




The Control of X-ray Deformable Mirrors

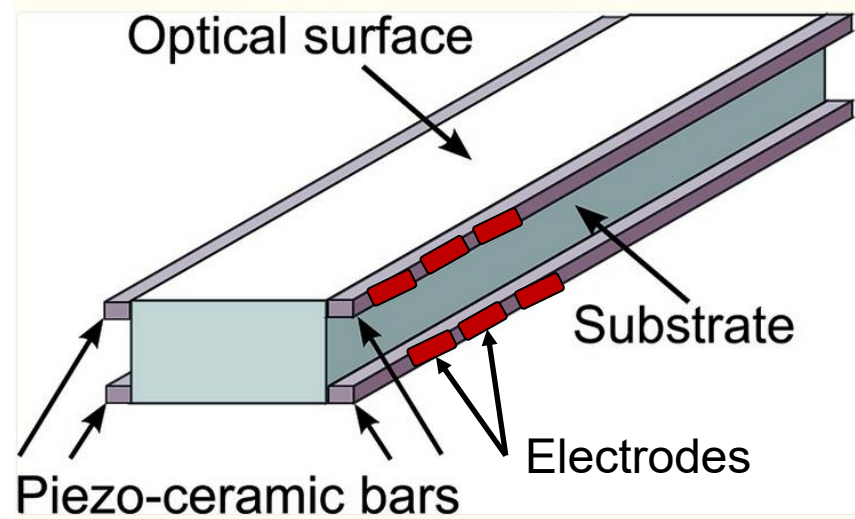




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Introduction & Motivation

-  Piezo-electric, deformable “bimorph” mirrors are used to focus X-rays at many synchrotrons and XFELS



-  Original, older Bimorph Power Supplies, suffered from poor RS-232 communication, locks-ups and EPICS screens going white (disconnecting) while a command executes
-  A particular problem was in the commissioning of a mirror when scripts, continually setting voltages and examining the response on the beam shape and size were left running overnight – only to find they’d failed 45 minutes after the scientist had gone home...

The beamline scientists weren't happy...

Why can't I see what's happening on the screen?!?

Why does this keep locking-up?

Why does it take so long to apply large voltages?

I want to commission my mirror much quicker... We're wasting beamtime!



One night, over drinks, a plan

was hatched...

What about EPICS support?

I've found a new power supply!



That's what the software guys are for...

WANTED
DEAD OR ALIVE



New Programmable HV Power Supply



- ☀ HV-ADAPTOS from CAEN (based on earlier Elettra model)
- ☀ Hardware is from CAEN, the software is from S.RI.Tech (excellent support from Matteo Fusco & Riccardo Signorato)
- ☀ Programmable voltages (speed & shape of voltage impulse)



HV Adaptors PSU Back



8-channels per amplifier card, possible 6 cards



HV-Adaptos Power Supply

- ☀ Channels can be configured into groups (mirrors) e.g. 16-channels, 8-channels etc
- ☀ Ubuntu Linux system underneath, but limited access for the facility
- ☀ Special Admin privileges to be able to set:
 - ☀ Maximum slew rate (typically more than 100V/s, cf. 10V/s previous PSU)
 - ☀ Maximum voltage between neighbouring bimorph electrodes (500V)
 - ☀ Maximum absolute voltage (+/-1500V)
- ☀ But these parameters depend on, at least:
 - ☀ The age of the mirror
 - ☀ The way the mirror is mounted
- ☀ Being too cavalier can end-up with a broken mirror!
- ☀ Set once by an Optics expert and left



HV-Adaptos Power Supply

Originally, limited EPICS Support

- ☀ On-board EPICS IOC – abandoned: “black-box”, didn’t do what we wanted
- ☀ Instead, added a feature-rich TCP/IP interface which we can talk to from our own IOC’s
- ☀ We have worked closely with Riccardo & Matteo to improve the TCP/IP interface and the reliability of the communication
- ☀ Although the TCP/IP interface is simple ASCII commands like:
“GROUP0:VOUT%d:%f”
- ☀ We opted to write an asynPortDriver instead of using streamDevice for two reasons:
 - ☀ Initially there were some communication issues and we wanted to prove it was not at the EPICS level – easier to see what was going on in asynPortDriver code.
 - ☀ It was a good learning exercise!



I24 Synoptic (Micro-Focus MX, 10um)

BL24I Synoptic

Help | Overviews... | Left to Right

Status Vacuum Controls

OH1 OH2 EH3A EH3B

Jungfrau Cold Enabled 13.01 C
Jungfrau Warm Chilli 18.0 C
Eiger Chiller 25.1 C

Beam

STEER

CAENs Web I/F
CAENs PFM
BPM3
CAENs MFM

SLOW

FAST

Plat detected

ROBOT LPP ANNEAL
ROBOT GPIO LN2 Washer

FSHT2 GB1 S1 FL1 GB2 DCM GB3 FL2 XBPM1 OSHTR S2 HPFM S3 BPM3 S4 XBPM2 SHTR1 HMFM ATT XBPM3 SHTR2 FZOOM OAV1 AP1 HSTG VGON CSTRM FLUO OAV2 BL BS DET

CRYO1 VPFM I400 DC I400 DC MFM CTAB AP2 TTAB PTAB Viewer Viewer

Optics Hutch 1 Searched & Closed Optics Hutch 2 Searched & Closed Experiment Hutch 3A Searched & Closed CAENs PSU RESET Experiment Hutch 3B Searched & Closed

Absorber 1	Port Shutter	Optics Hutch Shutter	FE Beam Permit	Experimental Hutch Shutter	ID Gap	Energy	Ring Energy	Ring Current	Fill	Beam Dump Countdown	Lifetime
Closed	Closed	Closed	Closed Open	Closed	26.00 mm	20.00 keV	-0 GeV	0.0013 mA	Standby	-1	0.000 h

Mode Motion Experimental Equipment

Shutdown STOP MOTORS Equipment FANS PSUs General Purpose PV's PMAC Command I/F EP2338 Test Feedback Loops Flux Calculation Bluesky server Smaract Control Pico Control

Messages: Mode: Shutdown Mag 1: Shutdown

Front End: Aperture Front End Status Interlocks Hardware Status 1 Hardware Status 2 EXIT

Pre-Focus Mirrors

Secondary Source

Micro-Focus Mirrors





I24 Micro-Focus Control

I24 MFM - Bimorph PSU

Group VMFM ON

Chn	Target Voltage			Voltage on Bimorph			Status
	Demand	Readback	Shift By	Demand	Readback	Status	
1	0.0	892.4	0.0	0.0	892.4	ON	
2	0.0	895.4	0.0	0.0	895.0	ON	
3	0.0	897.0	0.0	0.0	897.0	ON	
4	0.0	898.0	0.0	0.0	898.0	ON	
5	0.0	899.0	0.0	0.0	899.0	ON	
6	0.0	900.0	0.0	0.0	900.0	ON	
7	0.0	901.0	0.0	0.0	900.0	ON	
8	0.0	902.0	0.0	0.0	902.0	ON	
9	0.0	903.0	0.0	0.0	903.0	ON	
10	0.0	904.0	0.0	0.0	904.0	ON	
11	0.0	905.0	0.0	0.0	905.0	ON	
12	0.0	906.0	0.0	0.0	906.0	ON	
13	0.0	908.0	0.0	0.0	908.0	ON	
14	0.0	909.0	0.0	0.0	909.0	ON	
15	0.0	910.0	0.0	0.0	910.0	ON	
16	0.0	911.0	0.0	0.0	911.0	ON	

Shift All:
 Set All:
 Mode: FAST FAST

Chns: ON OFF
 Board Temperatures:
 Alarm Status: NO ALARM

TARGET ARRAY LIST

Group HMFM ON

Chn	Target Voltage			Voltage on Bimorph			Status
	Demand	Readback	Shift By	Demand	Readback	Status	
1	0.0	892.0	0.0	0.0	892.0	ON	
2	0.0	893.0	0.0	0.0	893.0	ON	
3	0.0	895.0	0.0	0.0	895.0	ON	
4	0.0	897.0	0.0	0.0	897.0	ON	
5	0.0	899.0	0.0	0.0	899.0	ON	
6	0.0	900.0	0.0	0.0	900.0	ON	
7	0.0	901.0	0.0	0.0	901.0	ON	
8	0.0	902.0	0.0	0.0	902.0	ON	
9	0.0	903.0	0.0	0.0	903.0	ON	
10	0.0	904.0	0.0	0.0	904.0	ON	
11	0.0	905.0	0.0	0.0	905.0	ON	
12	0.0	906.0	0.0	0.0	906.0	ON	
13	0.0	908.0	0.0	0.0	908.0	ON	
14	0.0	909.0	0.0	0.0	909.0	ON	
15	0.0	910.0	0.0	0.0	910.0	ON	
16	0.0	911.0	0.0	0.0	911.0	ON	

Shift All:
 Set All:
 Mode: FAST FAST

Chns: ON OFF
 Board Temperatures:
 Alarm Status: NO ALARM

CONNECTED
 Device:
 Device Busy: ■
 List of Groups:

Blue – writeable demand
Green – readback value





Zooming in...

I24 MFM - Bimorph PSU

Group VMFM

Chn	Target Voltage			Voltage on Bimorph			Status
	Demand	Readback	Shift By	Demand	Readback		
1	0.0	892.0	0.0	0.0	892.0	OK	
2	0.0	895.0	0.0	0.0	895.0	OK	
3	0.0	898.0	0.0	0.0	898.0	OK	
4	0.0	903.0	0.0	0.0	903.0	OK	
5	0.0	908.0	0.0	0.0	908.0	OK	
6	0.0	912.0	0.0	0.0	912.0	OK	
7	0.0	945.0	0.0	0.0	945.0	OK	
8	0.0	950.0	0.0	0.0	950.0	OK	
9	0.0	955.0	0.0	0.0	955.0	OK	
10	0.0	958.0	0.0	0.0	958.0	OK	
11	0.0	993.0	0.0	0.0	993.0	OK	
12	0.0	997.0	0.0	0.0	997.0	OK	
13	0.0	997.0	0.0	0.0	997.0	OK	
14	0.0	1000.0	0.0	0.0	1000.0	OK	
15	0.0	1100.0	0.0	0.0	1100.0	OK	
16	0.0	1101.0	0.0	0.0	1101.0	OK	

TARGET ARRAY LIST

Set Target Voltages Shift All Set All Mode FAST

Chns Status Board Temperatures Alarm Status

UPDATE TARGET LIST UPDATE HYSTERESIS LIST

WIPE TARGET LIST WIPE HYSTERESIS LIST

TARGET LIST HYSTERESIS LIST

Device CONNECTED

Device Busy List of Groups: 16

Target Voltages are a staging post

These are the voltages on the outputs

Tells us if a mirror is busy

Tells us when the device is busy

Are we still talking to the power supply?
Uses ASYN record .CNCT field





Device Busy PV

- ☀ The asynPortDriver has a polling task (1 second)
- ☀ One of its jobs is to read back the status of each mirror (group) and update the PV's for the state of each mirror
- ☀ A CALC record combines the two individual states to give us “Device Busy”
- ☀ Using this PV is **crucial** in the way we drive the power supply
 - ☀ We don't want to flood the power supply with commands, while it is still busy
 - ☀ If we do, commands are lost, voltage settings don't happen
- ☀ So, our client code must always look for: IDLE->BUSY->IDLE, after sending each command, and before sending the next command
- ☀ Following this paradigm, the communication is rock solid and there are no disconnections



Back to commissioning...

- ☀ What happens during commissioning?
 - ☀ We set each voltage to a value and make a measurement of the beam off the mirror. This is done multiple times, to generate a response matrix.
 - ☀ But that means for every set of voltages, we have to send 16 commands, per mirror, and wait IDLE->BUSY->IDLE for each one - still quite slow...
- ☀ Wouldn't it be better if we could send all 16 as an array?
 - ☀ That's where the Target Voltages come in!
 - ☀ We can send the whole set of Target Voltages to the outputs with a single command ("Set Target Voltages" button on the interface)
 - ☀ But, hold on, we still have to set each individual target voltage first, that's 16-commands!!
- ☀ At this point...

This thing is still too slow...



...can we make it go quicker?!?

Target Array Command

- ☀ The answer is, of course, YES!
- ☀ We add another command, which allows us to **set** the target voltages as an array
- ☀ We need another set of EPICS records to hold the values. Writing to these does not send a command to the device. They are just “soft” records
- ☀ Use `ca_put_callback()` in the client code, to know when they are all written
- ☀ Now send the new command! →

I24 MFM - Bimorph PSU

Group VMFM				Group HMFM			
Chn	Target Voltage	Demand		Chn	Target Voltage	Demand	
1	852.0	17	<input type="text"/>	1	-832.0	17	<input type="text"/>
2	395.0	18	<input type="text"/>	2	-844.0	18	<input type="text"/>
3	291.0	19	<input type="text"/>	3	-646.0	19	<input type="text"/>
4	318.0	20	<input type="text"/>	4	-547.0	20	<input type="text"/>
5	476.0	21	<input type="text"/>	5	-669.0	21	<input type="text"/>
6	478.0	22	<input type="text"/>	6	-182.0	22	<input type="text"/>
7	543.0	23	<input type="text"/>	7	316.0	23	<input type="text"/>
8	625.0	24	<input type="text"/>	8	-125.0	24	<input type="text"/>
9	639.0	25	<input type="text"/>	9	-34.0	25	<input type="text"/>
10	638.0	26	<input type="text"/>	10	-34.0	26	<input type="text"/>
11	798.0	27	<input type="text"/>	11	-533.0	27	<input type="text"/>
12	832.0	28	<input type="text"/>	12	-533.0	28	<input type="text"/>
13	933.0	29	<input type="text"/>	13	-38.0	29	<input type="text"/>
14	1069.0	30	<input type="text"/>	14	-458.0	30	<input type="text"/>
15	1161.0	31	<input type="text"/>	15	-76.0	31	<input type="text"/>
16	1151.0	32	<input type="text"/>	16	-478.0	32	<input type="text"/>

SEND ARRAY G0 SEND ARRAY G1 EXIT

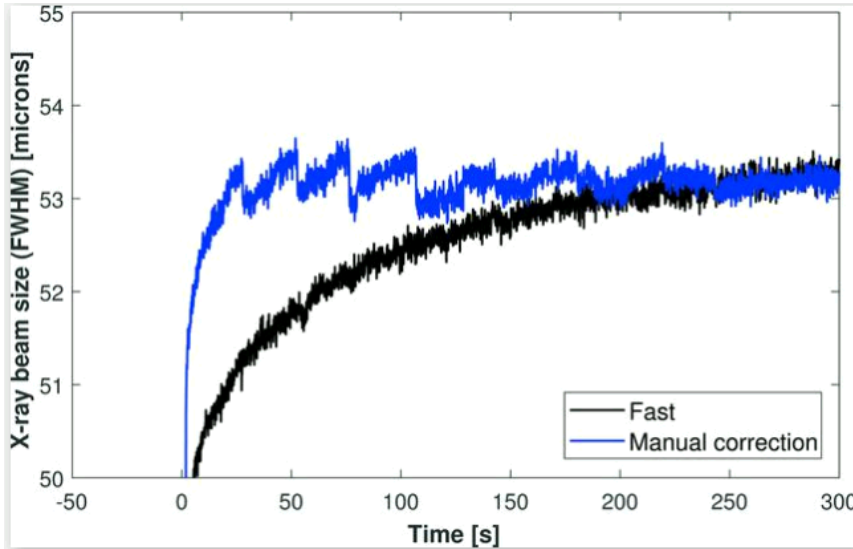
Database logic formats the command and sends it the device



Timings...

- ☀ Using the Target Array Command:
 - ☀ 500 sets of 32 random voltages on a single mirror: 250 minutes
- ☀ Compared to setting output voltages individually:
 - ☀ Running the same 500 sets of 32 voltages: 534 minutes
- ☀ In continuous running, we have achieved more than 72 hours and never had a problem with lock-ups or communication. We stopped the script at that point.
- ☀ Remember where we started from with the old power supplies...
 - ☀ Failure after 45 minutes!

More Features



“Dynamic adaptive X-ray optics. Part II. High-speed piezoelectric bimorph deformable Kirkpatrick-Baez mirrors for rapid variation of the 2D size and shape of X-ray beams”, S.G. Alcock, I-T. Nistea, R. Signorato, R.L. Owen, D. Axford, J.P. Sutter, A.J. Foster, K. Sawhney. J. Synchrotron Radiat. 26, 45-51 (2019)
<https://doi.org/10.1107/S1600577518015965>

- ☀ Piezo creep can be reliably predicted and automatically compensated
- ☀ Hysteresis command
- ☀ Apply larger target voltage
- ☀ Then, automatically apply small voltage offsets as a time series afterwards
- ☀ 2-D X-ray beam size changed and stabilised in < 10 seconds!!

- ☀ Once we have our sets of commissioned voltages for various foci and beam shape
- ☀ Up to 16 sets can be read from a JSON file and made available to EPICS through the “Update Target List” command.
- ☀ These can be applied, at will, to change focus etc.

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- ☀ Many Diamond Beamline Scientists... for their patience!

The End

Thanks for your attention!

Time to ride off into the sunset...

