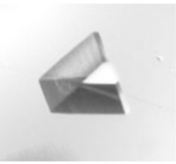
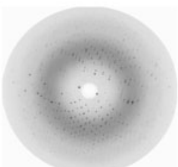
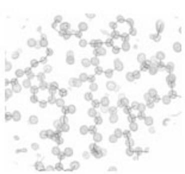






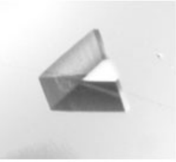
CDI interface to real-time EtherCat

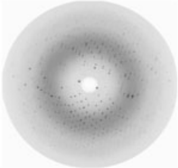
Uwe Ristau

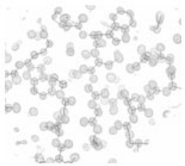
Petra III Instrumentation EMBL-Hamburg

TINE Workshop 9/2007 27th September 2007

Outlook

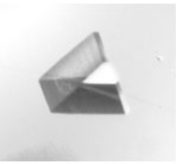


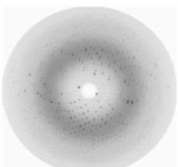


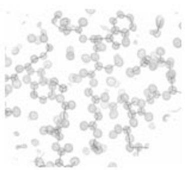


- **Multilayer Monochromator @ BW7A**
- **Announcements**
- **Future Projects**

The Beckhoff redundant real time ethernet based ETHERCAT fieldbus



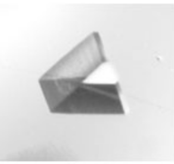


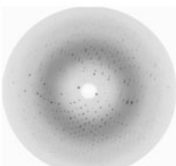


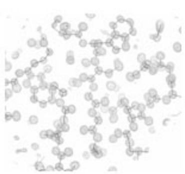
- In 12/2006 there was a Beckhoff TwinCat tutorial at the EMBL in Hamburg this was the start of the development with EtherCat and the K-Bus fieldbus at the EMBL

- The first test project was the BW7A Multilayer Monochromator which is 100% equipped with Beckhoff DAQ

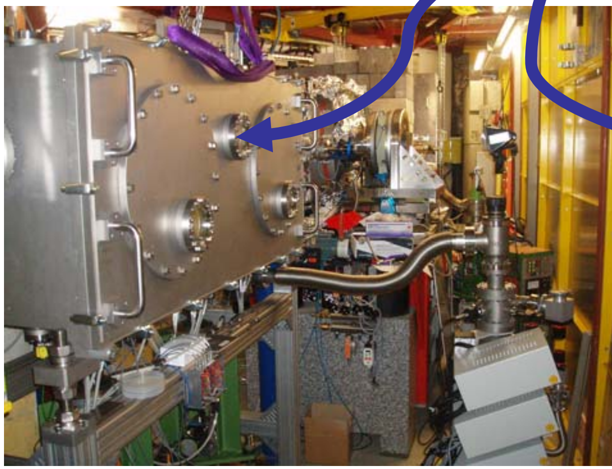
The Multilayer project @ BW7A (S.Fiedler)

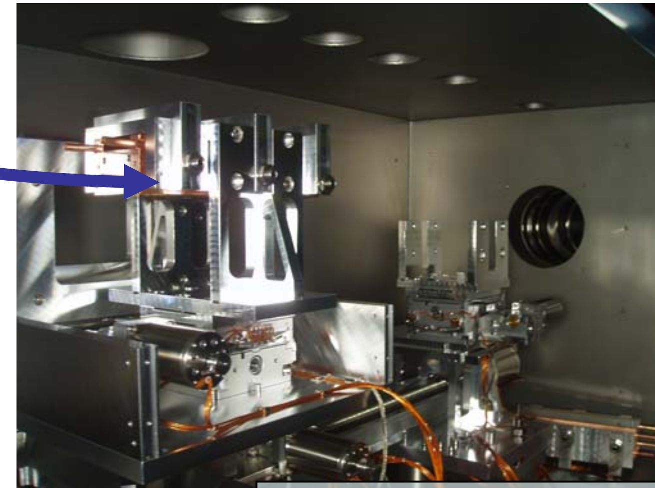






Vessel, motors, encoders(Renishaw, LVDT), substrates etc.

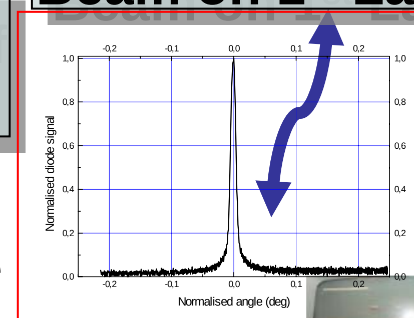




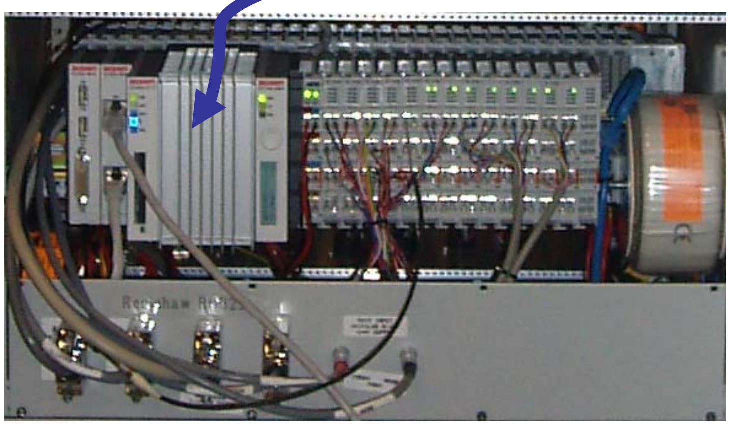
WIN-CE 2GHz,1GB Computer
TINE, MotorServer, CDI

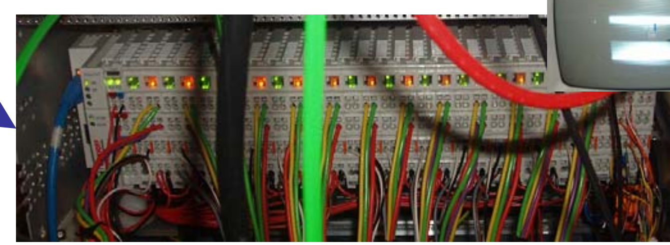
Beckhoff CX-1020

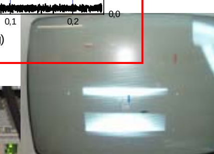
Beam on 1st Layer



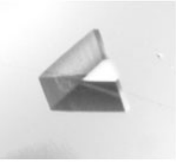
backside

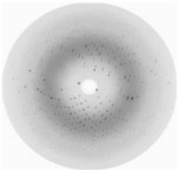
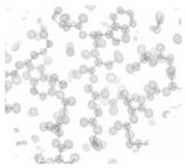




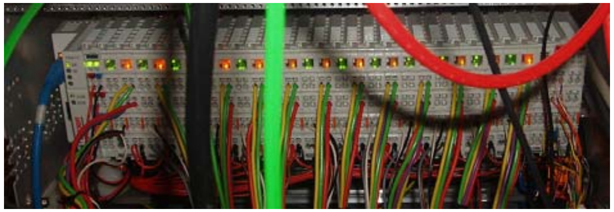


Control of the BW7A Multilayer

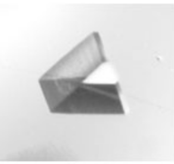


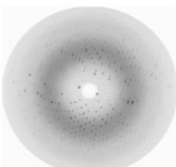
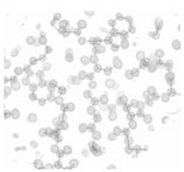




- 14 Stepper motors driver by
  - 5Ampere Stepper motor controllers with amplifiers
  - 2 puls direction stepper motor controller with Berger Lahr driver unit
- 18 Analog inputs
  - Thermocouples
  - LVDTs
  - Diodes
  - Potentiometer
  - Vacuum Gauges
- 24 Digital inputs and outputs
  - Vacuum valves
  - Shutter control
  - Trigger signals
- 4 Counters
  - Renishaw digital encoder



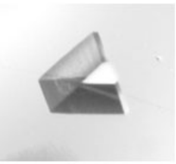

The Multilayer control system

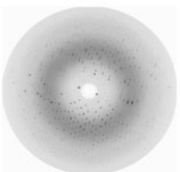


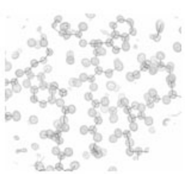




- Data acquisition with Beckhoff Ethercat realtime fieldbus system and the older K-Bus
- Running on a WIN-CE Computer
- Device servers for TINE are generated by CDI (Common device interface)
- Device server will run embedded on the PLC computer as soon as the WIN-CE Tine support is available

PLC: Where are they used?

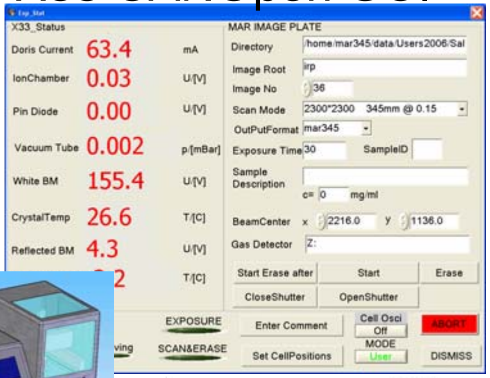


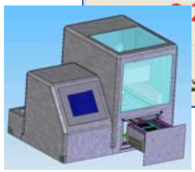


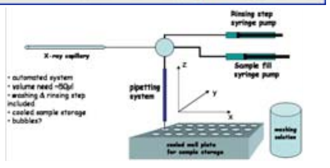


- Interlock control, Vacuum control, Machine interlock
- Undulator control for PetraIII
- ESRF uses WAGO also at the beamlines
- New possibilities because of the **stepper motor controller** available
- **EMBL started 2004 with CANOpen at the small angle scattering beam line X33 with good results**.
- Since than new ethernet based real time fieldbus systems have been developed
- Since 12/2006 EMBL tests the Ethercat fieldbus and has chosen the multilayer monochromator as a test case for the PetraIII project.

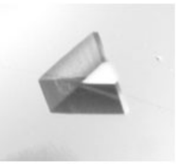
X33 CANOpen GUI

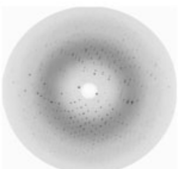


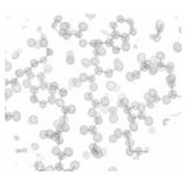




Some EtherCat specifications

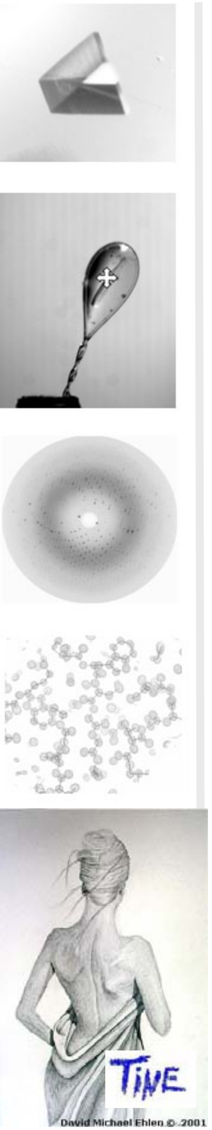






- Flexible small distributed units
- Clock synchronization of connected controllers up to 1 us
- Real time Ethernet based with cycle times down to 100 us possible
- Connected via CAT5 Ethernet cable and ordinary network switches
- Counter, DIO, AIO, Stepper, DC-motor control all in one system available
- High reliabililty, industrial standard, Computer without rotating parts (fans, hard disks, etc)
- Triggers and AI with XFC modules of Beckhoff synchronized by 100ns and incremental delays of 10ns possible, analog input up to 200kHz (15 bit,0.5%precission)
- Cheap, fast delivery, long live products supported for many years
- (CAN, S5, SerCos, Profibus Gateways available)
- Easy interfacing between fieldbuses

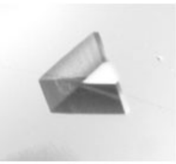
Beckhoff motor control

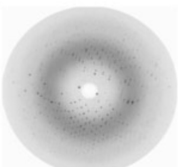


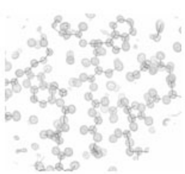
- Controller & Amplifier/Driver support closed loop operation of stepper motors
- KL-2541:5 A,64microStepping,100KHz, very integrated and small, 240Euro
- KL-2531:1.5A, no closed loop option available, 150Euro

- KL-2521: Puls-direction motor controller for single axis without closed loop option, 150 Euro
- In combination with the PLC (as many analog and digital signal inputs as needed), flexible product
- PLC allows ON-THE-FLY motor scans
- Read out of all parameters of the controller/ amplifier and Statuses and positions up to 10 Hz readout of all statuses and positions by a single call.
- Beckhoff offers also servo motor drivers we just started with the AX2003 module

Stepper motor control

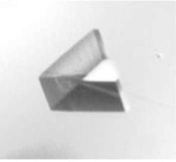


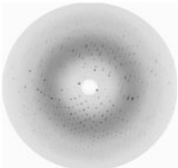
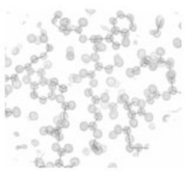




- Chopped stepper motor amplifier offer up to 20 times micro stepping
- Linear amplifier are able to support up to 128 micro stepping
- Chopped amplifier are source of electromagnetic noise. Shielded cables and the use of disc motors which are 10% more expensive but do suppress the noise induced by the inductivity of the motors
- Chopped modules are smaller and produce less heat load

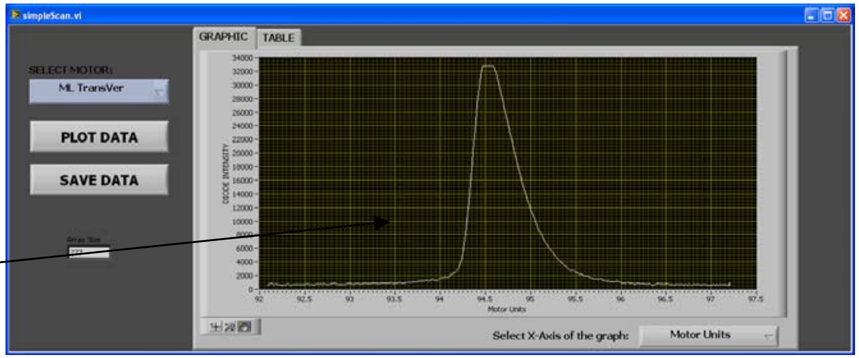
On the fly Scans



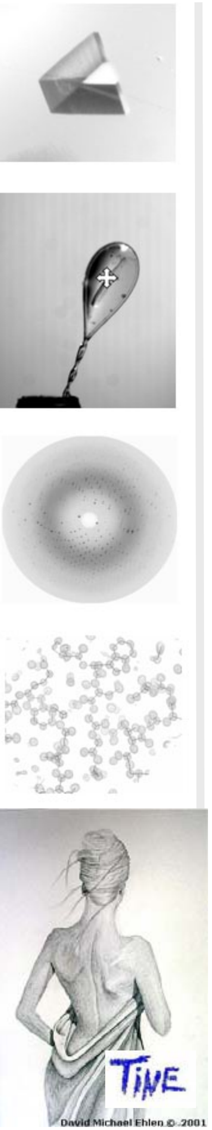




- The structure of the PLC program is very flexible and allows to perform **On the Fly Scans**
  - after the start of a motor in each cycle of the PLC the data will be written into arrays.
  - Up to 32kB of data can be written to a array during one single move (diode analog input LVDT, Renishaw) .
  - The readout can be continous or at once after finishing the move. This reduces the network traffic and is still fast.

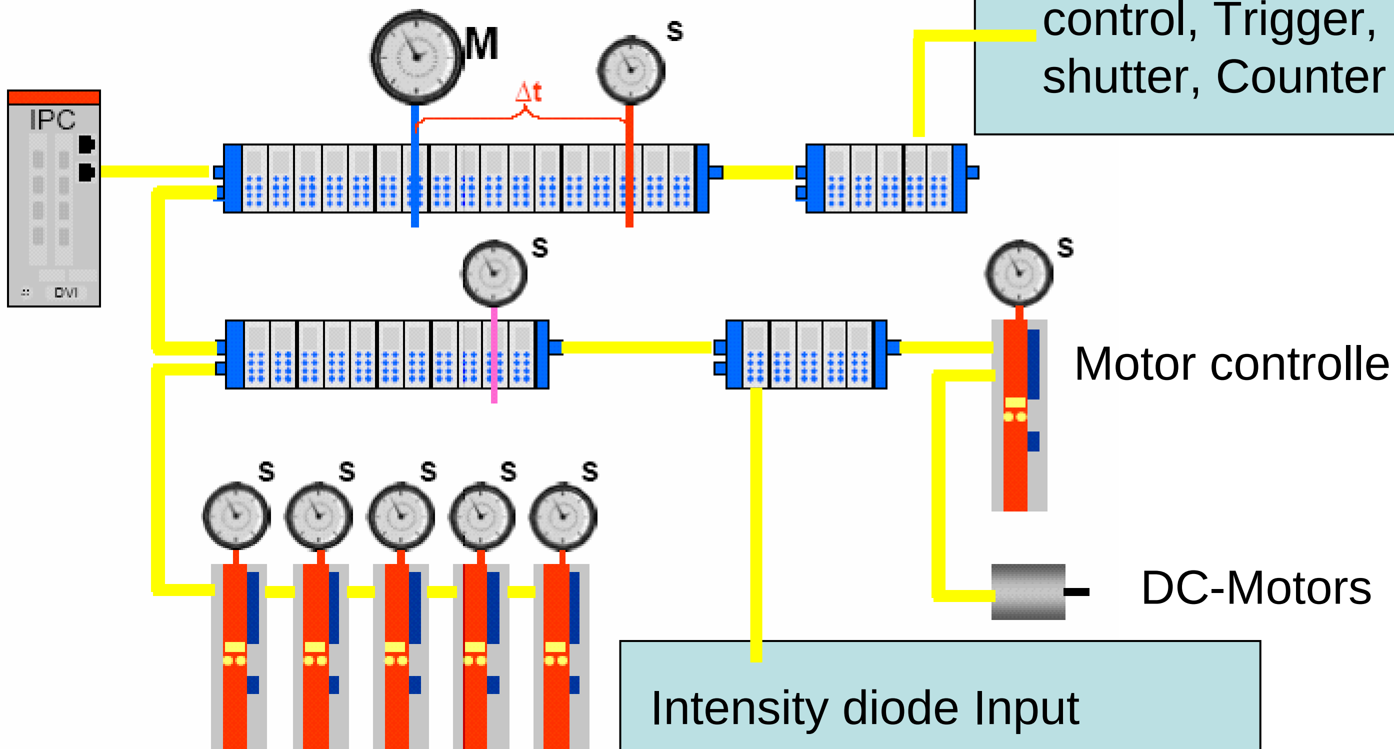
The start of a ‘On The Fly’ scan is proceeded by selection of the axis to scan and performing a move.



The synchronization problem



Precise Synchronization (<< 1 µs!) by exact adjustment of distributed clocks



DIO – valve control, Trigger, shutter, Counter

Intensity diode Input

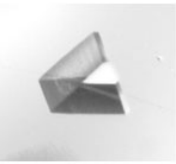
LVDT input

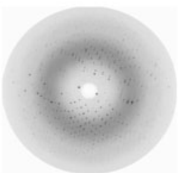
POTI

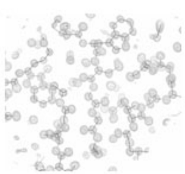
Renishaw encoder

EtherCat offers Redundant Installation by not using a line configuration but a ring

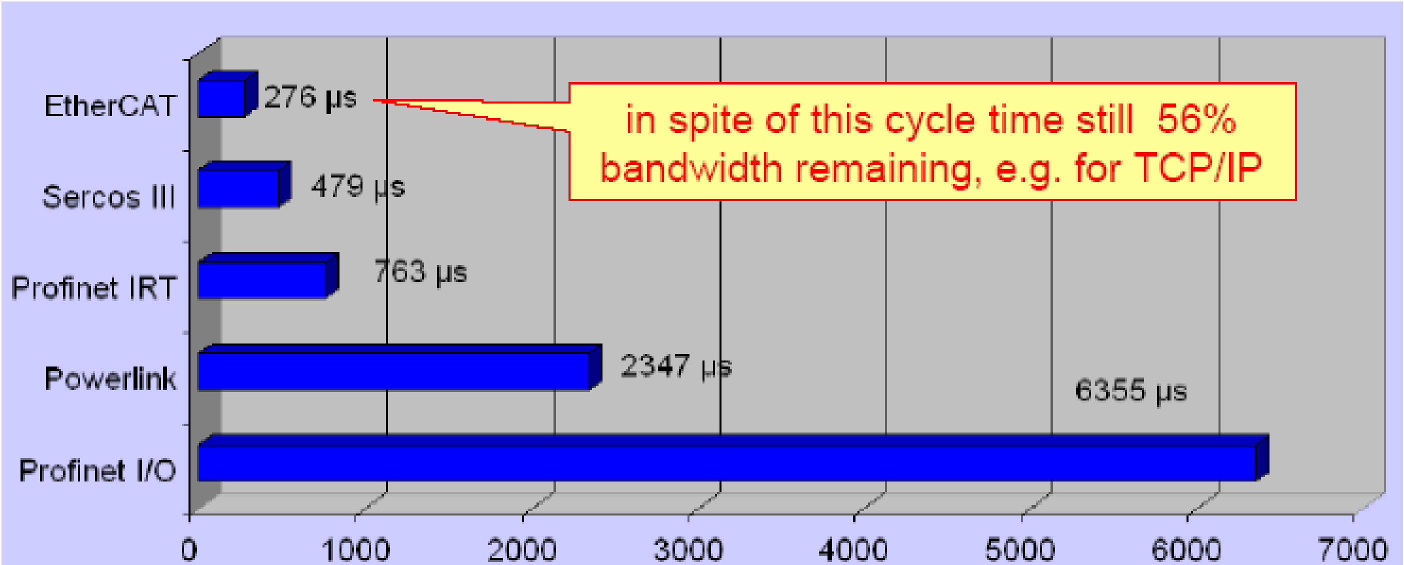
EtherCAT Performance Example





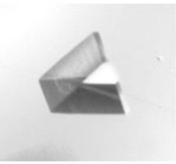


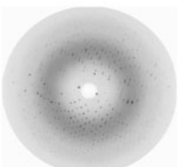
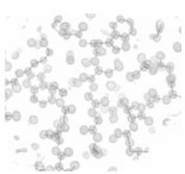
- 40 Axis (each 20 Byte Input- and Output-Data)
- 50 I/O Station with a total of 560 EtherCAT Bus Terminals
- 2000 Digital + 200 Analog I/O, Bus Length 500 m
- Performance EtherCAT: Cycle Time **276µs**
  at 44% Bus Load, Telegram Length 122µs
- For comparison:
  Profinet IRT **763 µs**, Powerlink V2 **2347µs***, Profinet RT **6355 µs**



Beckhoff

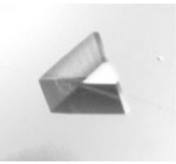
CDI and TINE device server

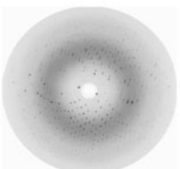


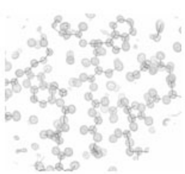




- CDI uses in a csv file defined variables, TwinCat/EtherCat devices and Templates for automatic device server generation.
- Only one line of code per device or variable is necessary to export this function as device server property.

The TINE CDI csv file for automatic server generation

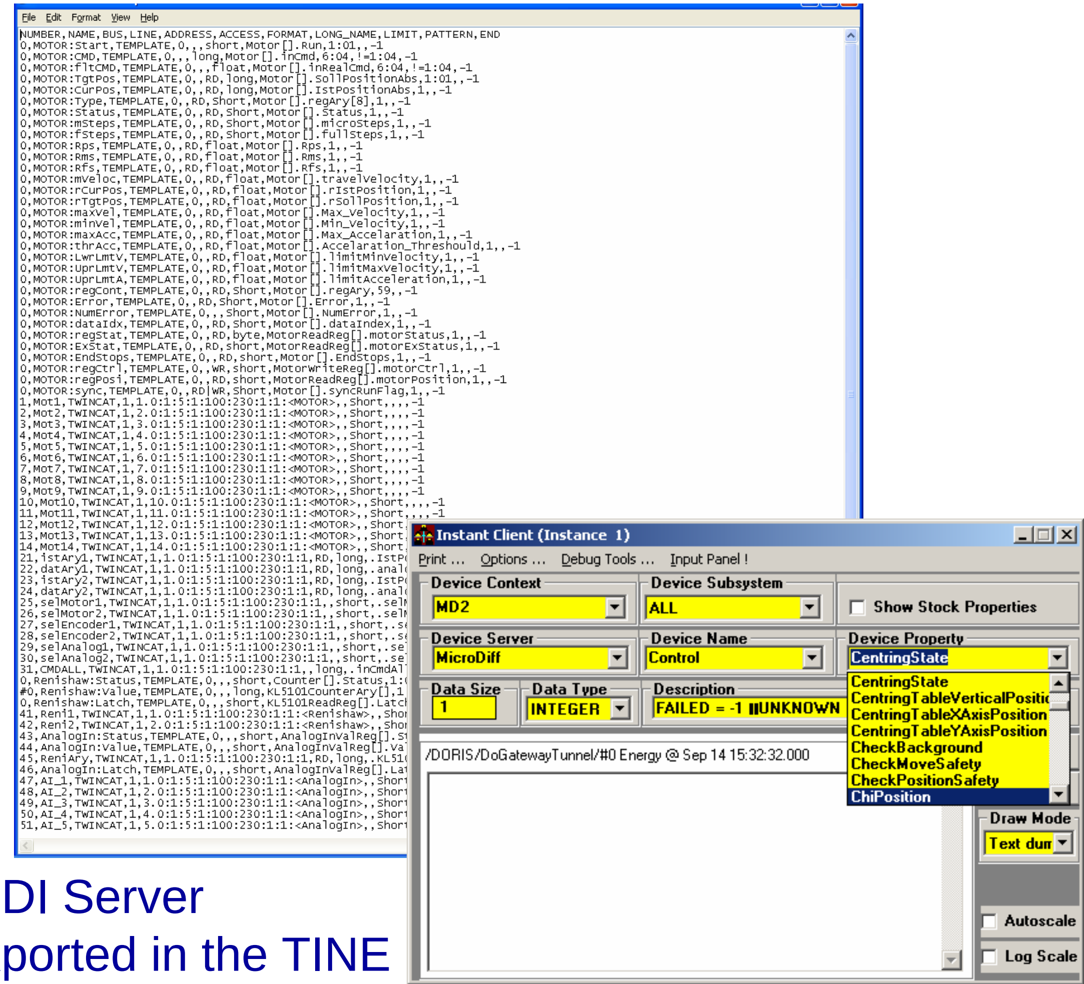






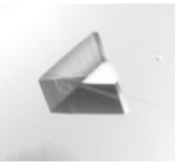
Motor template →

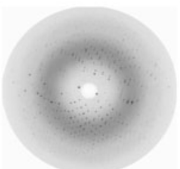
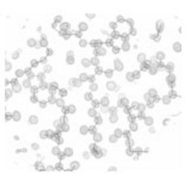
Templates for hardware
Device groups →



After the start of the CDI Server
All variables will be exported in the TINE
Instant Client the TINE General System Client which allows to access all
Data of Servers connected to the Control system

The CDI Templates: Example Motor





```
NUMBER,NAME,BUS,LINE,ADDRESS,ACCESS,FORMAT,LONG_NAME,LIMIT,PATTERN,END
0,MOTOR:Start,TEMPLATE,0,,,short,Motor[].Run,1:01,,-1
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0,MOTOR:fltCMD,TEMPLATE,0,,,float,Motor[].inRealCmd,6:04,!=1:04,-1
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0,MOTOR:rTgtPos,TEMPLATE,0,,RD,float,Motor[].rSollPosition,1,,-1
0,MOTOR:maxVel,TEMPLATE,0,,RD,float,Motor[].Max_Velocity,1,,-1
0,MOTOR:minVel,TEMPLATE,0,,RD,float,Motor[].Min_Velocity,1,,-1
0,MOTOR:maxAcc,TEMPLATE,0,,RD,float,Motor[].Max_Accelaration,1,,-1
0,MOTOR:thrAcc,TEMPLATE,0,,RD,float,Motor[].Accelaration_Threshould,1,,-1
0,MOTOR:LwrLmtV,TEMPLATE,0,,RD,float,Motor[].limitMinVelocity,1,,-1
0,MOTOR:UprLmtV,TEMPLATE,0,,RD,float,Motor[].limitMaxVelocity,1,,-1
0,MOTOR:UprLmtA,TEMPLATE,0,,RD,float,Motor[].limitAcceleration,1,,-1
0,MOTOR:regCont,TEMPLATE,0,,RD,short,Motor[].regAry,59,,-1
0,MOTOR:Error,TEMPLATE,0,,RD,short,Motor[].Error,1,,-1
0,MOTOR:NumError,TEMPLATE,0,,,short,Motor[].NumError,1,,-1
0,MOTOR:dataIdx,TEMPLATE,0,,RD,short,Motor[].dataIndex,1,,-1
0,MOTOR:regStat,TEMPLATE,0,,RD,byte,MotorReadReg[].motorStatus,1,,-1
0,MOTOR:ExStat,TEMPLATE,0,,RD,short,MotorReadReg[].motorExStatus,1,,-1
0,MOTOR:EndStops,TEMPLATE,0,,RD,short,Motor[].EndStops,1,,-1
0,MOTOR:regCtrl,TEMPLATE,0,,WR,short,MotorWriteReg[].motorCtrl,1,,-1
0,MOTOR:regPosi,TEMPLATE,0,,RD,short,MotorReadReg[].motorPosition,1,,-1
0,MOTOR:sync,TEMPLATE,0,,RD|WR,short,Motor[].syncRunFlag,1,,-1
```
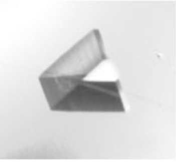
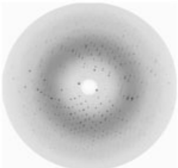
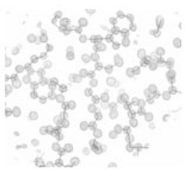

The CDI definition csv file





```
30,selAnalog2,TWINCAT,1,1.0:1:5:1:100:230:1:1,,short,.selAnalog2,1,,-1
31,CMDALL,TWINCAT,1,1.0:1:5:1:100:230:1:1,,long,.inCmdAlle,6:04,!=1:04,-1
0,Renishaw:Status,TEMPLATE,0,,,short,Counter[].Status,1:01,,-1
#0,Renishaw:Value,TEMPLATE,0,,,long,KL5101CounterAry[],1:01,,-1
0,Renishaw:Latch,TEMPLATE,0,,,short,KL5101ReadReg[].Latch,1:01,,-1
41,Reni1,TWINCAT,1,1.0:1:5:1:100:230:1:1:<Renishaw>,,short,,,,-1
42,Reni2,TWINCAT,1,2.0:1:5:1:100:230:1:1:<Renishaw>,,short,,,,-1
43,AnalogIn:Status,TEMPLATE,0,,,short,AnalogInValReg[].Status,1:01,,-1
44,AnalogIn:Value,TEMPLATE,0,,,short,AnalogInValReg[].Value,1:01,,-1
45,ReniAry,TWINCAT,1,1.0:1:5:1:100:230:1:1,RD,long,.KL5101CounterAry,5,,-1
46,AnalogIn:Latch,TEMPLATE,0,,,short,AnalogInValReg[].Latch,1:01,,-1
47,AI_1,TWINCAT,1,1.0:1:5:1:100:230:1:1:<AnalogIn>,,short,,,,-1
48,AI_2,TWINCAT,1,2.0:1:5:1:100:230:1:1:<AnalogIn>,,short,,,,-1
```

Hardware Type

Input Line

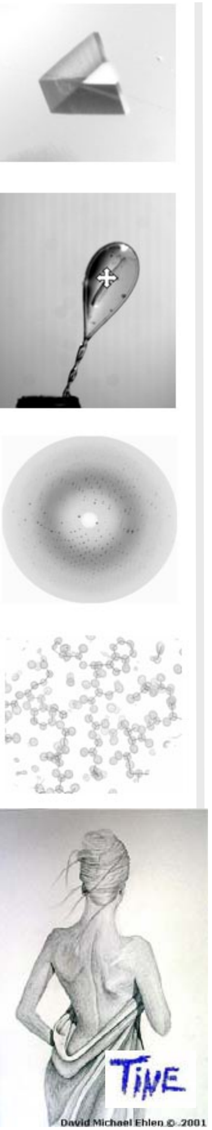
IP-address of Device to connect

Name of the variable in TINE

Type of variable

Additional : Limits, scaling factors, display format , etc can be defined inside this table

CDI supports CANOpen, TwinCat/EtherCat, SEDAC, RS-232, Siemens S5/S7



TwinCat system manager

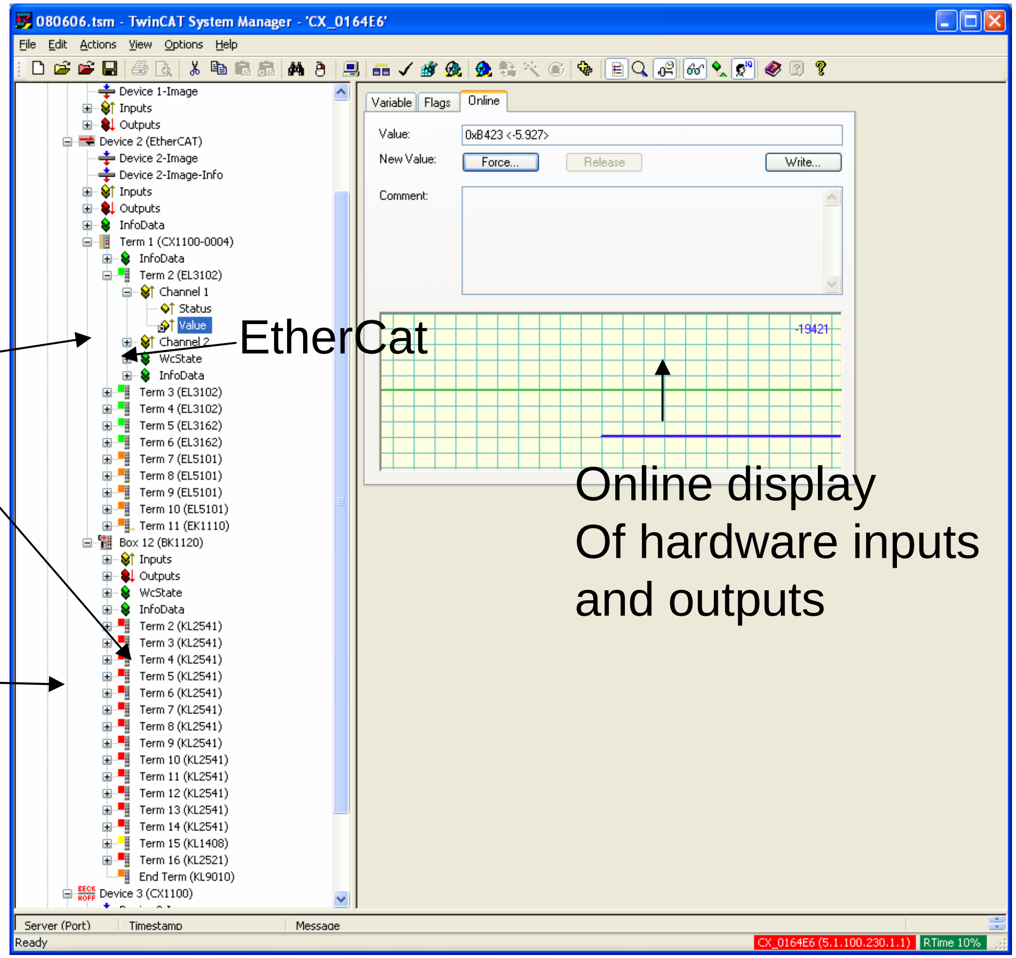
Manages the hardware connected

Links hardware inputs and outputs with acessciated variables which then can be accessed either directly or with the PLC.

Hardware connected

K-Bus

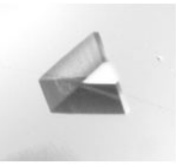
EtherCat

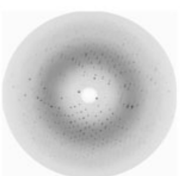


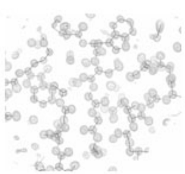
Online display
Of hardware inputs and outputs

TWINCAT PLC Cycle time etc

The PLC collects all connected hardware input and output signals connected to the PLC with shortest cycle times of 100us for EtherCat and 10ms for the TwinCat system.

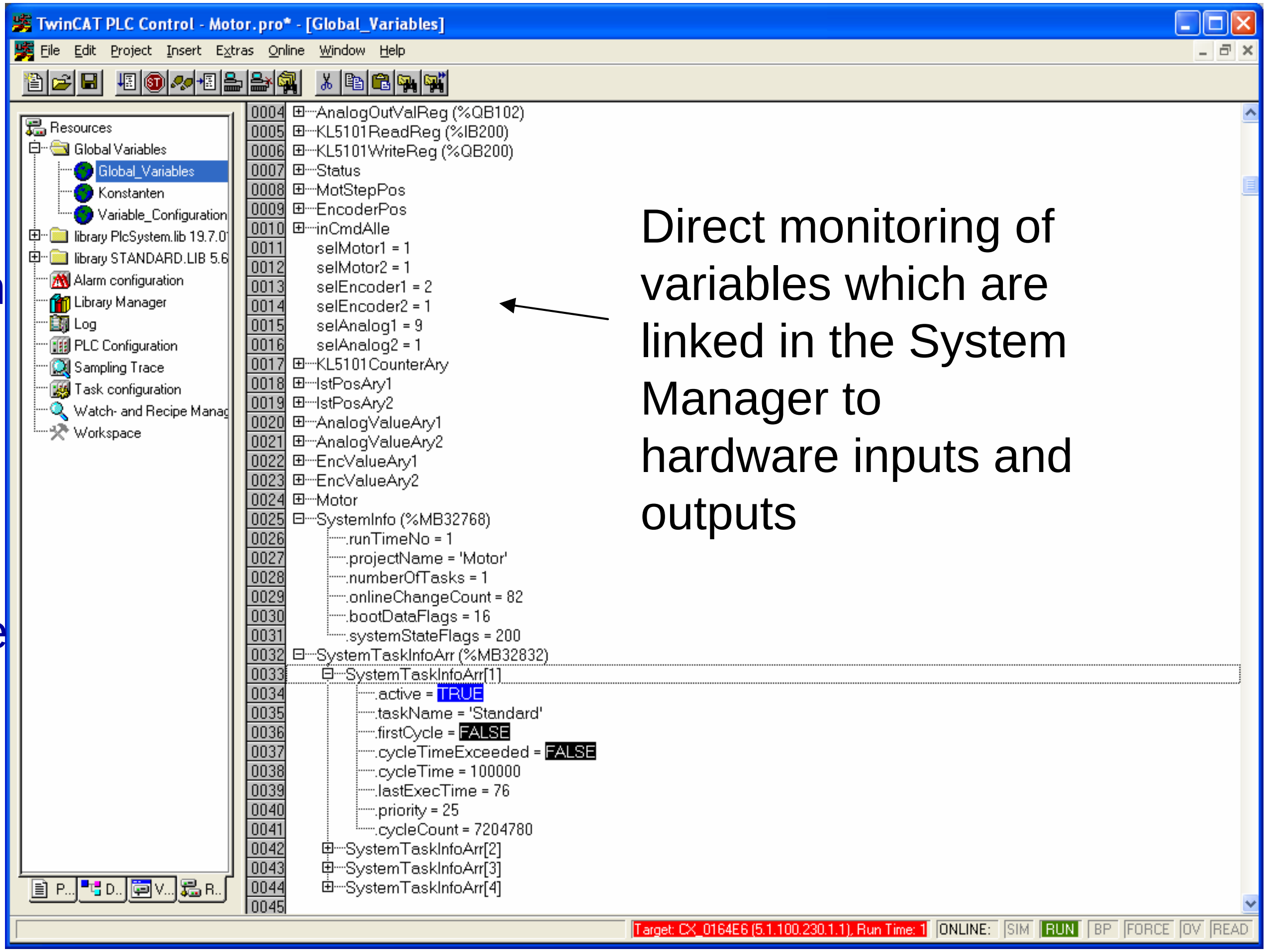






Advantage of PLC programming:
Easy programming in FUP, AWL, Kontaktplan or STRUCTURED TEXT.

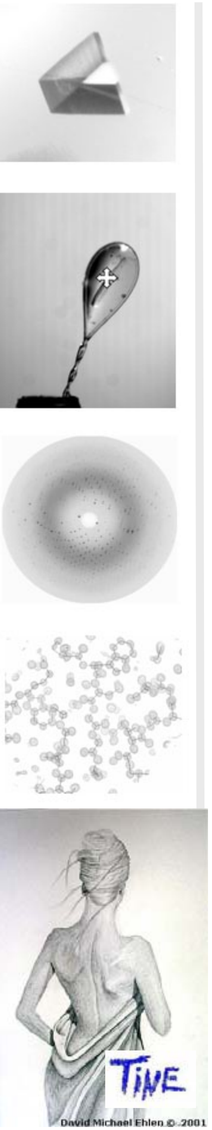
Structured Text is the language
Used for complex tasks



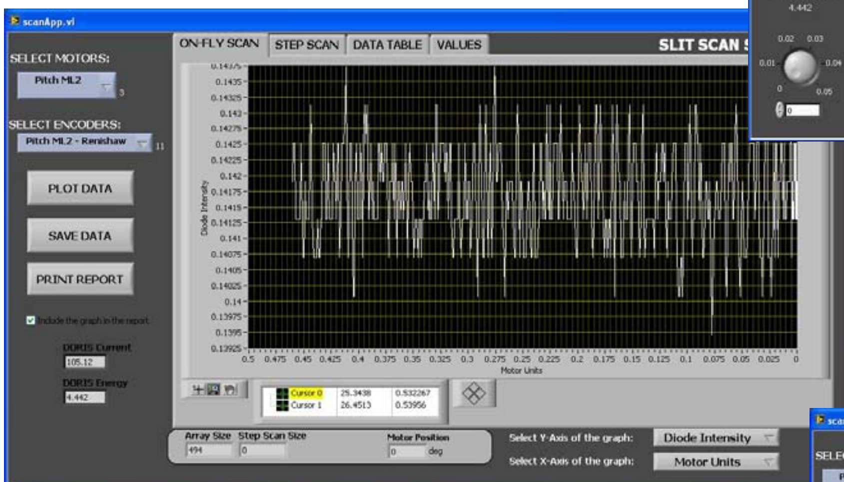
Direct monitoring of variables which are linked in the System Manager to hardware inputs and outputs

Cycle time X100ns.

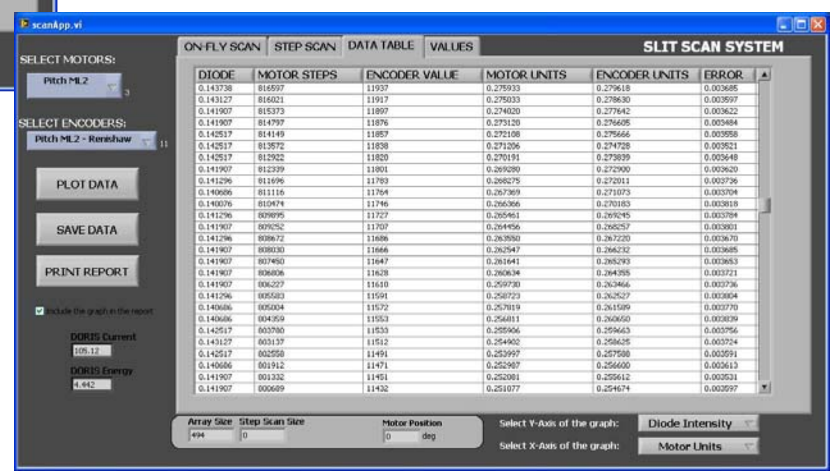
Multilayer control available



Motor control unit.
Encoder readout.
Multi axis move, pseudo axis
Softlimits etc

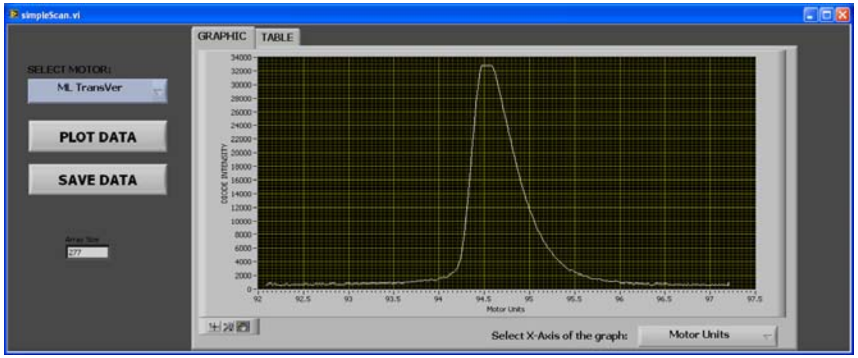


Raw scan data presentation



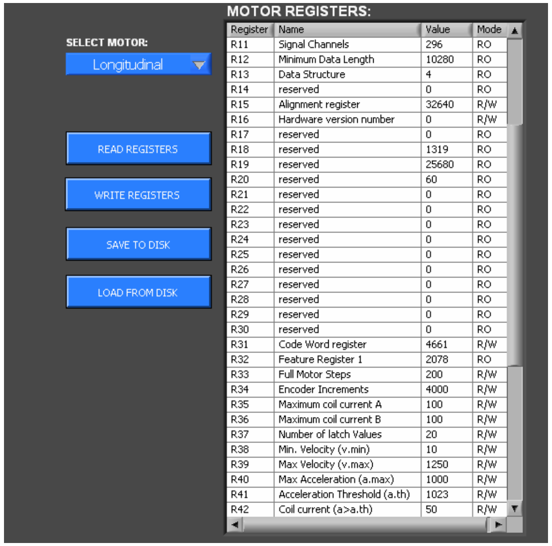
Example scan. For every move
The data can be read out if wanted

Multilayer Control Scan application

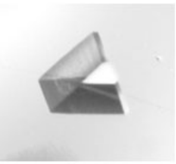


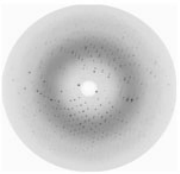
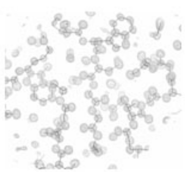
•Scanning on the fly up to 32kByte data points per scan
•Option to scan and save to disk

The motor control tool Client
Enables to set all motor and controller parameters

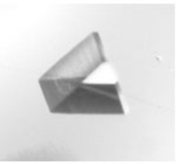


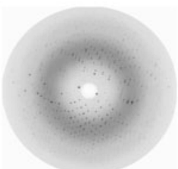
Register	Name	Value	Mode
R11	Signal Channels	296	RO
R12	Minimum Data Length	10280	RO
R13	Data Structure	4	RO
R14	reserved	0	RO
R15	Alignment register	32640	R/W
R16	Hardware version number	0	R/W
R17	reserved	0	RO
R18	reserved	1319	RO
R19	reserved	25680	RO
R20	reserved	60	RO
R21	reserved	0	RO
R22	reserved	0	RO
R23	reserved	0	RO
R24	reserved	0	RO
R25	reserved	0	RO
R26	reserved	0	RO
R27	reserved	0	RO
R28	reserved	0	RO
R29	reserved	0	RO
R30	reserved	0	RO
R31	Code Word register	4661	R/W
R32	Feature Register 1	2078	RO
R33	Full Motor Steps	200	R/W
R34	Encoder Increments	4000	R/W
R35	Maximum coil current A	100	R/W
R36	Maximum coil current B	100	R/W
R37	Number of latch Values	20	R/W
R38	Min. Velocity (v.min)	10	R/W
R39	Max Velocity (v.max)	1250	R/W
R40	Max Acceleration (a.max)	1000	R/W
R41	Acceleration Threshold (a.th)	1023	R/W
R42	Coil current (a>a.th)	50	R/W

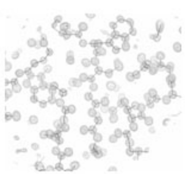



Graphical user interface of the Vacuum controls



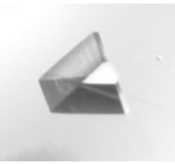


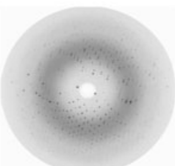
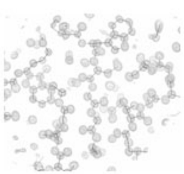


Monitoring of Valves, Temperatures, Pressures etc

In future control will also be possible

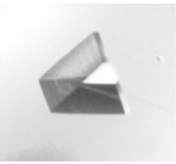
Stepper motor control

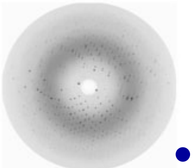


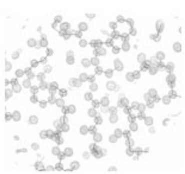




- Chopped stepper motor amplifier offer up to 20 times micro stepping
- Linear amplifier are able to support up to 128 micro stepping
- Chopped amplifier are source of electromagnetic noise. Shielded cables and the use of disc motors which are 10% more expensive but do suppress the noise induced by the inductivity of the motors
- Chopped modules are smaller and produce less heat load

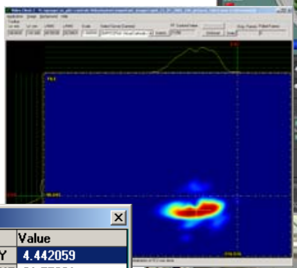
Control of the EMBL-HH beam lines at DORIS

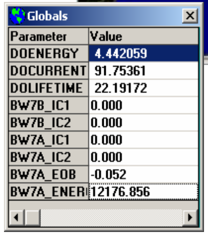




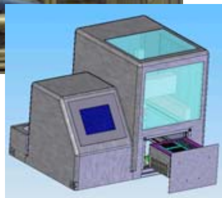


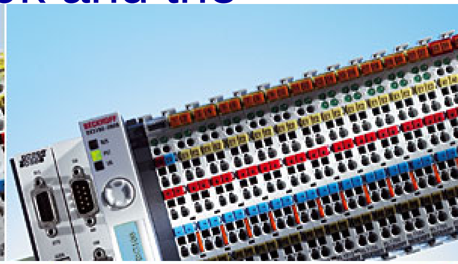
- **Control System of the EMBL is TINE (DESY/MCS)**
- Highlights
  – Robotic Sample Changer BW7B
  – X33 Sample Changer
  – Mulitlayer Monochromator Beckhoff/EtherCat
- Next Projects
  – Generic TINE Detector server for the Pilatus 500k and the MAR 555 Flat panel Detector
  – PXI integration of a Fast digitizer 1GS/s
  and a FPGA (NI)

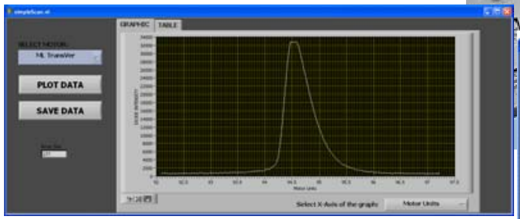



Globals

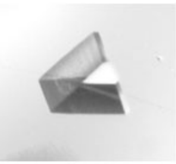
Parameter	Value
DOENERGY	4.442059
DOCURRENT	91.75361
DOLIFETIME	22.19172
BW7B_IC1	0.000
BW7B_IC2	0.000
BW7A_IC1	0.000
BW7A_IC2	0.000
BW7A_EOB	-0.052
BW7A_ENER	12176.856

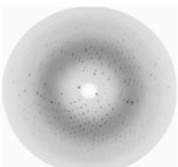


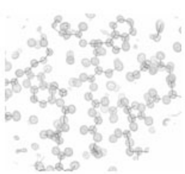




Acknowledgements







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– Andres Pazos Pilatus
– Mario Di Castro since 7/2007

Doris Instrumentation group
Group Leader: Christoph Hermes

– Bernd Robrahn Beckhoff PLC programming
– Lifu Gao
– Fernando Ridoutt

Dimitri Svergun SAXS group

– Timo,Alexej,Daniel Franke X33 SC,Pilatus,CANOPEN

- COSYLAB (Roc Stefanic TANGO2TINE)

- Phil Duval, Reinhard Bacher, Mark Lomperski DESY/MCS Hong Gong Wu Beckhoff integration CDI
- Stefan Weisse DESY Zeuthen Video system