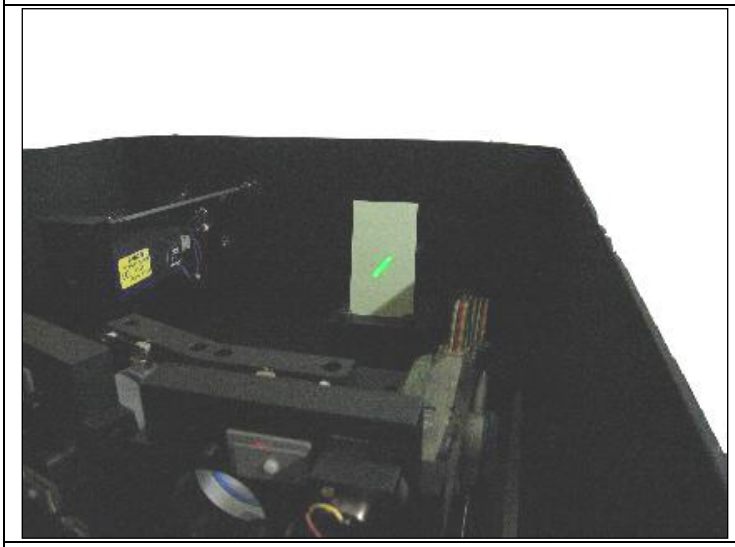
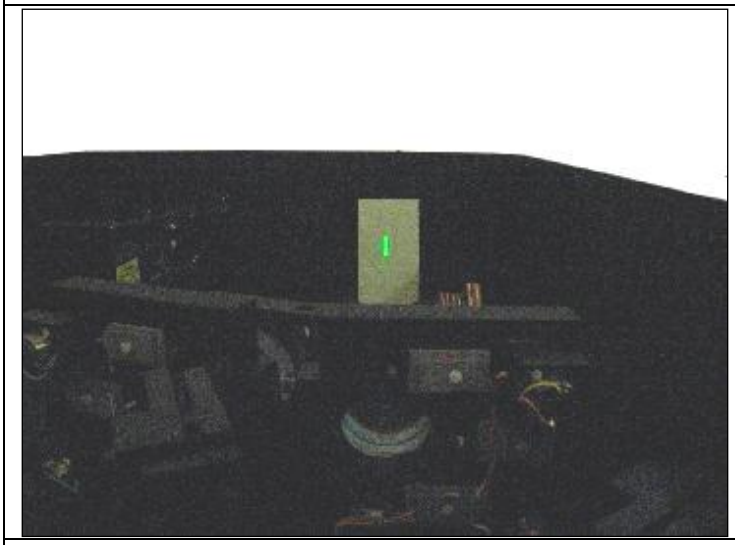
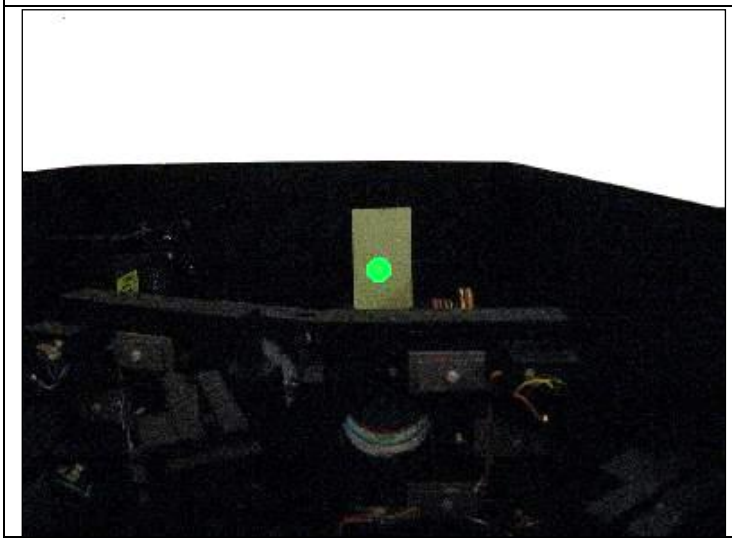
An alternative method to test the orthogonality is to use a beam splitter immediately before the input pinhole, and rotate it slightly so that the light reflected from FP1 falls onto a small piece of paper placed near the pinhole, as shown in the picture.

Caution: do not rotate the glass plate too far or the scattered light beam will be displaced so that it does not enter the pinhole. If the light does not go in, it cannot come out again!

In cases when it is impossible to access or follow the reflected beam out of the input pinhole, for example when the microscope appendix CM-1 or some other kind of complex setup is installed in close proximity of the input, it is possible to use the Michelson-style alignment tool, in conjunction with a special additional support, to check the orthogonality of the 1st pass. See the specific part in section 7.2.4 for details.

7.2.3 Manual alignment of the spectrometer's passes

During the whole process of alignment, it is necessary to keep the optical Fabry-Perot cavities in transmission with manual adjustments. This is basically done using the control unit's knobs X1+Y1+Z for the FP1 cavity (passes 1-3), and X2+Y2+ΔZ for the FP2 cavity (passes 4-6). Due to the continuous fluctuations of temperature inside the spectrometer, the FPs will tend to misalign continuously, so consequently will require continuous compensations to make the beam visible. The following pictures are an example of manual alignment on the first pass; subsequent passes are similar.

	Place a piece of card after FP1 and observe the light transmitted through the first pass. Probably just one fringe will be visible. If no fringe is visible, adjust Z until a fringe comes into view. Assuming a fringe as shown, adjust the axis Y1 and the fringe will rotate.
	Continue to adjust Y1 until the fringe is vertical. Now adjust the X1 axis and the fringe will get narrower or broader. It will be necessary to adjust Z in order to keep the fringe in sight.
	Adjust X1 until the fringe is so broad that it fills the whole field of view. This condition of alignment on FP1 must be maintained by means of small manual corrections, as needed, for the rest of the alignment check procedure.

It will be relatively easy to optimise and maintain the alignment of the first three passes by looking only at the light output from the 3rd pass. The FP2 cavity has however completely independent voltages and will require an independent optimisation.

7.2.4 Orthogonality of the 2nd and 3rd passes

The condition to be checked is that the beam hits orthogonally the surface of the interferometers mirrors at each pass: for passes 2, 3, 4 and 6 this can be done in three different ways, with increasing precision:

- using a piece of paper with an hole in the middle
- using the λ/4 tool and the leakage interference fringes
- using the Michelson-style alignment tool

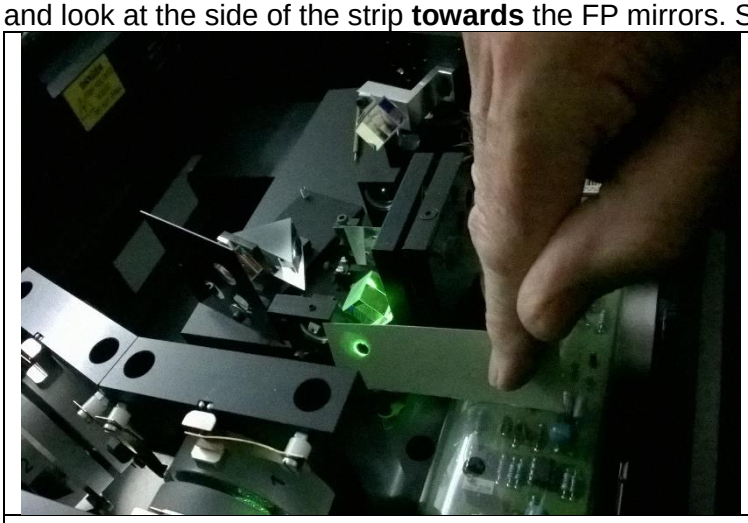
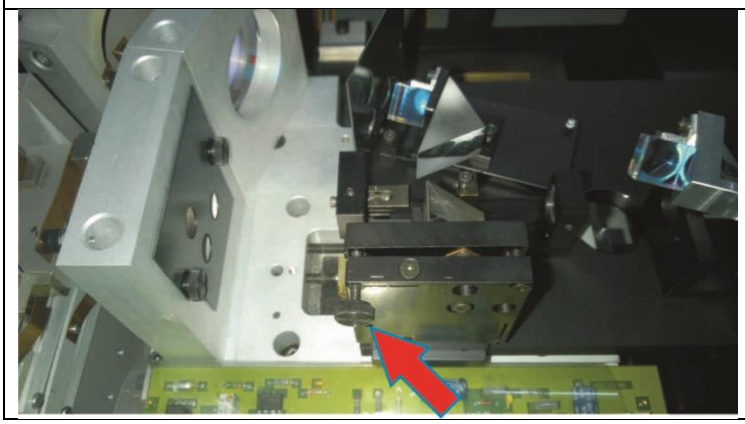
The last method is the easier and more precise of the three, so we suggest to use it whenever possible. In the following, all the three methods will be described.

Each of the passes 2, 3, 4 and 6 can be adjusted **on one axis only**, by rotating a black knurled screw located on the retro-reflecting prism mount before the pass, which rotates the prism around the direction of the longest edge.

- ***Alignment of a pass using a punched-through paper slip***

Despite the apparent roughness of this method and the theoretically low precision, it can be very useful when a pass is very far from being orthogonal, and still able to put the spectrometer in condition of working very well.

The principle of this method is to place the strip of paper along the optical path, in such a way that the hole is approximately at the centre of the beam, immediately before the pass to be checked, and look at the side of the strip **towards** the FP mirrors. See the pictures.

	Light passing in direction of the mirror will be reflected and will hit again the paper: if the reflected light is not superimposed with the hole (i.e. if a bright halo is visible around the hole) then the instrument is slightly misaligned. The image on the left shows how to place the paper in front of the top hole of FP1 to check the second pass.
	If a correction is necessary, you can adjust the incidence of light by using the knob indicated in the figure here at left. The picture at left indicates the knob related to 2nd pass. Turn the knob and observe the movement of the reflected light disc on the paper strip, then try to set the knob so that the reflection is perfectly centred on the hole.

- ***Alignment of a pass using the λ/4 alignment tool and the fringes***

If a λ/4 alignment tool (Figure 7-3) has been provided together with the instrument, the spectrometer can be aligned completely using this tool.

This method relies on the interference between a leakage of the light travelling through the internal polarising beam splitters and the back-reflected light reflected from the next Fabry-Pérot mirror surface. If the beam is collimated but not perfectly orthogonal, these two components will interfere and produce a fringe pattern on a surface of the polariser. If these fringes are visible to the operator, their number being proportional to the misalignment, he/she will be able to adjust the incidence angle in order to have no fringes at all in view.

In the TFP-2 HC the fringes are made visible on small opal paper screens glued on the polariser's sides towards the operator, as evidenced in Figure 4-10.

Theoretically, a perfectly aligned pass would exhibit just one fringe, being dark or bright; in the real case, the goodness of the alignment will be limited by the deviation of the retroreflector's angles from the nominal value, so that there will be a minimum number of fringes attainable, usually in the range from 2 to 10.
An example of this effect is show in Figure 7-2, still referred to alignment of the back reflector for second pass of a TFP-2, where a set of three fringes is visible. In this condition, a small movement of the adjustment screw will lead to a change in orientation and number of the fringe: this is also useful to discriminate the fringe set from the background light visible on the cube.

Figure 7-2 Fringes on a polariser's side

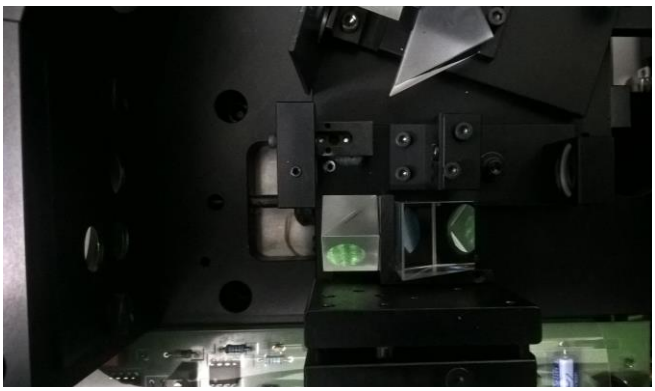


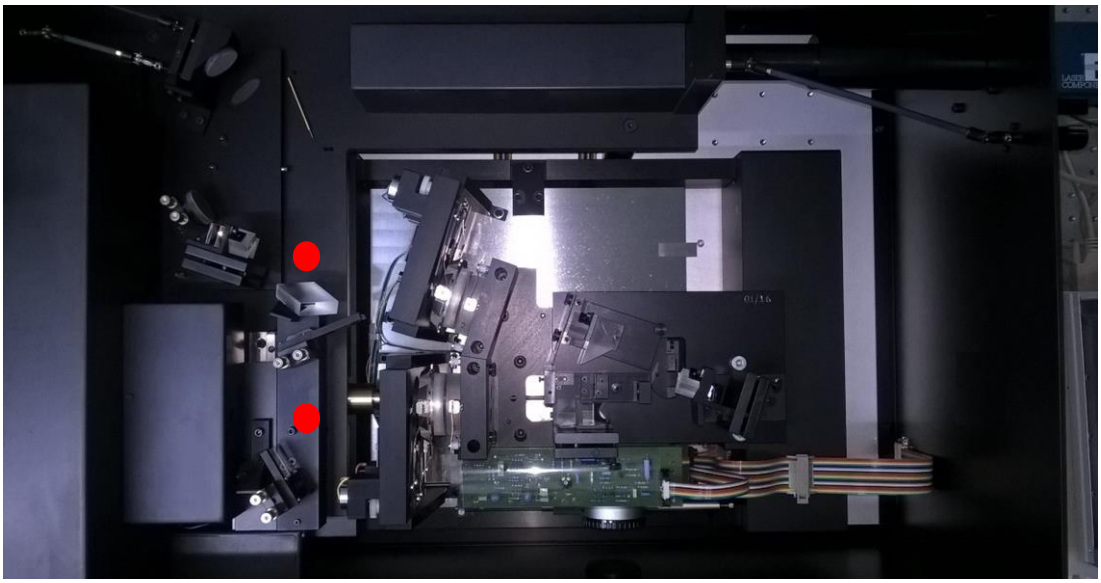
Figure 7-3 λ/4 aligment tool

In most of the passes, the fringes are always visible and the reflector can be adjusted as mentioned before. In two cases (pass 3 and pass 5), it is necessary to place a λ-quarter wave plate between the reflector under adjustment and the next FP surface in order to create the fringe pattern.

The λ/4 alignment must be placed immediately before the FP cavity at the pass to check. The next image (Figure 7-4, red spots) shows the position inside the spectrometer.

The fringe pattern on the first beam splitter is the most intense and easy to see, the next ones are increasingly weaker.

Figure 7-4 Positions for λ/4 alignment tool use



- ***Alignment of a pass using the Michelson-style alignment tool***

The Michelson-style alignment tool, shown in the picture at right, is designed to work in 4 fixed positions on the TFP-2 HC optical plate, corresponding to the alignment of passes 2, 3, 5 and 6.

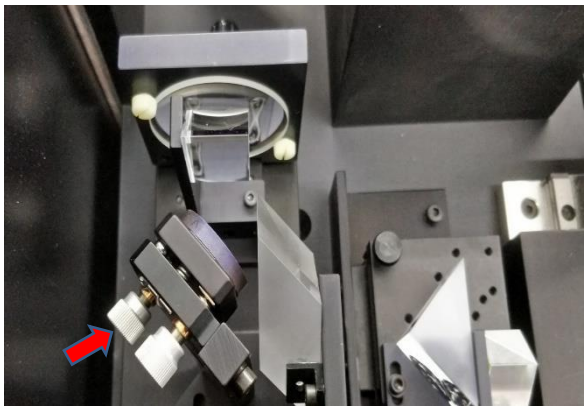
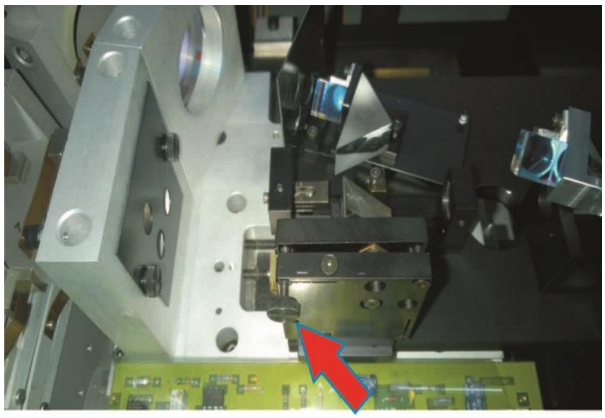
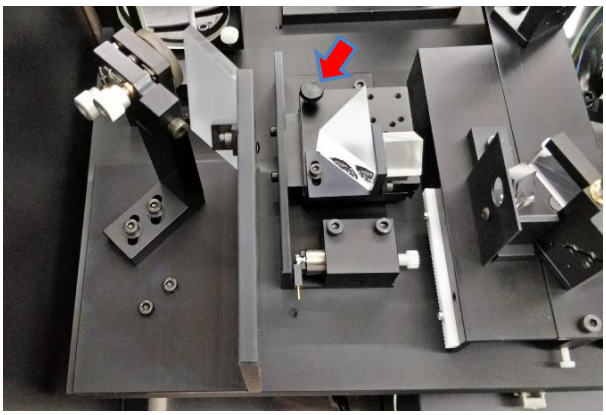
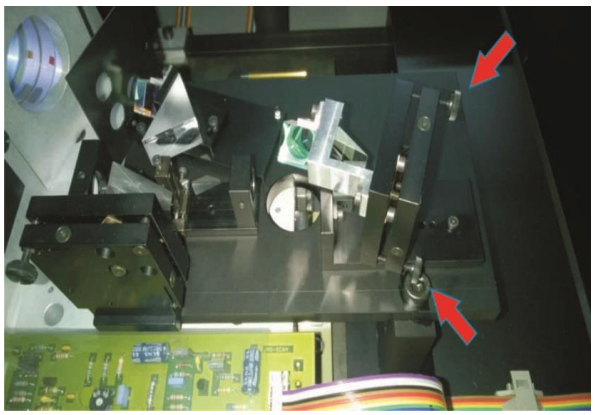
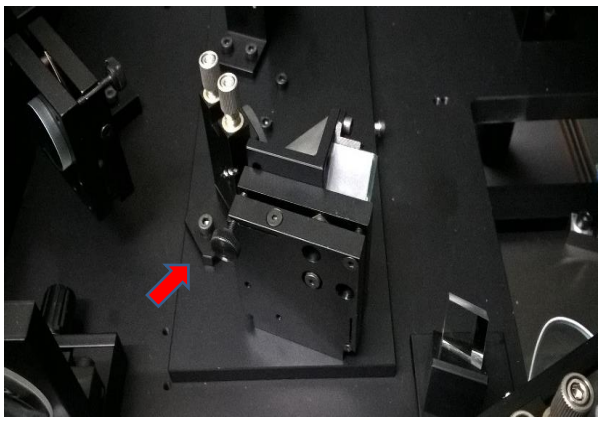
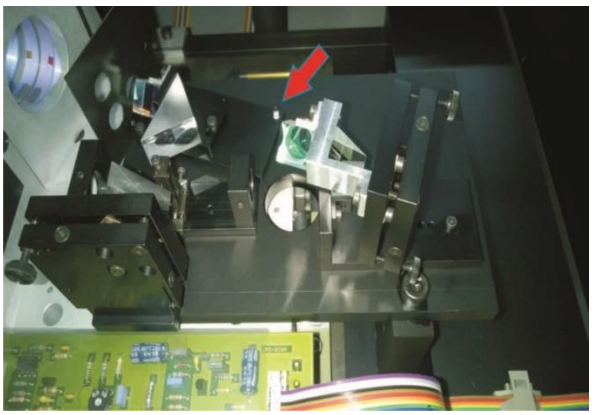
On recent instruments, these positions are marked by small metal disks mounted on the optical plate, however the distance between the tool and the pass under alignment is not relevant.

When you need to use the tool, mount it immediately before the pass of interest. The tool must be positioned so that the light passes through it and so that the input surface of the tool is orthogonal as possible to the incoming beam. The angle between the surface of the tool and the beam does not affect the results, however it is better to keep the tool orthogonal to the beam, so the upward beams are vertical: a horizontal rotation will change the direction of the upward beams.

When in position, the tool will send two beams of light **out of its top lenses**; these two beam will reach a focus at a certain distance: observe the two tiny spots of light on the focal plane by means of a paper screen.

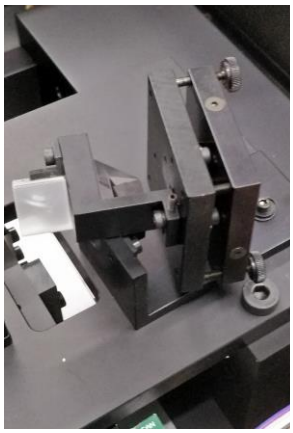
In order to adjust the orthogonality of light in the pass, you need to use the adjustment knob on the last retroreflector before the pass. The adjustment knob will generate a movement of the two spots along a direction: bring the two spots as close as possible. Sometimes the two spots will get so close to appear like a single one, and this is indeed a good thing, but sometimes a small distance will remain between them and you will not be able to correct it. In this case, just make sure they are as close as possible.

Figure 7-5 TFP-2 HC passes adjustment knobs locations

1st pass	2nd pass
	
3rd pass	4th pass
	
5th pass	6th pass
	

An additional support is available for the Michelson-style tool**, in order to allow the use of this tool to check the orthogonality of the first pass**, in case the standard methods to align the 1st pass cannot be used. The support must be placed on top of the alignment-tandem stage in order to intercept the beam entering the instrument, and the Michelson tool on top of it. The tool will provide the usual 2-beams pattern. The adjustment knobs of the 1st pass can be used to make the spots coincide and adjust the orthogonality of the beam. The support is not a particularly specific component: in case it is lost or was not provided with the spectrometer, it can be replaced by any other object providing a height shift of 18 mm.

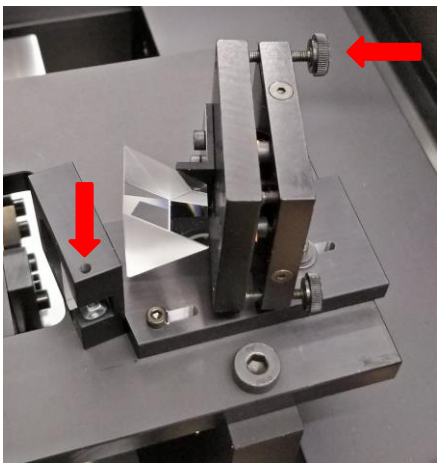
7.2.5 Orthogonality of the 4th pass



If the G4 layout is the one shown in the picture at right, the adjustment is made by means of the two black adjustment knobs at right.

While light is passing through the group, a fringe system should appear on the face of the cube towards the operator; the adjustment knobs must be moved in order to enlarge the fringes and/or reduce the number of fringes in view.
When the alignment is close to the best possible one, the fringes will start to bend and eventually become circular. One can then try to obtain the best possible centring of the fringe system within the visible beam spot.

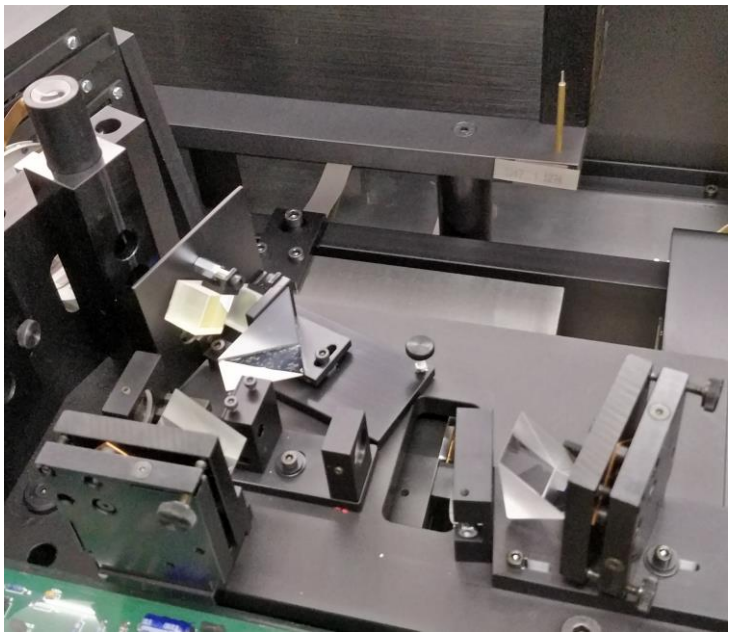
The adjustment can be also cross-checked using the Michelson-style tool, as described later in this paragraph.



If the G4 layout is similar to the one depicted at left, the alignment is adjusted by means of the top knob and rotating the grub screw close to the triangular prism by means of a 1.5 mm hex screwdriver (see arrows in picture).

In order to verify the alignment, the Michelson-style tool must be placed on the interferometer stage between mask A3 and FP2 (see last picture in this page). In order to do so, it is necessary to lift the Michelson tools by 18 mm: in order to obtain this, a specific base is provided among the spectrometer's tools.
G4 is adjusted until the two spots provided by the Michelson-style tool coincide on the tool's output focal plane.

This setup of the Michelson-style tool can be also used to cross check the adjustments made with the alternative G4 layout.

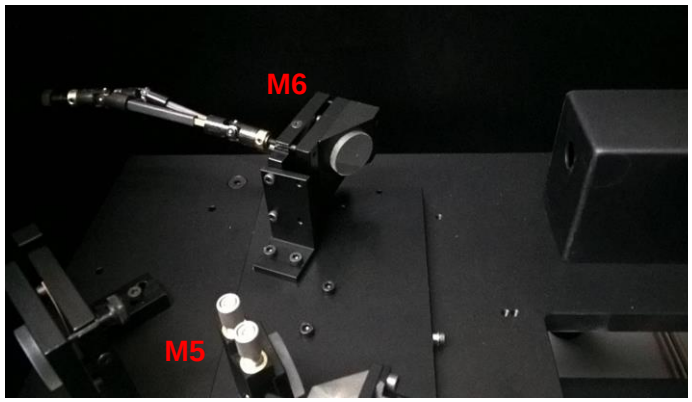


7.2.6 Orthogonality of 5th and 6th passes

Passes 5th and 6th can also be aligned by means of the three methods described previously in section 7.2.4, and with reference to Figure 7-5 for adjustment knobs location.
When using the Michelson-style alignment tool on the 6th pass, the weight of the tool slightly perturbs the stage tilt: it will be necessary to readjust all the axes (Z, X1, Y1, ΔZ, X2 and Y2) before adjusting the knob related to 6th pass.

7.2.7 Output alignment

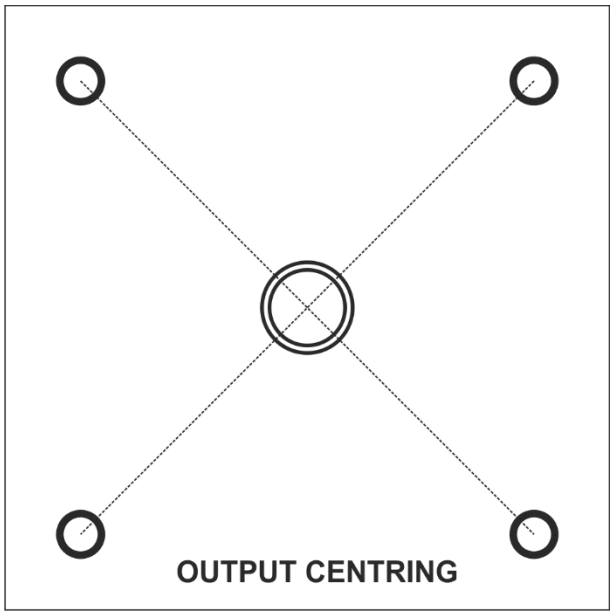
Once the spectrometer is sending out light through the 6th pass, and orthogonal to the FP2 cavity, the next step is making sure that the light is sent to the output pinhole, reaching then the detector. This is accomplished by the two mirrors M5 and M6 in the optical system. M6 tilts can be controlled by means of the two external black knobs on the left side of the spectrometer protective box.



If the detector is installed on the right side of the output pinhole assembly, it will be necessary to temporarily remove it in order to see the beam of light passing through the pinhole.

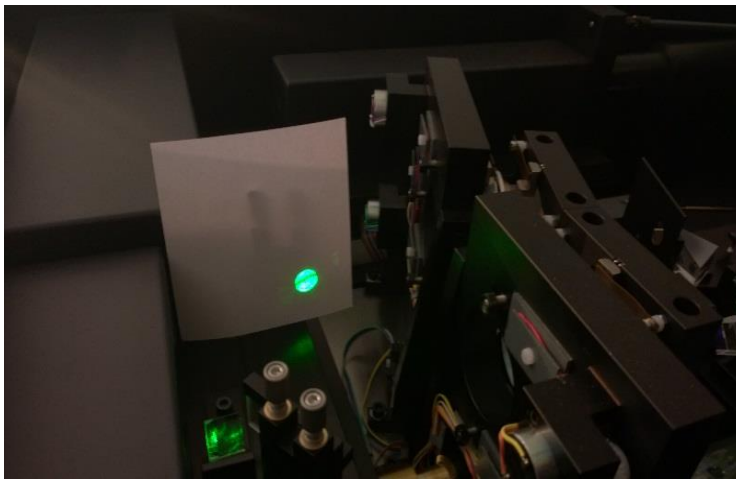
Adjust the centring of the output beam by means of the M6 external knobs, ensuring that the beam is able to pass through the pinhole using all the possible output pinhole choices.

The following mask, if installed as a target on the right side of the instrument box, can be used to check the centring of the beam on the detector mount. Use M5 and M6 in the previous figure to ensure that the output beam passes cleanly through all the possible output pinholes and hits the mask in the centre.



7.2.8 Alignment configuration check

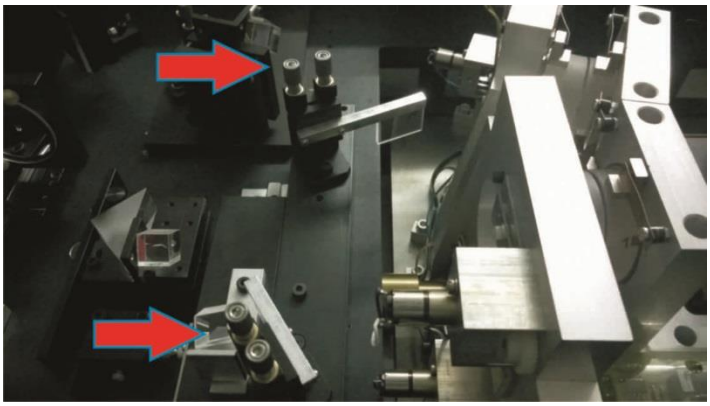
Switch to the alignment configuration on the instrument front control panel.



In order to familiarise yourself with the alignment mode signal, place a piece of card in front of BS2 as shown, and the light reflected from FP1 will be seen. When FP1 transmits, the reflection will go dark. Typically a dark fringe will be seen which can be adjusted to fill the field of view using X1, Y1 and Z.

Detune Z so that the reflected beam becomes bright. Remove the paper and let the light hit BS2 and go towards FP2.

The light reflected from FP2 should pass through the BS2 and PR2 on its way to the photon counter. Check that the beam passes through the largest output pinhole.



The alignment mode optics is adjusted using the tilt knobs of the two beam splitters BS1 and BS2, indicated by the red arrows in figure.

Use BS2 to obtain an orthogonal angle of incidence on FP2. When this condition is obtained, a pattern of moving interference fringes will be visible on the beam **forwarded** by BS2, i.e. the part of the beam coming from BS1 which is not reflected towards FP2.

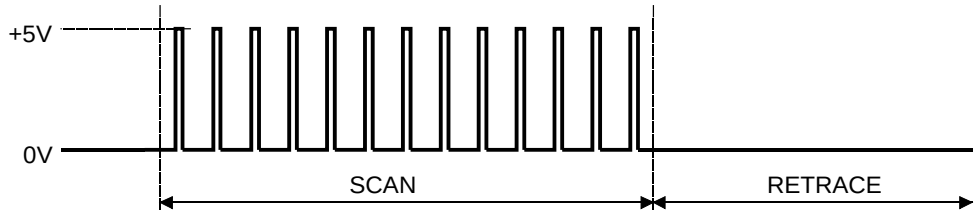
Use BS1 to correct positioning inside the output pinhole, so that the beam gets though all the pinholes, and approximately through the centre of the smallest one.

8 TECHNICAL INFORMATIONS

8.1 Control unit external connectors

- ***MCA CLOCK***

The MCA CLOCK output gives 2^N TTL clock pulses where N = 8, 9 or 10 as set by the number of channels switch on front panel.



- ***MCA TRIG***

The MCA TRIG signal is a pulse for triggering the start of an MCA scan. A slide-switch on board no. 5 allows a choice of three signals. The GHOST software requires the switch in the lower position to work properly.

The lower position:

The middle position:

The upper position:

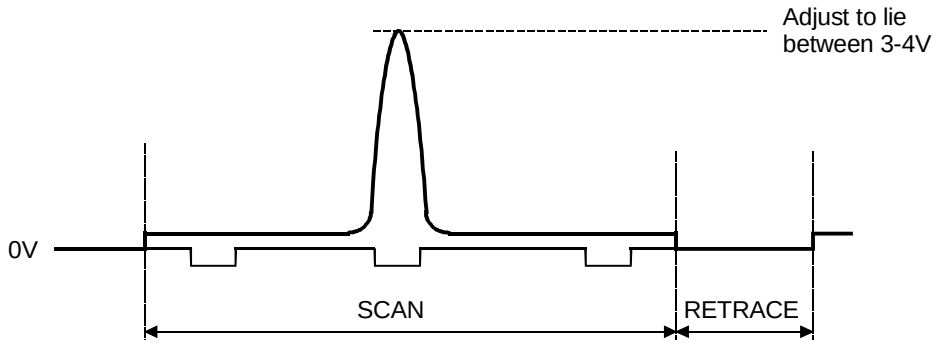
- ***X, Y***

The X and Y BNC outputs are used for display purposes only.

The X signal is a linear ramp from 0 to 5V, 0V during retrace, which is used instead of the internal time base of the oscilloscope. This enables the frequency axis of the display to remain linear even when using the ÷10 segmented ramp feature (see section 4.13).
The Y signal shows an approximately logarithmic display of the photomultiplier signal. The approximate sensitivity is:

Signal amplitude	Count rate per second
1V	70‘000
2V	270'000
3V	880'000
4V	2'500'000
5V	7'000‘000

The Y signal is a multiplexed combination of the photomultiplier signal with the window position signal and appears as below:



- ***REMOTE port***

On the rear panel of the control unit is a D-Sub 15 F socket allowing remote control of some of the control unit functions. The pin connections are given below:

pin	designation	type	voltage or range
1	-5 V	supply	-5 V
2	+5 V	supply	+5 V
3	ΔZ	input/output	-5V to +5V
4	Y2	input/output	-5V to +5V
5	X2	input/output	-5V to +5V
6	Y1	input/output	-5V to +5V
7	X1	input/output	-5V to +5V
8	Align	output	TTL
9	GND	supply	GND
10	Optics configuration	input	TTL (1=Align, 0=Tandem)
11	photon multiplier shutter*	input	TTL (1=open, 0=closed)
12	main shutter	input	TTL

* The photon multiplier shutter is an optional component

			(1=opens SH1 and closes SH2) NB: shutter switch to "window"!
13	V_z	output	-5V to +5V impedance 68K proportional to voltage on scan PZT
14	Vscan Z	input/output	-5V to +5V
15	busy	output	TTL optical system changing mode

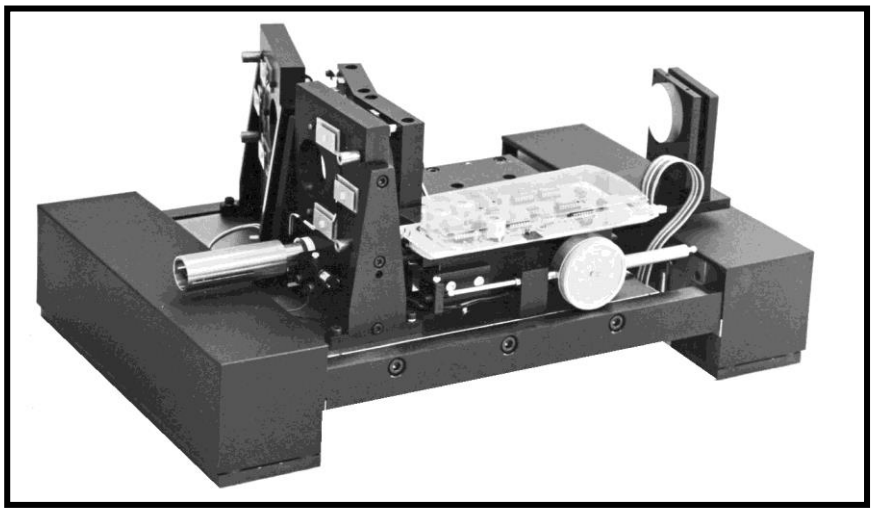
- **INTERFEROMETER port**

The D-sub 25 connector from control unit to interferometer has the following pins:

pin	designation	cable colour	type	voltage or range
1	X1 piezo	brown	output	-50 to 0 V (or -60 to +60 V)†
2	Y1 top piezo	orange	output	-50 to 0 V (or -60 to +60 V)†
3	X2 piezo (X2+ΔZ)	green	output	-100 to 0 V (or -110 to +110V)†
4	+HV	mauve	supply	+190V..+250V
5	–HV	white	supply	-190V..-250V
6	GND	brown	supply	
7	V_z	orange	output	
8	Vscan	green	output	
9	Align	mauve	output	TTL
10	busy	white	input	TTL optical system changing mode
11	PM shutter GND†	brown	supply	
12	PM shutter TTL†	orange	input	TTL (1=open, 0=closed)
13	GND	green	supply	
14	Y1 bottom piezo	red	output	0 to 50 V (or -60 to +60 V)†
15	Y2 top piezo (Y2+ΔZ)	yellow	output	-100 to 0 V (or -110 to 110 V)†
16	Y2 bottom piezo (Y2–ΔZ)	blue	output	0 to 100 V (or -110V to 110V)†
17	NC	grey		
18	NC	black		
19	GND	red	supply	
20	+5V	yellow	supply	
21	–5V	blue	supply	
22	NC	grey		
23	optics configuration	black	input	TTL (0 for Tandem, 1 for Alignment)
24	+5V	red	supply	
25	+5V	yellow	supply	

† The voltage range reported in brackets refers to instruments sold before December 2014

8.2 Specifications of tandem Fabry-Pérot interferometer



A scanning combination of 2 Fabry-Pérot Interferometers on a common translation stage. Shown here mounted on the isolation system AVI-35 LPR

Designed for mirrors of diameter 2 inch (50 mm).

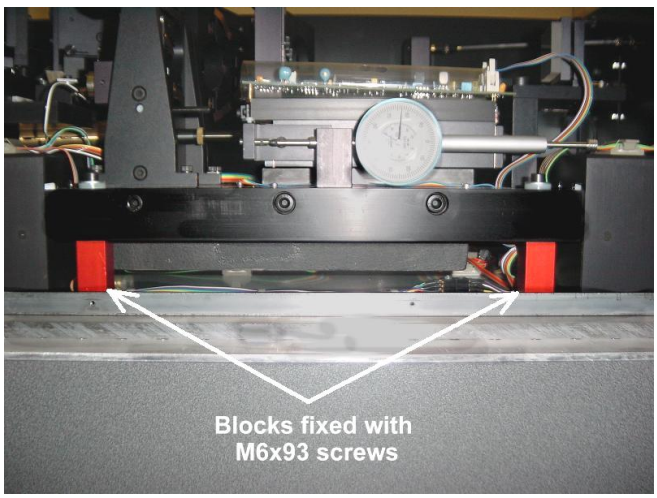
- The common translation stage ensures automatic synchronisation of the scans of the two interferometers.
- Mirror spacing may be set by motor control of the stage within the range 30 µm to 30 mm with very little loss of alignment.
- Mirror spacing read directly by means of a dial gauge.
- Scanning range 0-2.5 µm using a deformable parallelogram scanning stage.
- Maximum mirror tilt during scan: 10^{-8} rad.
- Maximum jitter during scan: 1 Å.
- Each interferometer equipped with remote controlled fine mechanical and PZT alignment controls.
- Linear scan – departure from linearity $2 \cdot 10^{-3}$ of scan amplitude, or better.
- Dimensions: 300x300x250 mm. Weight: 35 kg.

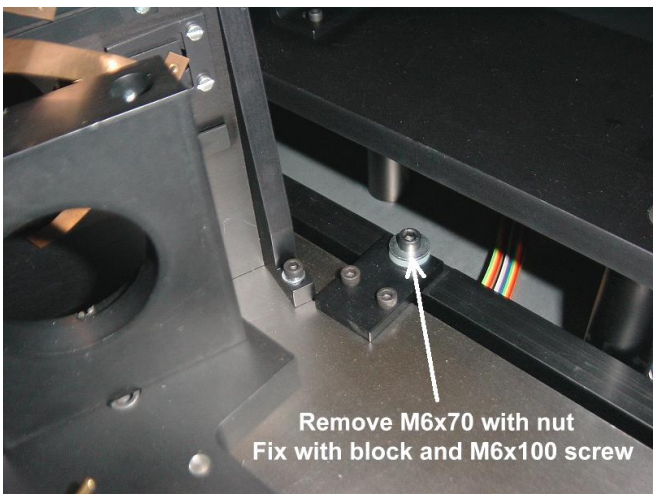
8.3 How to prepare a TFP spectrometer for shipping

During shipping it is essential that certain delicate parts of the interferometer be protected. This is achieved using transport locks to prevent relative movements. The instrument remains intact: only the mirrors and pinhole viewer are removed and packed separately.

1. **Remove the interferometer mirrors**: remove the lid and increase the mirror spacing as necessary for an easy handling of mirrors. Remove the interferometer mirrors and place them back in the original boxes provided. The reflective surface goes towards the bottom of the box, place a circular piece of optical paper and then a soft rubber foam spacer over it, then close well the box (the upper lid is sensitive to orientation).

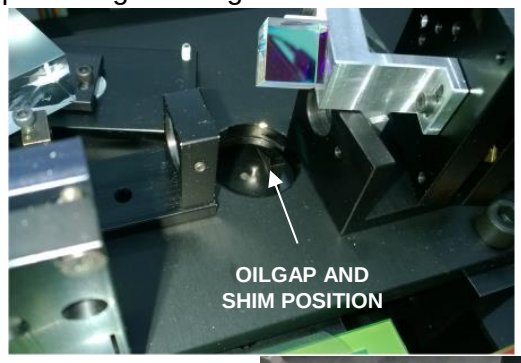
2. **Clamp the vibration isolation system:** remove the front panel of the interferometer housing box by unscrewing the 4 small M3x6 screws from the bottom side of the front panel and 3+3 screws fixing it from the left and right front vertical edges. While removing the panel, carefully disconnect the connector of the front panel control block, by gently opening the plastic clips that hold it in position before pulling it out.
   Remove the M6x70 bolt and nut which attaches the interferometer to the rear support bar. Place the blocks provided under the front and rear support bars and using the long M6 bolts provided screw down into the base plate. Adjust the number of washers under the bolt heads so that the screws do not extend beyond the lower surface of the base plate.

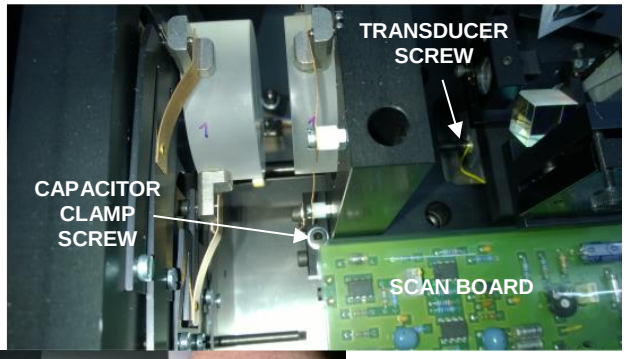


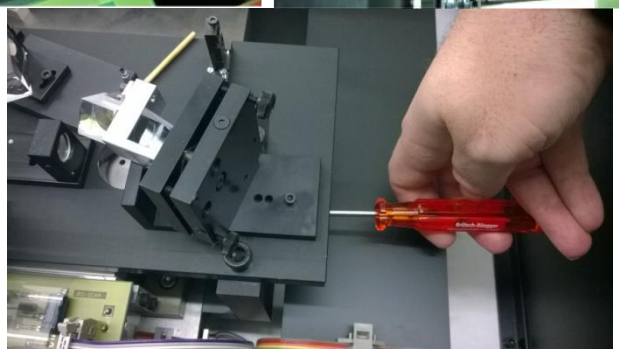


3. **Clamp the interferometer parallelogram translation stage:** in a TFP-2 HC, set the mirror spacing at a distance such that the oil gap of the translation stage is accessible through the

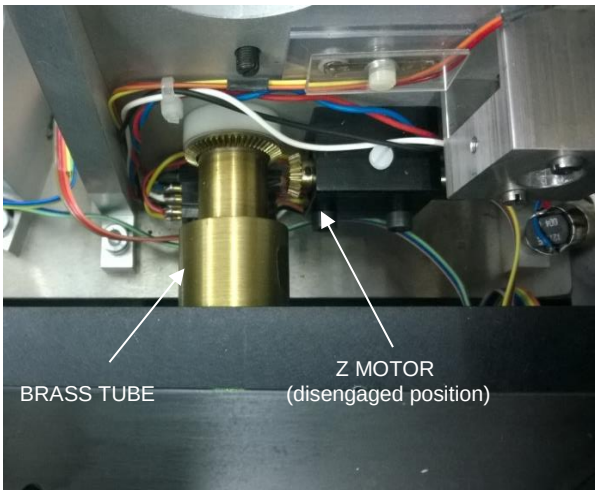
hole in the right upper plate of the instrument (left in the following figure). In a TFP-1, the gap is accessible independently of the mirror spacing.
Using a pair of thin tweezers, place the 20 μm shim into the oil gap, paying attention that it lies below the edge of the top plate; release the scanning transducer by turning the transducer screw (figure at right) counter clockwise using the specific tool provided with the instrument. The transducer should then just sit loosely in its mounting, with the screw free of load.
Undo the capacitor clamp screw by about one turn. Finally tighten the parallelogram lock screw **gently**. This latter is accessible on the right side of the translation stage (bottom image hereafter): be careful not to over-tighten the lock screw, or you may damage the parallelogram stage.





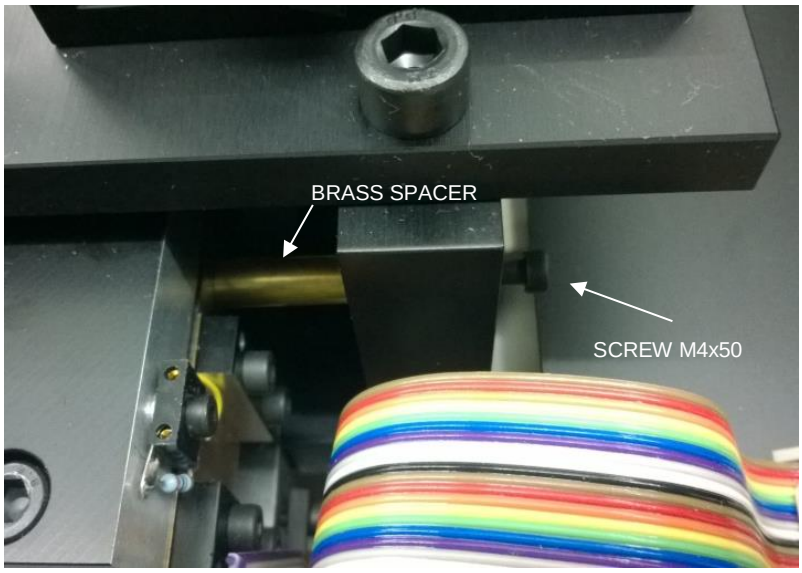


4. **Clamp the interferometer rolling translation stage:** disengage the Z motor which is usually controlling the mirror spacing (image below). The mirror spacing can now be changed by manually turning the brass tube visible on the left of FP1. To access the locking tube position, remove the scan board (image at step 3, right) pulling it gently upwards and removing the right top connector. Change the spacing to about 30 mm and then feed in the M4x50 screw provided, and a washer, through the vertical plate on the right of the instrument (next image). Slide on the brass spacer tube and then screw into the corresponding hole on the edge of



the translation stage. Before tightening this screw increase the mirror spacing until the spacer

is just lightly held. You can now fully tighten the M4 screw. Check that the brass tube can still be turned: back it off by about ½ turn. Place back the scan board in the original position.

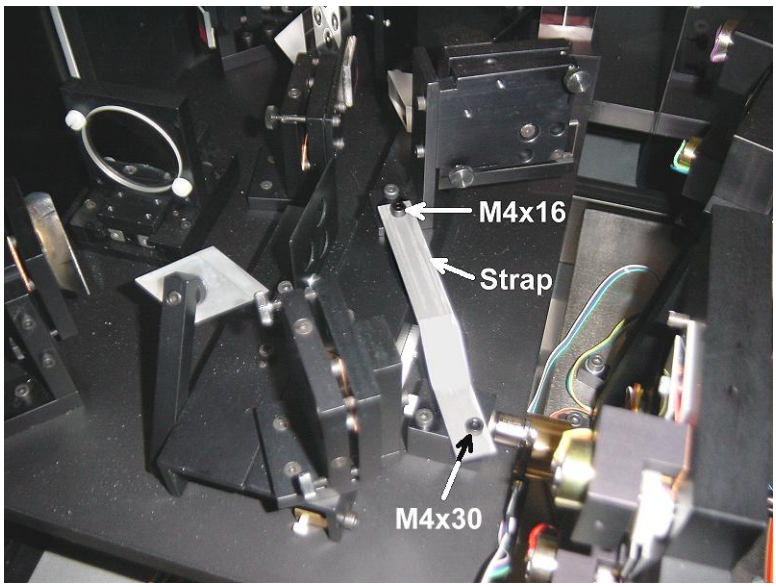


5. **Removing the pinhole viewer:** Remove the pinhole viewer camera by undoing the two screws at the base of the camera tube and replace the original cover on the top of the shutter unit, using the same screws. Close the camera in a plastic bag and wrap it with bubble paper for protection.

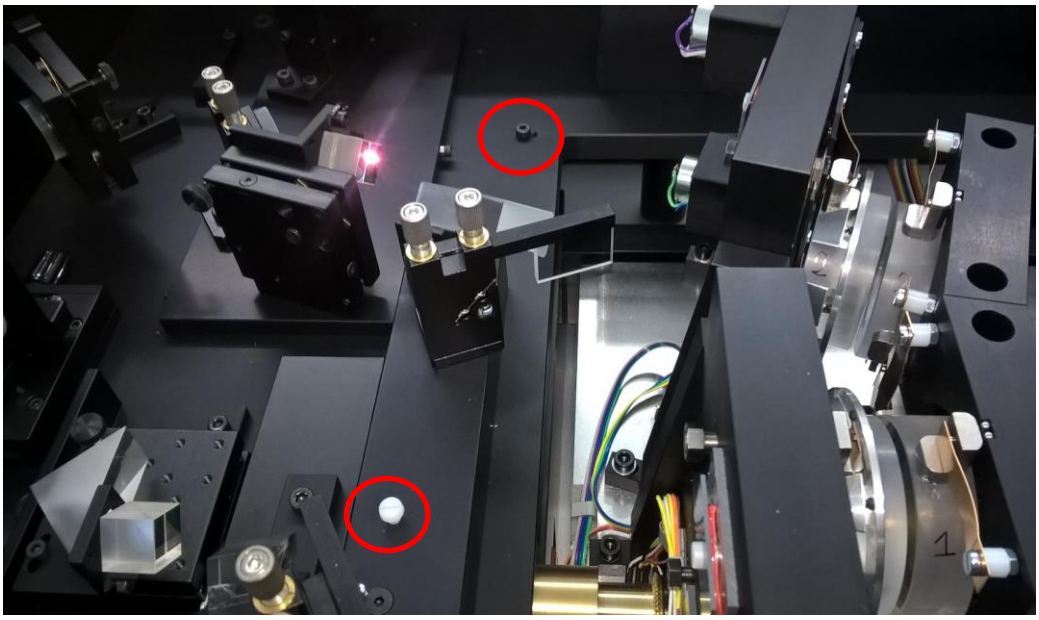
6. **Remove the internal screens (only for TFP-2 HC):** the internal black screens need to be removed before shipment. Refer to section 7.2.1 for description of this operation. The larger screen (screen 1) is composed by two subparts fixed together. These can be easily detached before shipping. Wrap the screens in bubble paper to prevent scratching during transport.

7. **Lock the alignment/tandem stage**

- In a **TFP-1,** the alignment/tandem is locked by means of a metal strap, fixed to two of the optical plate screws. With reference to the following picture, undo the nylon screw which fixes the alignment/tandem motor and disengage the drive. The stage can now be freely moved. Remove the two M4 screws indicated and fix the stage with the aluminium strap provided. Longer screws (M4 x 16 and M4 x 30) will be needed. A washer placed under the strap will prevent marking of the black anodised interferometer parts.



- In a **TFP-2 HC**, disengage the alignment/tandem motor by loosening the nylon screw that holds it in place, shifting it to left and fixing again in this second position. The alignment optics is now free to move: push it to the opposite end of its motion range. Remove the M4x10 screw which sits at about 50 mm in front of the BS1 mount (lower circle in the next figure) and replace it with a M4x16 (or longer) nylon screw. It will not be possible to insert the screw completely: the screw must be finger tightened, just enough to hold the stage in place. The M4x10 screw can be safely "stored" for shipping in one of the holes near the internal edge of the optics plate, which are unused (upper circle in figure).



8.4 Box and shock isolation material for shipping

If the instrument needs to be completely packed and shipped, we advise to use a foldable 6 mm thick plywood box, conveniently filled with Styrofoam chips in order to isolate the device from shocks. Boxes of about 80 x 120 x 90 cm (L x W x H) are quite standard and easily available on the market. Such a size provides enough space for the instrument, and to accommodate as well the control units and all the additional material. The height of the box includes a pallet base which is very useful in handling.

If a box of this size is used, about 1.5 m^3 of Styrofoam chips will be required to fill it.

After performing the locking procedure described in the previous chapter, the instrument should be ideally wrapped in a plastic air bubble foil (approximately 2m x 2m will be required) and then inserted in the box.

We recommend to prepare a 25 cm thick layer of Styrofoam chips under the spectrometer. Once the spectrometer and all the useful components are inside, the remaining space will be also filled by chips.

Notes

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