Appendix B

IPBPMs Movers

B.1 System Description

At the ATF2 IP, inside the vacuum chamber, the BPMs positioning system has been installed during the first two weeks of July 2013. It moves two independent blocks: Block IPAB and Block IPC. Each block has three degrees of freedom: vertical, lateral and pitch angle, by using using 4 piezo-movers: three vertical and one horizontal.

Movers made by the german company “PI” electronics moves IPC and the french company “Cedrat Technologies” moves IPAB.

B.1.1 The Piezo Movers

Piezo mover changes its position as a function of voltage. Each one of the eight movers has its own control electronics block composed of:

- the mover
- the strain gauge
- the control box (manufacturer module) to:
  - set piezo mover voltage (high voltage)
    - PI module E-621
    - CEDRAT module LA75
  - read strain gauge
    - PI module E-621 (same as control)
    - CEDRAT module SG75
  - set feedback operation (ON/OFF)
  - set control mode (external control, PLC is used for setpoint setting)
- PLC channel to
  - set voltage to displace the mover
  - read voltage to determine mover position (with FB ON, read voltage approaches the set voltage.)

B.1.2 Electrical connections

Figure B.1 shows the connections diagram of electrical connections between the movers displacement system. It shows the connexion to the local network by Ethernet, the DACs and ADCs used to set and read the voltage levels, the connection to the dedicated control boxes, a linking box to match the cable conexions, the 25 m cable to connect to the vacuum chamber flanges, the movers, and temperature probes.

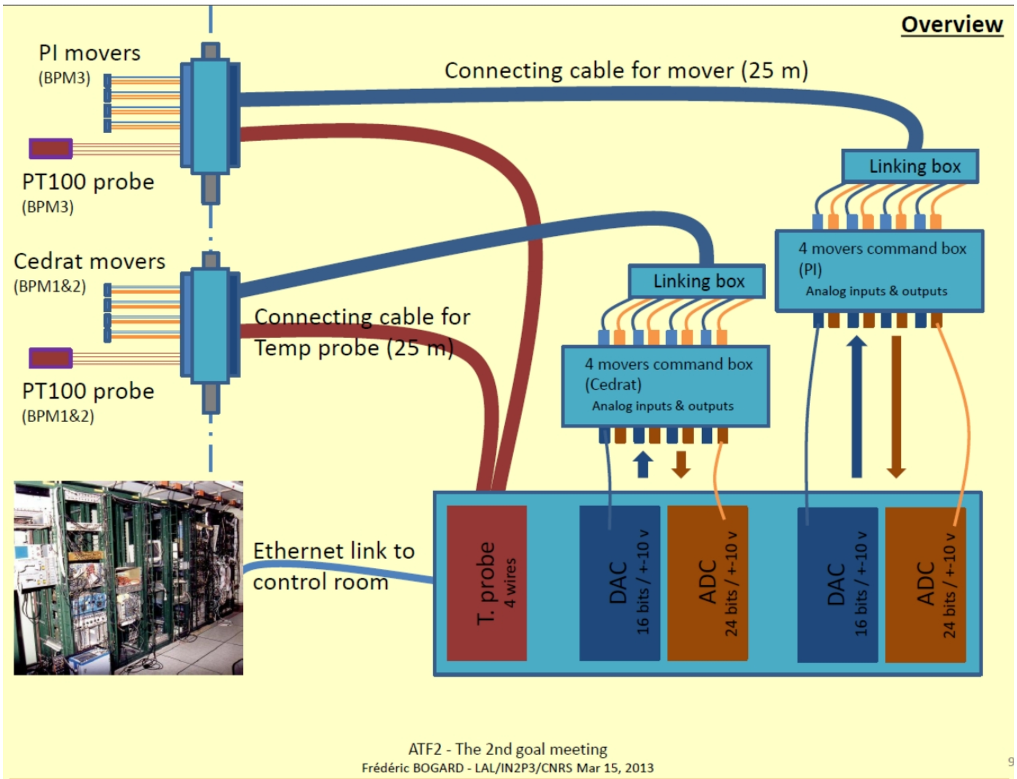


Figure B.1 – Piezo mover system connection diagram.

Mover range

PI and Cedrat have different ranges: PI (300 um), Cedrat (250 um). The Control voltage and displacement (min-max) is opposite between companies:

- PI: (min) 0V to (max) 10V
- CEDRAT: (max) -1V to (min) 7V

It is important to note that:

- The voltage-displacement relation is inverse for CEDRAT movers.
- When the system is OFF (0V), PI mover are at its minimum, however CEDRAT are not.

Mover Control

Figure B.2 shows an schematic of the control system per mover. The voltage value is set via an EPICS Process Variable (PV), and it is send to a DAC, the analog voltage set the control box to move the piezo-electric. The displacement is measure by a set of strain-gauges. The FB loop is closed at the Control box. A read-out voltage is taken by the ADC and publish as another PV.

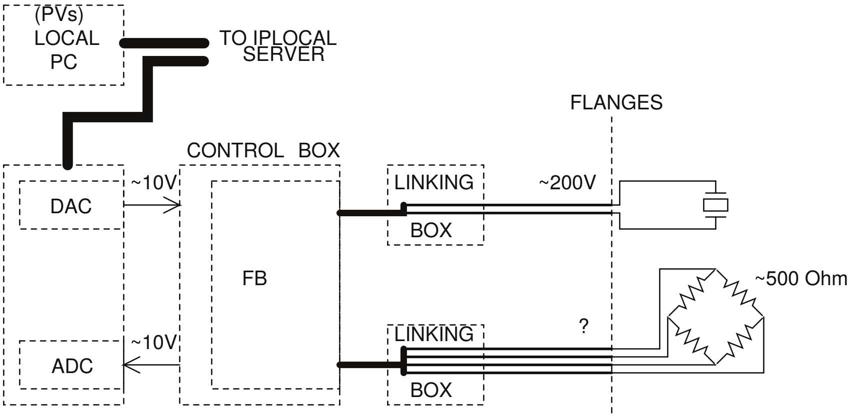


Figure B.2 – Control system per mover.

BLOCK AB 1 mV=31.25 nm, BLOCK C 1 mV=30 nm

Feedback and NO Feedback

There are two operation possibilities per mover: Feedback (fb) and No Feedback (no fb). It means 8 feedback loops. On each case the control module sets a voltage value on the mover and read the strain gauge to create a closed loop. However, their implementations are different on each company.

B.1.3 The PLC

Two NI9263 are used to set analogue voltage into the mover control electronics. Two NI9239 are used to read analogue voltage from the strain gauge readback. One NI9219 is used to read temperature. These modules are connected to the chassis NI9188 which is connected by network to a working station with Labview installed. The block chassis+NI modules is called **PLC**.

National instruments Chassis: NI9188

- Mac Address: 0080.2f14.b777
- DHCP
- IP address (ATF) 31.1.1.39
- IP address (KEK): None
- Host name: ipmv-plc.ip-local
- Net Mask: 255.255.255.0
- connected to ip-local during installation

Chassis NI9188 can connect up to 8 modules, not all are used:

- PI
  - Module 5: NI9263 Digital to analogue converter
  - Module 6: NI9239 Analogue to digital converter
- Cedrat
  - Module 2: NI9263 Digital to analogue converter
  - Module 3: NI9239 Analogue to digital converter
- Temperature
  - Module 8: NI9219 Temperature probes
    - Cedrat: Channel 0
    - PI: Channel 2
- The other slots are not used

B.1.4 The PC

It is used to control from close locations the BPM positioning system. It sets the digital values to put in the PLC and reads the digital values from the PLC channels corresponding to strain gauges.

Characteristics

LAL Computer (Laptop) Processor Inter Core i7 vPro

Mac Address: d067.e550.620e

Network Parameters

DHCP

IP address(ATF): (31.1.1.38) ipmover-pc.ip-local

Net Mask: 255.255.255.0

Connected to ip-local server

Used Software

Windows 7 Francàis

National Instrument - Labview 2011

National Instruments - Measurement & Automation Explorer (NI MAX) 5.4

Evince 2.32.0

CALab (Labview + EPICS) [54]

In adition, this Software is present but not used by movers:

SIOS Interferometer Software INfasNTC 6.3.1.42 2012

Festo Positioning Drivers

Access

Account (Nom d'utilisateur): *******

Password: KEKJapan2012

Folder Content Description

Path to applications and info

`Bureau/Actionneurs Piezo/Applis`

All applications were done in Labview. Filenames gives a hint of its content (keywords used in filenames):

- `oscilloscope`: uses de ADC to read signals
- `generateur`: function generator, uses de DACs to produce signals
- `Actionneurs positionnement BPMs`: activate the system displacement
- `Ethernet`: connected by wired network,
- `USB`: corresponds to previous version connected by USB.
- `Verticaux groupe`: all 3 vertical mover movers are activated by one voltage control
- `mouvements identiques`: first version of BPM displacement system (PI and CEDRAT) integrated.
- `Jauges`: stores the strain gauges info in excel format.
- `temp`: stores temperature info in excel format.
- `epics`: control from epics system, Labview works as interface.
- `Actionneurs multicycles`: several cycles over the defined voltage range are performed
- `Cedrat, PI`: identifies the group of movers to use.
- `Vertical, lateral fixe`: it means that one direction of movement is set (fixed) to a voltage value while the other direction varies in cycles.

PVs

Epics PVs (Process Variables). Write: sets a value on the DAC. Read: reads from ADC.

Channels IP:BPM-AB:Mover0 and IP:BPM-C:MoverB are for lateral movement.

IP:BPM-AB:Mover0:Read

IP:BPM-AB:Mover0:Write

IP:BPM-AB:Mover1:Read

IP:BPM-AB:Mover1:Write

IP:BPM-AB:Mover2:Read

IP:BPM-AB:Mover2:Write

IP:BPM-AB:Mover3:Read

IP:BPM-AB:Mover3:Write

IP:BPM-C:MoverB:Read

IP:BPM-C:MoverB:Write

IP:BPM-C:MoverC:Read

IP:BPM-C:MoverC:Write

IP:BPM-C:MoverD:Read

IP:BPM-C:MoverD:Write

IP:BPM-C:MoverE:Read

IP:BPM-C:MoverE:Write

IP:BPM-AB:Temp

IP:BPM-C:Temp

B.2 The BPMs

B.2.1 Coordinate system

Each BPM has its own coordinates with respect to a reference system centered electrically as in Fig. B.3.

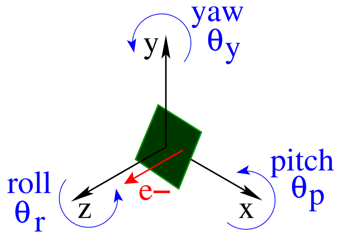


Figure B.3 – BPM coordinate system centered ellectrically. Beam in red, BPMs in green.

The coordinates of the beam and the BPM angle rotations are given by:

- Beam Position: x_A, y_A, z_A, x_B, y_B, z_B, x_C, y_C, z_C
- BPM Angles respect to ref. system: $\theta_{Ap}, \theta_{Ar}, \theta_{Ay}$, $\theta_{Bp}, \theta_{Br}, \theta_{By}$, $\theta_{Cp}, \theta_{Cr}, \theta_{Cy}$

All systems relate to a common **mechanical** reference system with no rotations, just translations in Fig. B.4. However, IPB could be chosen to coincide with the common to simplify the description.

There is a set of movers to control BPM position shown in Fig. B.5. This is expressed in Eq. (B.1) where during the installation all initial values (with 0-index) are set. A mover combination can change the transverse positions and the pitch angle per block.

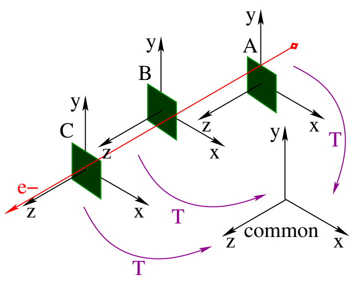


Figure B.4 – Reference system for the 3 BPMs.

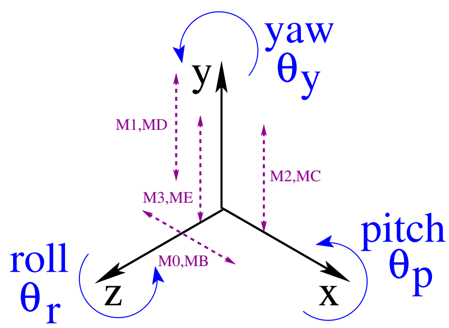


Figure B.5 – Set of movers: M_{01234} in Block IPAB and M_{BCDE} in Block IPC.

$$
\begin{aligned}
x &= x_0 + f_x(M_{0,B}) \\
y &= y_0 + f_y(M_{123,CDE}) \\
z &= z_0 \\
\theta_p &= \theta_{p0} + f_p(M_{123,CDE}) \\
\theta_r &= \theta_{r0} \\
\theta_y &= \theta_{y0}
\end{aligned}
\tag{B.1}
$$

Figure B.6 shows the location of the movers along the longitudinal direction. This information is used to calculate the aligment correction limits of the system.

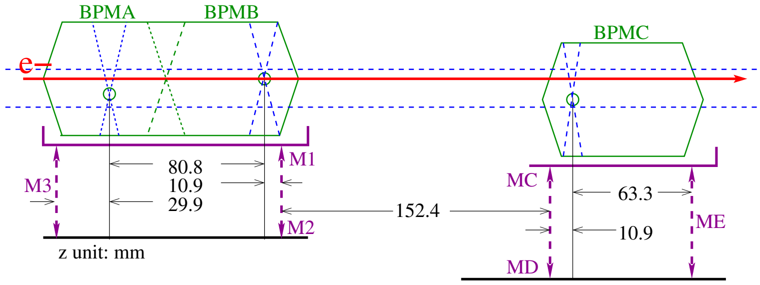


Figure B.6 – Longitudinal position of the movers.

B.2.2 Alignment adjustment

Normalizing the movers range to -1 to 1 units, as in Eq. (B.2), it is possible to calculate the effect of movers displacement on the cavity position shown in Table B.1.

$$M_{0123} = \frac{3 - V_{0123}[\mathrm{V}]}{4} \qquad M_{BCDE} = \frac{V_{BCDE}[\mathrm{V}] - 5}{5} \tag{B.2}$$

Block IPAB movers are able to correct a maximum of ±1 mrad or ±125 μm, while Block IPC is able to correct ±2mrad or ±150 μm. Correction of IPA and IPB position is not independent, therefore, special effort is put into minimize the offset in the block IPAB.

By making $y = 0$ and $y_0 = 0$ it is also possible to find a set of movers that keeps the vertical position and changes the angle per BPM. This gives the possibility to scan sensitivity to pitch angle.

	Adjustment		
	IPB	IPA	IPC
$x[\mu\mathrm{m}]$	$x_{0B} + 125M_0$	$x_{0A} + 125M_0$	$x_{0C} + 150M_B$
$y[\mu\mathrm{m}]$	$y_{0B} + 11.2M_{1,2} + 113.8M_3$	$y_{0A} + 94.8M_{1,2} + 30.2M_3$	$y_{0C} + 128.0M_{CD} + 22.0M_E$
$z[\mathrm{mm}]$	z_{0B}	$z_{0B} - 80.8$	$z_{0B} + 174.2$
$\theta_p[\mathrm{mrad}]$	$\theta_{p0B} + 1.03(M_3 - M_{1,2})$	$\theta_{p0A} + 1.03(M_3 - M_{1,2})$	$\theta_{p0C} + 2.02(M_{DC} - M_E)$
$\theta_r[\mathrm{mrad}]$	θ_{r0B}	θ_{r0A}	θ_{r0C}
$\theta_y[\mathrm{mrad}]$	θ_{y0B}	θ_{y0A}	θ_{y0C}

Table B.1 – $M_{0123,BCDE} \in [-1, 1]$, $\Delta M_{0123,BCDE} \geq 1.25 \times 10^{-2}$

B.3 Alignment

B.3.1 Vacuum chamber

The goal is the alignment of the vacuum chamber with respect to external references by less than 200 μm. Below this range, the piezo-electric movers in each cavity block are used to align the cavity with respect to the beam.

The beam positioning system should not interfere with the IPBSM measurements. Therefore, mechanical dimensions and weight should be restricted to those supported by the vertical optical table. This will allow to have a common reference point between the two structures.

B.3.2 Effect of alignment on dynamic range

Dynamic range is reduced by misalignment because of the constant I' and Q' signals from position and angle. This should be minimize aiming to use the minimum dynamic range possible.

However, IPA and IPB are located in a common movers system and therefore BPM position and angle can not be corrected independently. Both BPMs centers can be aligned with the beam by making an angle, but, due the cavity sensitivity to angle of 3.2 μm/mrad, the Q' will substract the dynamic range available for position scans. This adds to the Q' static signal per BPM and therefore it could become critical.

The initial BPM installation [44] had alignment issues attributed to loose tolerances between the inner cavity surface and the external reference points [55]. During 2014, new cavities were fabricated and installed in the ATF2 line. This set of BPMs has been in use since November 2014.

- Position scans with $I' = 0$. This is fairly simple because it only tries to find the center of the BPM without considering the Q' signal. The issue is that beam angle through the IPBPMs changes and these leads to different alignment results. A typical change of 0.1 mrad in the beam trajectory by a QD0 displacement of 100 μm could change the aligment results by 25 μm from IPA to IPC. Additional ± 10 μm changes in $I' = 0$ have been seen between samples. Table B.2 shows the horizontal and vertical alignment of the new BPMs taken in separated shifts.

- First, make $I' = 0$ and then use a movers and QF7 combination to make $Q' = 0$. This method is valid for Q' entirely from angle. At the moment it has not been tested with the new BPMs. Table B.3 shows the vertical position results for the previous BPMs.

Plane	IPA	IPB	IPC	Comment
X [μm]	-5	+18	-41	QD0 mover(X)=-70 μm, 10BX1BY optics
Y [μm]	-18	+24	-102	QD0 mover(Y)=160 μm, Low beta optics

Table B.2 – Alignment measurement using $I' = 0$

Vertical	IPA	IPB	IPC
Y [μm]	-7	+79	-
θ_p [mrad]	0.024	1.0	-

Table B.3 – Alignment measurement using $I' = 0$ and $Q' = 0$ for previous BPMs.

B.3.3 Effect of cavity alignment on calibration

After the installation the cavities are fixed in the piezo-movers system. Figure B.7a shows an static angle β between the movers direction and the BPM axis, while the beam makes an angle α with respect to the movers.

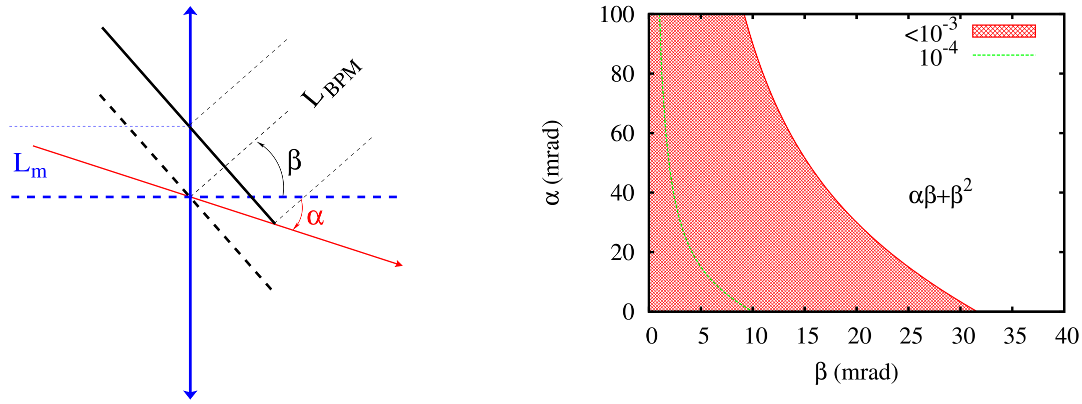
When doing a position scan to get the BPM calibration the BPM is displaced by L_m, however, the displacement seen by the BPM is L_{BPM}. Equation (B.3) shows the effect of the angles in the measured distance and Fig. B.7b shows the combinations of α and β affecting the calibration by less than 10^{-3} and 10^{-4}.

Considering α, the beam divergence is 0.35 mrad in the nominal optics which is very small and do not affect calibration. The angle change by QF7 has been simulated to have an excursion of 3 mrad at IPB per 1 mm of vertical displacement of QF7, this also remains in below the 10^{-4} effect.

$$\begin{aligned} L_{BPM} =& L_m \left(\cos\beta + \sin\beta \tan(\alpha+\beta)\right) \\ \approx& L_m (1 + \alpha\beta + \beta^2) \end{aligned} \tag{B.3}$$

If the movers are used to induce an additional angle γ to the BPMs as in Fig. B.8, then the net effect is and addition of $\beta + \gamma$ shown in Eq. (B.4).

$$L_{BPM} \approx L_m[1 + \alpha(\beta+\gamma) + (\beta+\gamma)^2] \tag{B.4}$$



(a) Displacement from the center. Movers displace by L_m. Cavity sees L_{BPM}

(b) α and β should be inside the dashed area to keep the calibration value within 10^{-3} precision.

The total correction possible for the BPMs is $|\gamma| \leq 1$ mrad. It is also a very small angle. The more restrictive angle is $|\beta| <5$ mrad.

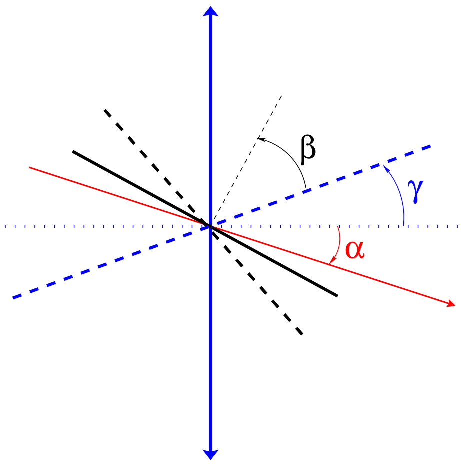


Figure B.8 – γ angle rotation over the BPM. The only effect on distance measured is to add γ to β.

B.3.4 Mechanical BPM alignment

The estimation of mechanical positions resolution is shown in Table B.4.

Axis (Symbol)	Mechanical Precision (μm)
Vertical (Δy)	1
Horizontal (Δx)	5
Longitudinal (Δz)	5

Table B.4 – Position mechanical precision