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The automation of the "Welding Machine" for the DUs integration in the KM3NeT experiment

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Abstract

This note describes some technical aspects, in particular the control system, of one of the tools used during Process-1 of the integration of the Detection Units (DUs) in the KM3NeT experiment. In particular, the device is designed to seal the Break-out-box (BOB). The BOB is a box interface between a Digital Optical Module (DOM) and the electro-optical cable (VEOC) for power and optical connection of each optical module (DOM) to the DU.

The original manual version of the tool developed by NIKHEF was then automatized by INFN-LNS in order to guarantee a replicable operation in the recursive process of the DU integration and two samples have been developed for the integration sites at LNS and Genova respectively.

The general principle and performances of the automated welding machine will be presented shortly in a dedicated INFN report. Here we summarize the cycle of the operations performed by the machine and how they are managed by corresponding control program and related electronics boards.

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Introduction

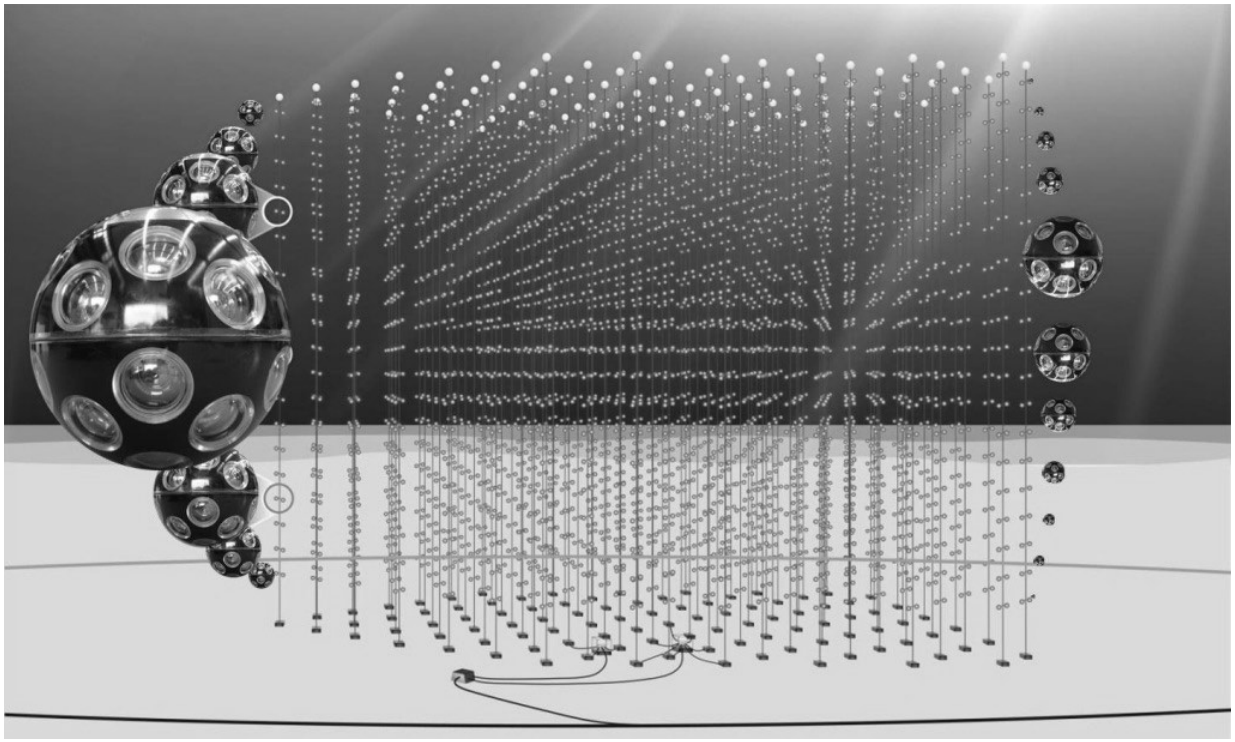

Figure 1 km3 experiment

The KM3NeT experiment (fig.1) for the detection of high energy cosmic neutrinos is being built in two sites of the Mediterranean Sea, Capo Passero in Sicily (ARCA) and Toulon in the French coast (ORCA). The full detection system includes 3 building blocks of DUs, each block of 115 DUs. Each DU accommodates 18 DOMs, is kept vertical by a top buoy and is connected to the DU base via the VEOC.
Each VEOC includes 18 breakout boxes (BOB) made in black SIMONA® PP-EL-S polymer to allow connection to the corresponding DOMs.
The integration of the 18 DOM to each VEOC is performed manually in one of the DU integration sites of the km3net collaboration.
This operation, described in detail in the Integration procedure manual on Google Drive [xx] includes the sealing of the BOBs, operation which is presently performed using a manual welding machine which heats and then keep pressed together the cap of the BOB to the open compartment of the BOB.
The automation of this process via the so called “automated welding machine” (AWM) can consequently be of great impact during the DU integration process not only with respect to time optimization but also to improve the reliability of the process.
The description of this tool will be detailed in a dedicated INFN report to appear soon.
In this note we only present the electrical layout and the control software to manage all the various steps of a full cycle to seal one BOB. This part was developed by the INFN-Genova integration team.

Chapter1 Electrical and automation parts

1.1 General layout and hardware

The general layout of our AWM is illustrated in fig.2

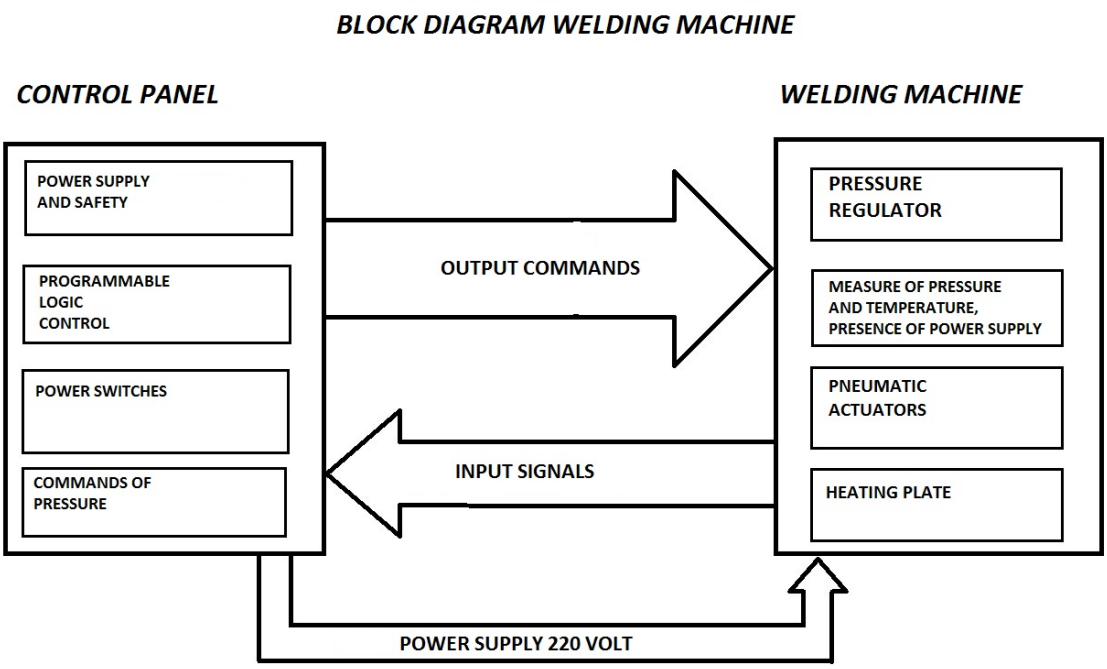

Figure 2 block diagram

The following major components can be identified:

- An electronic control panel powered by an electric cable with industrial plug
- A cable with 76 electrical pins connectors on both sides to drive the commands from the control board to the machine
- An electric cable between the control panel and for the 220V power supply
- The mechanical structure where the welding operation takes place-

This part includes:

- An aluminium frame
- A pneumatics actuator
- Various pneumatics valves
- A polywelder

In addition, some buttons like emergency, “start cycle”, “vacuum ON/OFF“ are located onboard to allow flexibility of operation during automatic cycle (fig.3 and fig.4).

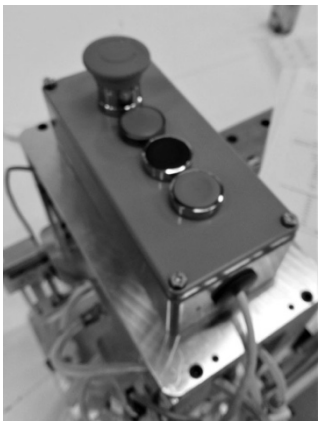

Figure 3 remote control

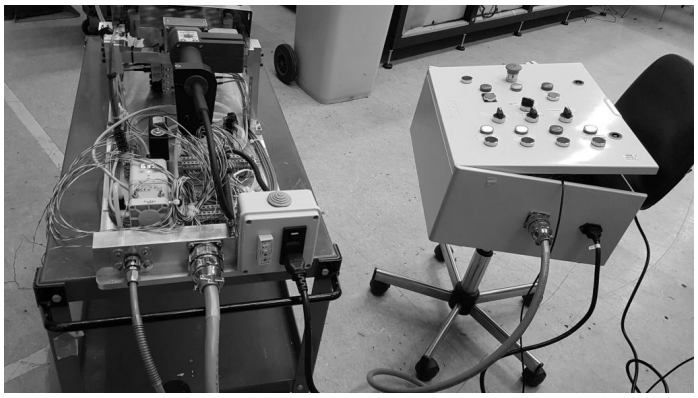

Figure 4 welding machine and control box

1.2 Electrical cabinet

The electrical cabinet is powered by a 3x2.5 cable through a standard 2P+T industrial plug (fig. 5)

Fig. 5 type CEE plug

The frontal panel of the cabinet (Fig. 6) contains all buttons, selectors and indicators required for functioning, and in particular:

- Push - Button “General Emergency”
- Button “Start Automatic cycle”
- Button “Error Reset”
- Button “Test indicator lights”
- Button “Auxiliary Power On/Off “
- Button “On/Off compressed air”
- Button “On/Off Welding plate”
- Button “On /Off Vacuum”
- Selector “Manual / Automatic”
- Selector “Cup Container Sup. Up/Down”
- Selector “Cup Container Inf. Up/Down”
- Selector “Welding plate Forward/Backward”

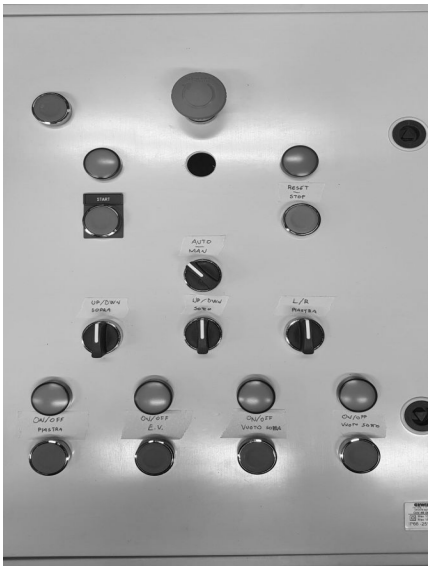

Fig. 6 control panel

The main internal components are:
The general electrical switch with fuses (Fig.7);
The main relay for alimentation of electrical cabinet;
The Plc type Schneider, Zelio Logic, 26i/o, 24V with network module lan Sr3mbuo1bd and expansion module i/o Sr3xt141bb (Fig.8);
The power Supply 220Vac/24Vcc (fig.7);
The Interface Relay type Omron;
The analogue driving board for the pneumatic circuit pressure;
The interface terminal block.

Figure 7 Power supply Unit **Figure 8 Programmable Logic Control**

1.3 Project wiring diagrams

A hardware fit for the electrical requirements of the project, has been mounted and cabled inside the cabinet. The latter can be found at the following link: https://drive.google.com/drive/u/0/folders/1FnyIS0TAWIcMb9xbG_UAjhYLRxqCY9ZJ ; folder “wiring diagrams pdf”.

An example of a wiring diagram in fig.9

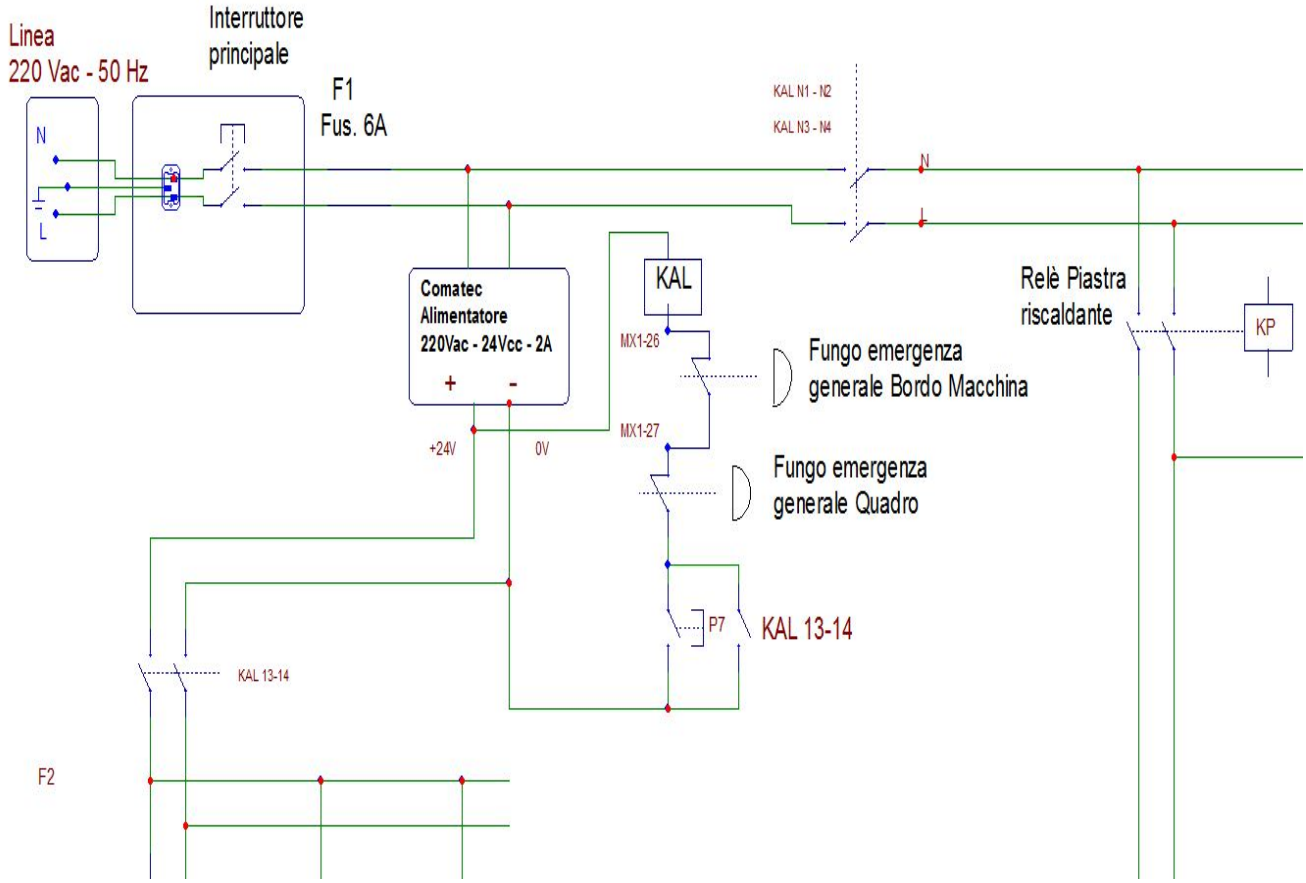

Figure 9 wiring diagram

Chapter 2 Manual and automatic cycles - Software structure

The software used with reference to the design of the machinery functioning is called SFC and contains both flowchart and literal language.
Fig. 10 descripts a sample programming.

Figure 10 screen shot of the flowchart

The Inputs/Outputs of Plc Zelio Logic used are the following:

N.20 Digital Input:

I1	Main Manual/Automatic selector position Man	
I2	Main Manual/Automatic selector position Auto	
I3	Button “Start cycle”	
I4	Button “Start/stop compressed air”	
I5	Button “Start/stop vacuum”	
I6	Micro BOB presence	FC5
I7	Micro Cap BOB	FC6
I8	Selector “Welding plate” on Forward position	
I9	Selector “Welding plate” on Backward position	
IA	Micro “Welding plate” front position	FC7
IB	Micro “Welding plate” rear position	FC8

IC	Power 220V “Welding plate” ON	
ID	Start/stop button Power 220V “Welding plate”	
IE	Selector “Cup Container Inf.” on Up position	
IF	Selector “Cup Container Inf.” on Down position	
IG	Micro “Cup Container Inf.” Up position	FC2
IH	Micro “Cup Container Inf.” Down position	FC1
IJ	Selector “Cup Container Sup.” on Up position	
IK	Selector “Cup Container Sup.” on Down position	
IL	Micro “Cup Container Sup.” Up position	FC4
IN	Micro “Cup Container Sup.” Down position	FC3
IP	Button “Error Reset”	
IQ	Button test indicator lights	
IR	Spare Input	

N.20 Digital Output

Q1	Light “Home position”	
Q2	Light “On cycle”	
Q3	Light “Error cycle”	
Q4	Solenoid valve (S.v.) Compressed air line	EV
Q5	Light “Compressed air line ON”	
Q6	S.v. Vacuum	EV4 + EV5
Q7	Light “Vacuum ON”	
Q8	S.v. “Welding plate” Forward	EV1/0
Q9	S.v. “Welding plate” Backward	EV1/1
QA	Relay Power “Welding plate” ON	
QB	Light Power “Welding plate” ON	
QC	SETUP High / Low compressed air pressure	
QD	S.v. “Cup Container Inf.” Movement Up	EV2/1
QE	S.v. “Cup Container Inf.” Movement Down	EV2/0
QF	S.v. “Cup Container Sup.” Movement Up	EV3/0
QG	S.v. “Cup Container Sup.” Movement Down	EV3/1

N.2 Analog Input/ Output

- Analog Output 0-10V / 4-20 mA for setup High pressure
- Analog Output 0-10V / 4-20 mA for setup Low pressure

2.1 Manual cycle

To manually operate, the main Manual/Automatic selector needs to be in the manual position. Using the appropriate buttons on the front panel one can activate/deactivate the power of the panel, the air pressure, the vacuum, the heating plate, the indicator light test.
With preconditions “General Power ON” and “Compressed air ON” true, with the appropriate selectors it is possible to move forward and backward the “Welding plate”; up and down the “Cup Container Inf.” and the “Cup Container Sup” .

2.2 Automatic cycle

To launch the automatic cycle with the Start Cycle button, the machine needs to be in Home Position and the apparatus meet the following requirements:
Selector on AUTO, Power On, Air Pressure On, Vacuum On, Heating plate On, for a period with t >20 minutes.
Specifically, the machine’s “Home Position” provides the following conditions:
“Welding plate” in the rear position; “Cup Container Sup. Up; “Cup Container Inf. Down; BOB Presence; Cap Presence.
The aforementioned conditions will allow the “Ready Indicator “ to ignite.
When the Ready indicator is on, the operator can initiate the automatic cycle by pushing the Start Cycle button, which will be carried out in the following way:
The “Welding plate” moves to the front position, (heating position).
The “Welding plate” is a standard tool for the butt-welding of polyethylene pipes. It reaches temperatures between 180°C - 230°C. When the “Welding plate” reaches its position, the lower and upper pistons act by pushing the BOB and the cap towards the “Welding plate”, with a 0.14 N/mm2 force as prescribed by the technical code DVS 2207 part 1, regulated by air pressure. The system then remains in such position for 60 seconds, until a bead will form in both the BOB and in the cap. At the end of bead-up time, the system, by regulating the air pressure, decreases the force applied on the BOB and on the cap down to 0.015 N/mm2, and maintains their respective positions for 60 additional seconds.
Then the pistons detach the cap and the BOB from the “Welding plate”, which returns at its parking position. Finally, the upper piston is activated to push the cap on the BOB, with a force of 0.14 N/mm2.
The system remains in this position for 300 seconds, until the complete cooling of the object.
This procedure guarantees the alignment between the BOB and the cap, full compliance with technical code DVS 2207 part 1, increased reliability, and a safer procedure than in the past.
At this step the operator can remove the welded BOB and start a new automatic cycle by simply putting on a new Cap and a new BOB in their correct position and pushing the “Start cycle button”.
This operation is facilitated by the fact that the vacuum can be turned on and off without this leading to the exit from the auto cycle.

Note: The description of the mechanical/pneumatic components and of the electronic/command/software parts are not included in this report.

2.3 Software Structure and emergency state

The software used with reference to the design of the machinery functioning is called SFC and contains both flowchart and literal language.
Essentially, the software is divided in three main partitions: manual cycle, automatic cycle and diagnostics; a few loops are always active.
The general emergency condition, as required by the norms, is not handled via the Plc software, but merely electromechanically. The action of the emergency pushbutton causes the power release of the general panel, the welding plate and all inputs and outputs.
The manual cycle partition is relatively simple in terms of structure, with inputs (buttons and selectors) that directly activate the outputs, unless such outputs are subject to prior prerequisites. For instance, the welding plate can go in heating position only if the "Cup Container Sup." is in the top position and the "Cup Container Inf." is in bottom position.".
The automatic cycle is more complex, as it is structured in flowchart style with sequential steps.
The transition from one step to the next is allowed by various conditions that have to all occur at once (and logic), this allows the program to move to the next step
When the program is stationary in a specific step all programmed actions of such step are active and in place.
Moreover, a diagnostic tool has been developed to check that a specific action/motion occurs and runs smoothly within a certain time frame. For instance, when the heating plate button is bushed backwards, the diagnostic tool checks that such position was not erroneously already employed and that it is active for the following 10 seconds. Accordingly, at every movement, the involved position sensors are checked both before and after the action.
Certain loops are always active and have been developed, among other things, to render timers such as the minimum heating plate one readily available.

Chapter3 Improvements

This version of Welding Machine is a prototype so some future improvements are possible:

- The stroke of "Cup Container Superior" system will have to be longer and adjustable

to allow for different BOB sizes.

- The the real "welding plate" temperature can be measured by a thermocouple, implemented in the software and shown with a display.
- The compressed air setup can be performed via an analog output 4-20mA or 0-10Vcc, for better precision and greater flexibility
- to improve the safety of the machine, a mobile screen may be installed in the bob area to prevent the operator from inserting his hands during the automatic

processing cycle.

Chapter4 Technical construction dossier

In this chapter the components used for the construction of the machine are described. An industrial approach has been adopted with regard to the components, to guarantee sturdiness and reliability. The RS components choice instead has been dictated by the current I.N.F.N. contract for supplies.
The used materials are divided into 3 main sections:

a- The frontal synoptic panel with manual commands
b- The inside of the electric cabinet with the remote-control switch and the programmable controller (PLC)
c- The side-machine equipment

a- The frontal synoptic panel

Code RS	Quantity	Note
330-8638	6	Button
795-1306	1	Emergency Button (mushroom)
330-8672	1	2 position rotary switch
330-8694	3	3 position rotary switch
331-0489	6	Contacts Block
330-8925	7	Indicator lights
330-8672	5	Rotary switch

Figure 11 Push button switch

b- Internal electrical cabinet

Code RS	Quantity	Note
706-1122	2	Switching Relay
861-3496	1	Auxiliary
331-0489	6	Contacts Block
891-9185	1	Power Supply 24 V
468-4371	1	Plc schneider, Zelio Logic, 26 i/o, 24 V
539-5000	1	Sr3mbuo1bd lan module
468-4293	1	Sr3xt141bb expand module i/o
482-893	1	Df fuse holder 2p 32 A
488-1831	1	Relay Omron 24 v
196-6147	1	Support for Omron

c- Materials on the Machine

Code RS	quantity	Note
789-2749	1	220 V presence sensor
682-0847	10	Sensor Position
815-723	20	DIN Rail Mounting Clamp
709-3352	2	Connector for Remote Control type 1
709-3412	2	Connector for Remote Control type 2
709-3352	100	Pin M for connectors
709-3822	100	Pin F for connectors
139-007	1	Machine Control Box
795-1315	1	Emergency Button
330-8638	2	Button for run and air pressure

fig. 12 presence sensor 220V

330-8925	1	Indicator lights
352-1825	1	Connector IEC

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