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Integration of the Instrument Control Electronics for the ESPRESSO spectrograph @ESO-VLT

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ABSTRACT

ESPRESSO, the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations of the ESO - Very Large Telescope site, is now in its integration phase.
The large number of functions of this complex instrument are fully controlled by a Beckhoff PLC based control electronics architecture.
Four small and one large cabinets host the main electronic parts to control all the sensors, motorized stages and other analogue and digital functions of ESPRESSO. The Instrument Control Electronics (ICE) is built following the latest ESO standards and requirements. Two main PLC CPUs are used and are programmed through the TwinCAT Beckhoff dedicated software.
The assembly, integration and verification phase of ESPRESSO, due to its distributed nature and different geographical locations of the consortium partners, is quite challenging.
After the preliminary assembling and test of the electronic components at the Astronomical Observatory of Trieste and the test of some electronics and software parts at ESO (Garching), the complete system for the control of the four Front End Unit (FEU) arms of ESPRESSO has been fully assembled and tested in Merate (Italy) at the beginning of 2016.
After these first tests, the system will be located at the Geneva Observatory (Switzerland) until the Preliminary Acceptance Europe (PAE) and finally shipped to Chile for the commissioning.
This paper describes the integration strategy of the ICE workpackage of ESPRESSO, the hardware and software tests that have been performed, with an overall view of the experience gained during these project's phases.

Keywords: ESPRESSO, control electronics, PLC, VLT, instrument integration

1. INTRODUCTION

ESPRESSO is the Echelle SPectrograph for Rocky Exoplanet and Stable Spectroscopic Observations of the European Organisation for Astronomical Research in the Southern Hemisphere (ESO). This instrument is going to be installed in the Combined Coudé Laboratory (CCL) of the ESO Very Large Telescope site on the Cerro Paranal. Its goals will be the measurement of high precision radial velocities of solar type stars for search for rocky planets, the measurement of the variation of the physical constants and the analysis of the chemical composition of stars in the nearby galaxies (see [1] for further details).
About 40 motorized stages, more than 90 sensors and several calibration lamps need to be controlled by the Instrument Control Electronics (ICE) and Software (ICS). In this paper the electronics cabinet distribution, the control strategy and the electronics integration plan is shown.

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2. THE INSTRUMENT ARCHITECTURE

To reach the prefixed science goals, a well determined instrument architecture is required. More precise information about the whole instrument architecture are given in [1] and [2].

As a general overview, four Coudé Train (CT) drive the light through a tunnel from each of the four Unit Telescopes to the respective Front End Unit (FEU) arm in the CCL.

Each of the FEU four arms is composed by an Atmospheric Dispersion Corrector (ADC), a focus translational stage and a system that performs the field and pupil stabilization. The latter is composed by a set of piezo tip-tilt stages to modify the light path, two technical CCDs (TCCDs) and a neutral density filter. The FEU provides, through a calibration slide, the means to inject the calibration light (white and spectral sources) into the spectrograph fibers when needed.

The FEU also provides a mode selector mounted on a rotary stage that feeds the spectrograph fibers with the light coming from the selected telescopes and passing through the corresponding FEU arms in one of the specific instrument mode (single telescope High Resolution, single telescope Ultra High Resolution or multi telescope Medium Resolution).

Two fibers feed the spectrograph simultaneously: the target fiber and the sky/calibration fiber. Finally, two ESO Next Generation Controllers (NGCs) control two scientific detectors: one for the red arm and one for the blue one. One of them is also responsible to drive one of the three shutters that correspond to the chosen resolution mode. To stabilize the spectrograph environment, an optical bench is placed in a vacuum vessel where the temperature is stabilized to 0.001°K, under a pressure lower than $5x10^{-3}$ mbar and where no moving or dissipating parts are located. Such a fine control is obtained with a multiple shells' thermal enclosure.

3. ELECTRONICS ARCHITECTURE AND CONTROL SYSTEM CONCEPT

ESPRESSO Instrument Control Electronics controls all the main functions of the instrument. ICE is described in detail also in [3] and [4].

The electronics controller and devices are installed in specific subracks placed inside electronics cabinets. Depending on the subsystem, dedicated cabinet are foreseen. Figure 1 shows the cabinets positioning in the VLT CCL.

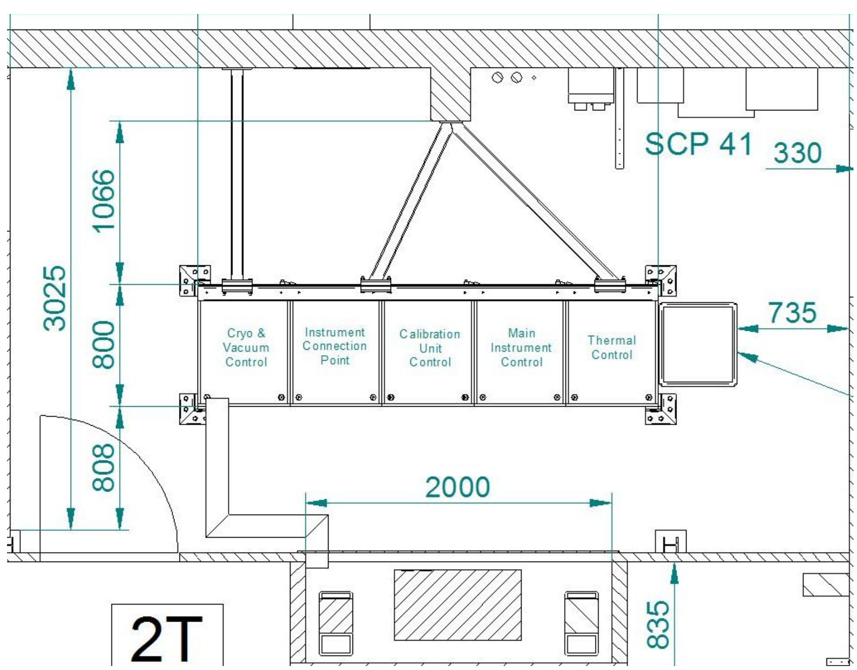

Figure 1 ESPRESSO main cabinets location in the CCL

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Cryostat and Vacuum Control System cabinet (VCS), Calibration unit control cabinet (CAL) and Thermal control cabinet (TCC) are under each subsystem responsibility. ESPRESSO Instrument Control Electronics duties are to provide the network, the power supply and the link to the alarm system to each cabinet; ICE is also totally responsible for the FEU functions control and for the Instrument Main Cabinet (IMC) setup. The IMC host the instrument control system core.
All the cabinets in Figure 1 are Schroff Varistar LHX3 type, 2000 mm high, 600 mm large and 800 mm deep, IP55 compliant. They are equipped with steel doors EMC, lifting eye for top cover, castors with adjustable feet, brush strip for base plate and door switches.
On the other hand, four cabinets foresee the electronic subracks for the control of the FEU arm functions (see Paragraph 4.1) and are placed near the respective arm.

3.1 Automation control system

The control system adopted for ESPRESSO is based on Beckhoff PLC [5]. Two PLC CPU CX2030-0122-N030 are placed in the IMC and represent the core of the control system (CPU#1 and CPU#2; the last one is shown in Figure 2). Analogue and digital input/output modules, PT100 sensors temperature modules, DC-motor output stage with incremental encoder interfaces and serial interfaces contribute to the control of the overall ESPRESSO functions. These components are distributed in electronic subracks positioned inside each cabinet.
Due to the space-distributed nature of ESPRESSO it has been necessary to exploit the decentralization features of the PLCs through the use of Beckhoff decentralization modules EK1100.
The first FEU cabinet is linked to the PLC CPU#1 in the IMC through the EtherCAT connection (EK1100 module). At the end of the Beckhoff modules row an EK1110 EtherCAT extension module allows to maintain the EtherCAT link with the following Beckhoff subrack in the next FEU cabinet. This happens until the last FEU cabinet subrack.
On the other side, another daisy chain is foreseen to link the PLC CPU#2 and the other Beckhoff subracks in the cabinets placed in the CCL. CPU#2 is directly linked with TCC PLC subrack and then, sequentially, to CAL cabinet and NGC interface cabinet.
The programming of the Beckhoff PLC is done through TwinCAT Beckhoff software. A control panel installed in the main cabinet allow to control most of the ESPRESSO functions especially for maintenance purposes.

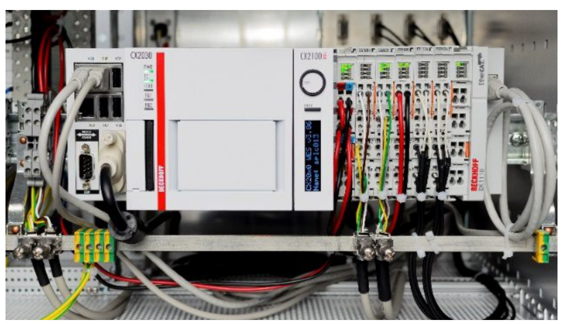

Figure 2 ESPRESSO PLC CPU#2 with functional modules

3.2 Motion control concept

The motion control concept is based on the Beckhoff TwinCAT NC software layer that operates between the hardware modules and PLC software runtime. Its purpose is to offer a standard software interface to the PLC software on one side (PLCopen MC compliant), and a flexible and heavily configurable software-controlled axis positioning system on the other side. The TwinCAT NC environment has fully configurable parameters for setting up PID control loops for the control of the velocity and positioning (see Figure 3). A set point generator provides means for controlling acceleration, deceleration and jerk of the axis.

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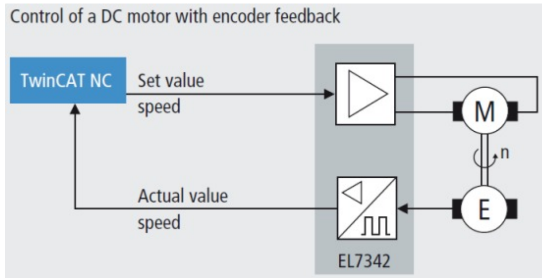

Figure 3 Beckhoff TwinCAT NC axis velocity control loop

3.3 High level software

The communication between the Instrument Work Station (IWS), with whom the user will manage the instrument, and the PLC is obtained through OPC-UA [6] protocol. OPC-UA server is installed in each PLC CPU.
Every device driver exposes, by means of the OPC-UA server, a set of process variables that are accessible by the higher levels of the control software running on the IWS.
The Observation Software (OS) coordinates the exposures. It receives the command sequences to be executed by the Broker for Observation Blocks (BOB) and forwards them to the involved control software subsystems: the Telescope Control Software (TCS), the Detector Control Software (DCS) and the Instrument Control Software (ICS). Eight TCCD device servers (two for each F/E arm, one for the pupil and one for the field stabilization) manage the pupil and stabilization phase, and the exposure meter device server manages the exposure meter.
At the end of the exposure, OS merges the information coming from the different subsystems and archives them.
Other software components perform different activities. For more information read [7] and [8].

4. ESPRESSO ELECTRONICS INTEGRATION

4.1 Assembling phase

ESPRESSO IMC, FEU cabinets and NGC interface cabinet are designed and assembled in Trieste (Italy).
The assembling phase covers the following main aspects:

- mounting and fixing of all the devices inside the cabinets,
- realization of the PLC subracks: assembling the mechanical subrack, inserting the PLC modules lines and completing all the internal wirings
- building the sensors cables
- realization of electrical panels
- installing the electrical main switch on one door of each cabinet

Instrument main cabinet
The IMC assembling involves the mounting of the following devices inside the mechanical structure:

- Two PLC CPUs, one for the control of the FEU functions (via decentralized Beckhoff modules in the FEU cabinets) and the other one for the control of all the other functions (calibration lamps, calibration slides, Lakeshore temperature controller, cabinet doors switches and Shutter-NGC interface)
- Beckhoff control panel
- Network switch
- ESO cabinet cooling controller
- SELCO Central Alarm System (CAS), that detects the power failure of each cabinets
- Shutters VDM1000 controller drivers and their power supplies

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All the connection cables are fixed inside plastic ducts. The electrical panel is fixed on the top of the cabinets.
Figure 4 shows the internal distribution of the IMC (on the left), with the Beckhoff control panel in the middle that allows the functions maintenance procedures.

FEU cabinets

The four FEU cabinets, placed in the FEU area, are of Schroff Varistar Seismic EMC type. Each one is 1000 mm high, 800 mm large and 800 mm deep, IP55 compliant (see Figure 4 on the right). They are equipped with EMC steel doors, lifting eye for top cover, castors with adjustable feet, brush strip for base plate, cable support rail and door contact switch.
The following functions and devices, belonging to the FEU subsystem, are controlled by Beckhoff decentralized modules placed in five subracks inside these four cabinets:

- Atmospheric dispersion corrector (DT-130 rotary stage, 2 for each FEU arm)
- Calibration injection (MICOS LS-65 linear stage, 1 for each FEU arm)
- Focus (MICOS LS-65 linear stage, 1 for each FEU arm)
- Neutral density filter (MICOS AFW-65, 1 for each FEU arm)

Figure 4 Instrument Main Cabinet on the left and Front End Unit Cabinet #4 on the right, both with double PLC subracks

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- Pupil and field stabilization (MICOS S330 piezo tip/tilt stages, 2 for each FEU arm), with their 3HE controller placed inside each cabinet
- Piezo tip/tilt controller power on
- PT100 temperature sensors (6 for each FEU arm, placed in different monitoring places)
- Cabinet door sensors (2 for each FEU cabinet), mounted inside the cabinets

The fourth cabinet host also a further subrack with the PLC modules to control the mode selector (MICOS PRS-200 rotary stage), the neutral density filter (MICOS AFW-65 rotary stage) and some further temperature sensors.

NGC interface cabinet

A further little cabinet is foreseen for the interface with the NGC, and is placed in the CCL niche. It hosts the Beckhoff modules and interfaces for the management of the NGC signals to control the shutters (see Figure 5). Starting from the latest integration phase, it will host also the electronics for the control of a flat field led, used for scientific CCD flat fielding.

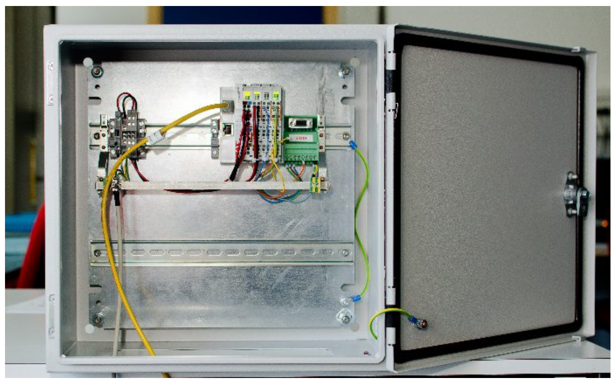

Figure 5 NGC interface cabinet, before the mounting of the Flat Field Led electronics

After the completion of each cabinet, everything was subjected to a preliminary test of functioning.
In the mounting procedures, the hardware configuration or components are not always the same for each cabinet, but when it was possible, the best option was to do the wirings and mount components serially.
This strategy allows to save time and to avoid as much as possible mounting errors.

Electrical parts

The assembling phase involved also the realization of the electrical panel for each cabinet.
In the VLT Combined Coudé Laboratory the Instrument Connection Point (ICP) provides the power supply for the whole system. It is split in three sections:

- Normal three-phase for the cabinets
- Normal three-phase for the thermal enclosure subsystem
- UPS for the cabinets

There is one main switch for each of the above sections; each section has a surge protection device, at power input, followed by an overcurrent breaker. Each line output, which is then routed to the cabinets of the instrument, has one Residual Current Breaker (RCD) and an Overcurrent Breaker (OC).
All the breakers have an auxiliary contact that is chained and fed to the SELCO alarm annunciator placed in the IMC. If an overvoltage, overtemperature or overcurrent occurs in any of the cabinets, the SELCO alarm annunciator in the IMC reveals them.
The electrical parts are placed in a dedicated panel (see Figure 6) usually mounted on the top of each cabinet. They include a mains EMC RFI filter and surge protection.

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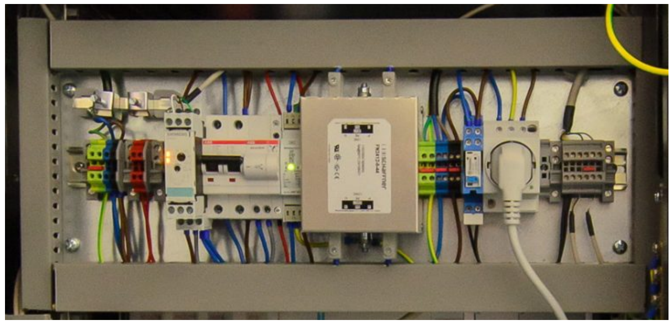

Figure 6 Electrical components in the FEU cabinets

4.2 First integration phase

FEU case

After having assembled the FEU cabinets in Trieste, the four FEU cabinets have been transported to the INAF – Astronomical Observatory of Brera (Merate, Milano) and installed for the first integration (see Figure 7 showing the four cabinets at the integration premises).

In this place all the FEU mechanical components and mirrors have been previously mounted on the holding structure and all the optics have been aligned.

Each FEU cabinet has been positioned near the FEU arm to control and all the sensors and motors cables have been connected. A PC, installed with a proper Beckhoff network interface board, worked as temporary PLC CPU and was linked with EtherCAT cable to the first PLC subrack in the first cabinet. Sequentially all the other cabinets were linked via EtherCAT.

All the movements and the sensor readings have been tested both through the PLC interface, and the VLT SW installed in a separated machine. Having the final motors driving the correct weights allowed to adjust also the PID parameters in the TwinCAT PLC software.

The PLC software installed in the PC is the same that is installed in the CPU#1 in the IMC. This, together with the one installed in the CPU#2, includes ESO libraries for: the motor drives, the digital and analog input/output devices, ThAr and LDLS lamp control, cooling unit control, Lakeshore monitoring and ADC tracking control. To the general libraries that have been fitted to the specific functions of ESPRESSO, also a non-standard library for the interface to the NGC and shutters has been included. The software parts that have been heavily improved before assembling phase have been fully tested during integration.

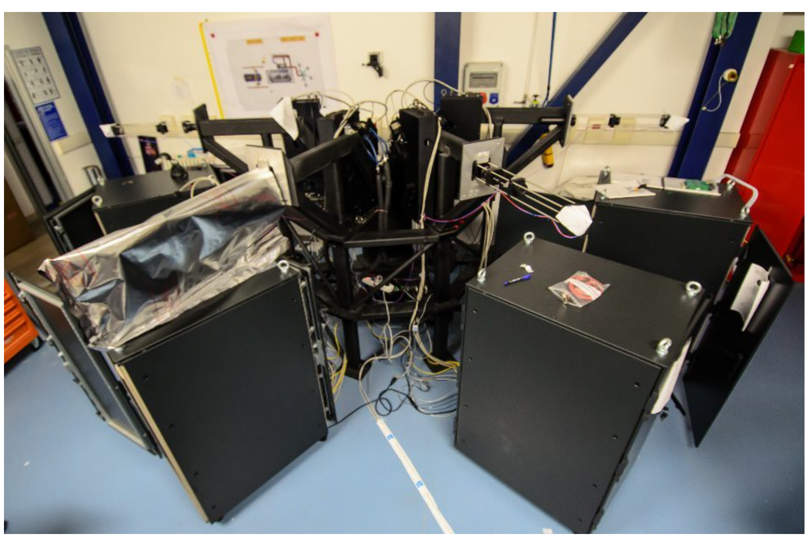

Figure 7 FEU cabinet integration in Merate

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Beckhoff TwinCAT software includes the possibility to monitor the PLC variables trend. In particular, for the motorized stages movement, the following signals are useful to be recorded:

- Actual position vs target position
- Actual velocity vs target velocity
- Current consumption

To report an example, Figure 8 shows a TwinCAT scope view with in blue the target position and in red the actual position of a filter wheel rotary stage in the FEU arm 1. Positioning precision fulfills the requirements for this function.

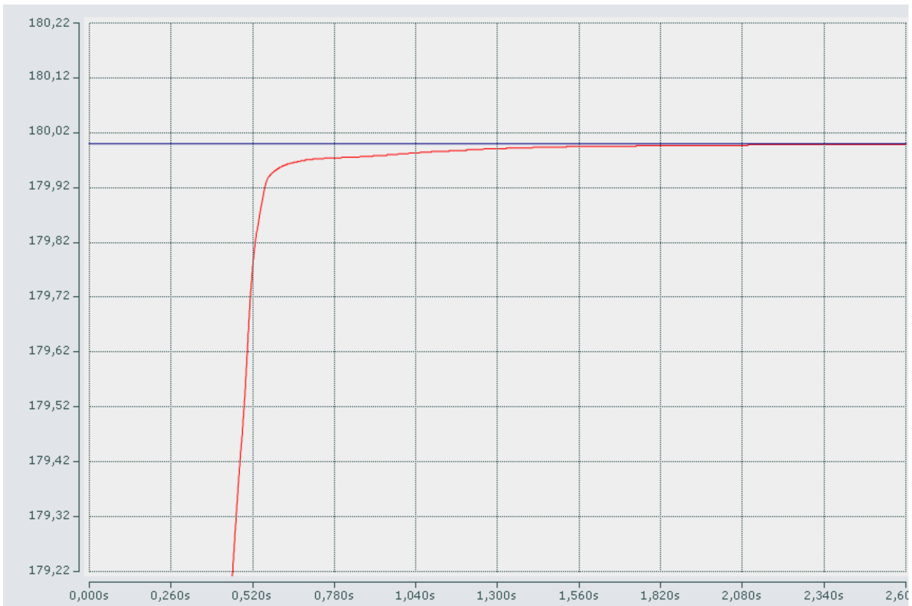

Figure 8 AFW65 Micos rotary stage, positioning detail

4.3 Later integration phase

The Europe final integration of the instrument took place at the Geneva Observatory (Switzerland). Here all the subsystems components had the first interaction all together.
Some days were required to fix the hardware connections and to perform electronics and control tests.
The electronic parts of the IMC, together with the NGC interface cabinet, CAL cabinet, TCC and VCS cabinets were tested there, with all the instrument functions available.
After their preliminary integration in Merate, also the FEU arms and cabinets were installed and tested there. In this way for the first time it was possible to set up the Beckhoff complete daisy chain and to do further system stress-tests. A successful integration of all parts in Geneva will allow the instrument to pass the ESO Preliminary Acceptance Europe (PAE).

4.4 Final integration

After the PAE everything will be sent to the ESO Paranal Observatory in Chile.
The electronic cabinets, together with all the other subsystems, will be placed at their final position and all the cables connections will be restored. The whole instrument will be integrated also with the Coudé Train infrastructures. There all the functionalities will be tested again, until ESPRESSO become ready for its first light.

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5. CONCLUSIONS

Assembly and integration phase of the Instrument Control Electronics allowed to verify that the design and project of each part of it were correct.
The assembly of the IMC, NGC interface cabinet and of the four FEU cabinets took place at the Trieste Astronomical Observatory. Once every part was well mounted and assembled, the FEU cabinets were sent to Merate and tested with the FEU arms functions. The assembling phase usually is the most laborious one, but trying to mount or build parts in series allowed to avoid errors and save time.
Then the four FEU cabinets, together with NGC and IMC cabinets, have been sent to the Geneva Astronomical Observatory for the latest integration with all the subsystems before the PAE. This is a very important phase, because only having all the subsystems together allowed to test all the hardware interconnections and the PLC software proper operations. The motorized stages in this phase were mounted with all the loads, and the PID parameters in the PLC software could be fixed in order to fulfill the motors velocity and position precision requirements.
The full testing of the functions was then necessary to guarantee the correct behavior of each subsystem once installed in Paranal, even if the corrections of some software or hardware details may also occur after the PAE.
The system at the integration phase was complete and had to be stressed as much as possible. The scope was to verify the control system responses both in well working case and in a lot of possible failure cases.
At the VLT site in Chile everything will be placed in its final position and all the cables connections will be restored. The PLCs will be reconfigured with the local IP and latest tests will be performed, waiting for the instrument first light.

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