IMPLEMENTATION OF REMOTE PRIMARY ENERGETICS MANUFACTURING AT CHEMRING ENERGETICS UK LTD (CEUK)

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INTRODUCTION

CEUK, Ardeer Site is the only UK bulk manufacturer of primary energetic materials and primary energetic articles. The company inventory currently includes 15 materials generally manufactured by a precipitation process known as double decomposition, with yields varying between 900-3500gm and seven materials processed by blending, with yields varying between 50-260gm. The materials tend to be based on toxic heavy metals and are by nature very sensitive to shock, friction and electrostatic discharge. The introduction of the current industry Approved Code of Practice, the Manufacture and Storage of Explosive Regulations 2005 (MSER), has encouraged a business and legislative drive to improve safety standards. The introduction of new technologies, offering automated procedures and practices, has been identified as a means of achieving risks which are as low as reasonably practicable (ALARP) for operator exposure to the explosive hazards and accumulative toxic effects of primary energetic materials produced at the CEUK, Ardeer Site.

DD1: BACKGROUND

The range of primary energetic materials produced at the CEUK, Ardeer Site includes:

- Lead styphnate
- Lead azide
- Silver azide
- Barium styphnate
- Tetrazene
- Lead 2,4-dinitroresorcinate
- Lead mononitroresorcinate

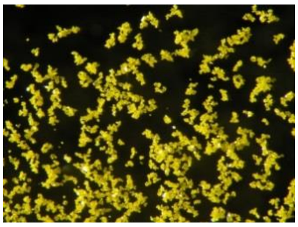

Figure 1: Lead Styphnate

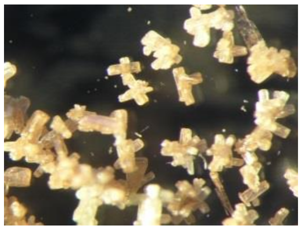

Figure 2: Silver Azide

These products are manufactured in the existing facility at Building DD1, a building with a deteriorating infrastructure, housing dated equipment and using 20th century manufacturing technologies. The procedures involve regular manual intervention during sieving, drying and dispensing of the various materials. The exposure of operators to bulk quantities of primary energetics, when conducting these processes, has been highlighted as the most significant health and safety risk within the site. Achieving the necessary safety improvements within the existing facility was deemed to be impractical and inappropriate due to the building layout and compliance with blast modelling calculations. Funding for a replacement facility was approved solely on the basis of safety, and a £3m capital investment has resulted in the design, development and commissioning of the Primary Composite Remote Manufacturing Facility (PCRMF) at Building DD6, CEUK Ardeer Site.

DD6: BACKGROUND

The PCRMF is a bespoke, purpose built facility with four cells designed to withstand a detonative event of 2000gm TNT equivalent. It provides fully automated procedures that separate operators from all processes involving bulk primary energetic materials. In line with the blast modelling, the scale of manufacture at precipitation has been standardised to provide a theoretical maximum yield of 2000gm, while blending has been limited to 105gm. The Human Machine Interface (HMI) is through a CX Supervisor mini Supervisory Control and Data Acquisition (SCADA) system, located in the control room. The operator is responsible for selecting the required recipe or process and an Omron Programmable Logic Controller (PLC) provides the plant or equipment control and sequencing, through digital and analogue signals, to complete the selected processes. The facility is divided into five distinct areas; Room 1-2 covering solution preparation, Cell 1 precipitation and processing, Cell 2 storage, Cell 3 and Cell 4 storage and blending, with dispensing and sampling unique to Cell 4. Nine CCTV cameras, with digital recording, provide opportunities for remote step-on decisions, remote intervention and remote visual confirmation of Cell 1 to Cell 4 status, prior to opening and entry to any cell. The facility includes support areas, such as quality control laboratories, chemical and solvent storage, small scale ingredient processing, etc.

The Omron PLC is of the CJ2H range of programmable logic controllers. The PLC controls the plant equipment via digital and analogue signals.

All four cells are equipped with an ATEX rated Staubli Robot manipulator, with automatic air purging systems. The robot manipulator has the ability to select the necessary tooling from the tool change stations, within the cells, appropriate to the type or size of processing and storage containers. Each robot manipulator and Schunk tooling gripper is controlled by a Staubli CS8C stand-alone six axis motion controller and the tool change stations by the Omron PLC. The robot controller contains the pre-written motion command software that drives the robot manipulator to the required position. The command is provided over the Ethernet using Modbus protocol, in the form of a motion code number, which when received by the robot controller is echoed back to the Omron PLC, for verification, before executing the move. Movement is currently restricted to 10% of the robot maximum operational speed.

The PCRMF eliminates any requirement for manual operator intervention or exposure to bulk primary energetic materials during precipitation, processing, dispensing or blending.
The net explosive quantity dispensed from Cell 4 will be 7gm, a weight modelled for primary energetic materials, combining an acceptable risk to the operator with production practicality.

SOLUTION PREPARATION: DD6 ROOM 1-2

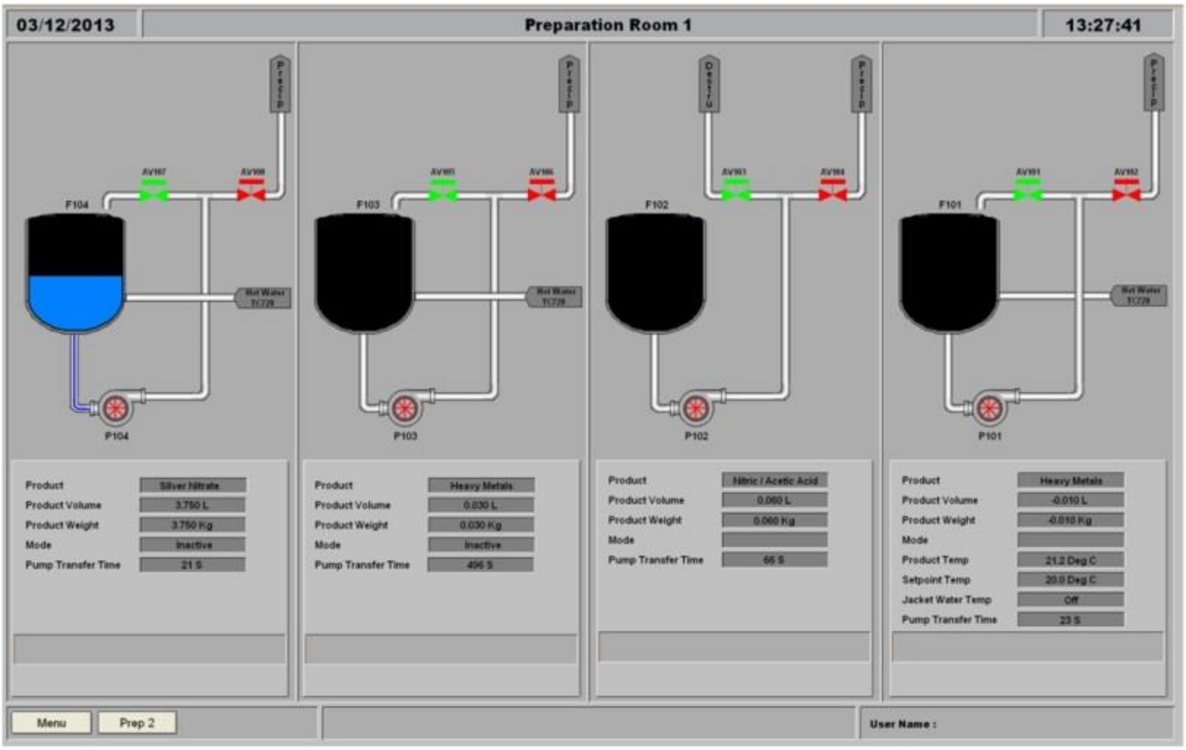

Figure 3: SCADA Schematic of Solution Preparation Room 1

The solution preparation area is divided into two zones, ensuring that incompatible materials or reactants can only be combined in the precipitation vessel in Cell 1, with spillage protection provided by stainless steel bunding trays and a 25 litre enclosed sump in each room. The solution vessels are designed to the appropriate volumes, ranging from 5-30 litres, stirred using an air motor and, where required, are heated by a Thermal Control Unit (TCU) to aid dissolution of reactants. The solution vessels are mounted on load cells which, with known specific gravities, allow the solutions to be prepared or converted as volumes and permits monitoring of the delivery rate from the recipe driven, pre-set displacement stroke on the Bran+Luebbe pumps.

Figure 4: Room 1 Solution Preparation

The precipitation process involves the controlled addition of solutions to the precipitation vessel and the formation of the respective primary energetic material as a crystalline solid. The selection of that product through the HMI and SCADA generates a DD6 Manufacturing Record Sheet, detailing solution vessels along with the materials and quantities required in the preparation of solutions. The weighing, addition and transfer of all ingredients to the solution vessels is a manual process, with SCADA prompts to ensure correct order of procedures and the PLC determining when temperature and stirring parameters have been achieved. Once the preparation of all solutions is complete, quality checked and confirmed, the automated valves and vessel pump await the PLC signal to commence transfer of the solutions to the precipitation vessel.

PRECIPITATION: DD6 CELL 1

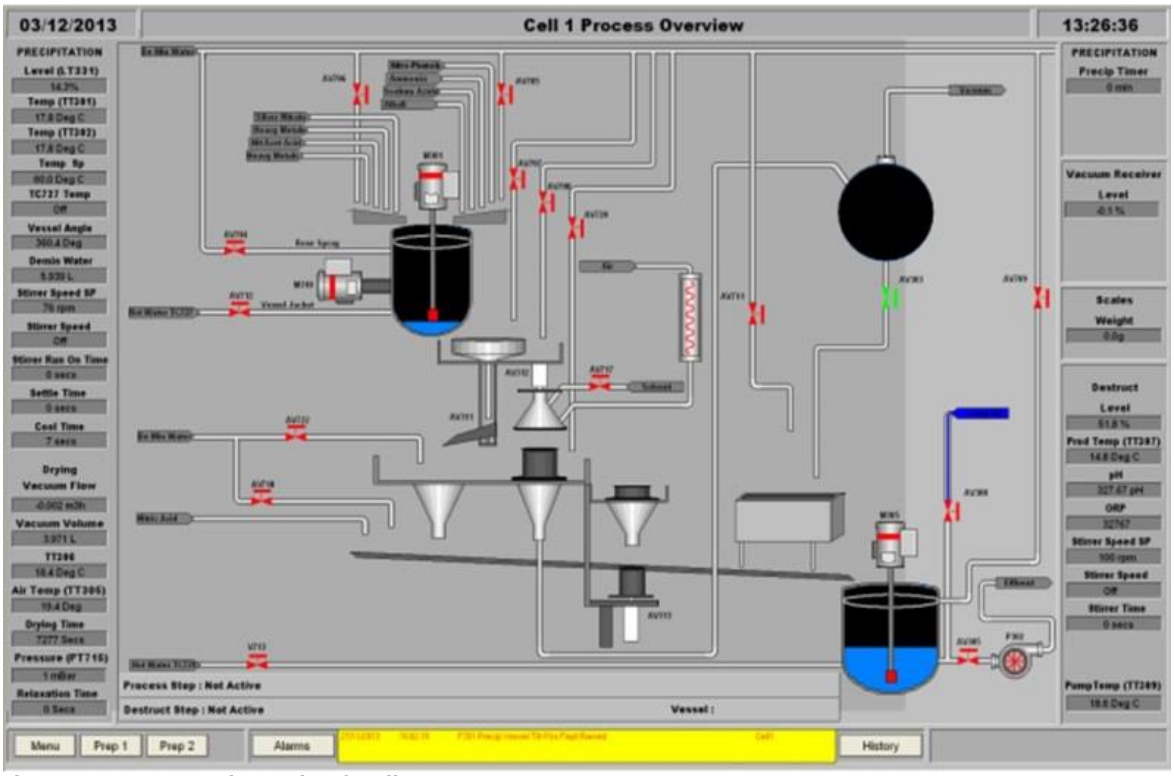

Figure 5: SCADA Schematic of Cell 1

Figure 6: Cell 1 Precipitation Vessel

The appropriate DD6 manufacturing record sheet generated at solution preparation applies to the precipitation stage, requiring a series of confirmations for critical tasks, such as positioning of storage pots, filter pots and sieve mountings, cleanliness of solution delivery pipes, precipitation vessel and destruct vessel and correct operation of extraction systems. The manufacture of primary energetic materials within Cell 1 is entirely remote, with no opportunity for manual intervention and is carried out in a stainless steel jacketed 60 litre precipitation vessel, with heating and cooling provided by a TCU. The precipitation vessel is PLC monitored for volume, temperature, stirrer speed and reaction times, with alarms and trips linked to critical conditions.

Acknowledging the control room SCADA prompt to close Cell 1 door commences the precipitation process, with the rate of solution delivery being monitored by the operator and sequence of solution delivery being governed by the PLC and the selected recipe. The SCADA provides a real-time display of delivery rates for the solutions, temperature of the precipitation vessel contents, stirrer speed and the volume of reactants. The load cells detect the completion of delivery of the relevant solution and the PLC moves the process forward until all solutions have been dispensed. The appropriate reaction time is allowed and if required the precipitation vessel can be cooled and any settling time observed. The washing and dispensing procedures are conducted through the SCADA prompts, with the 97° tipping and retraction of the vessel managed from within the control room and observed through either of the two mounted CCTV cameras in Cell 1. All washings at this stage are gravity fed to a chemically prepared destruct vessel.

The solid crystalline product is directed by water jets to a filter pot, where further washings with deionised water or solvents are conducted under vacuum extraction, with all surplus liquid being collected by the vacuum receiver prior to release into the destruct vessel. The drying head is remotely lowered and warm air, under vacuum is drawn through the material to remove all traces of deionised water and/or solvent. The drying duration and air temperature above the material, and air having passed through the material, is monitored throughout, giving a signature temperature/time profile that provides confirmation of adequate drying for the material. In order to mitigate concerns in electrostatic charging, the SCADA also displays the rate of flow of air through the material, the total volume of air through the material and the system vacuum level in mBar, ensuring that these values don't exceed the recommended drying process parameters.

With confirmation that the drying process is complete, the PLC raises the drying head and the robot manipulator in Cell 1 collects the filter pot from drying station and positions over the sieving station. A rotational vibrator operates against the sieve housing to encourage movement of the powder through the sieve mesh and the SCADA prompts the operator to incrementally step on the tipping of the filter pot contents into the sieve, until all powder has passed in to the 2kg storage pot below the sieve station. The PLC has a 30 minute relaxation time imposed, prior to moving either the sieve or the 2kg storage pot, to ensure that any build-up of electrostatic charge has dissipated. The filter pot and sieve, respectively, are positioned by the robot at the decontamination vessel and washed with water jets before inspection via CCTV, and finally placing on the lay down area. The 2kg pot is collected by the robot, the yield is confirmed using the Cell 1 scales and recorded on the PLC before lidding the 2kg pot and placing in the transfer hatch between Cell 1 and Cell 2.

All bulk material at this stage has been removed from Cell 1. The SCADA prompts for the decontamination process, commencing with the solution preparation vessels, the solution supply lines and purging using water jets to work down through the precipitation process to ensure all contaminants have been washed to the destruct vessel. Options exist to visually confirm that the decontamination process is acceptable, prior to the PLC commencing the destruct process with the addition of the appropriate chemical/s from their respective solution vessels.

The precipitation process washings, waste liqours and products are collected in the destruct vessel, prior to chemical destruction. The destruct process is monitored for the addition of solutions, the duration of the reaction and both the pH and oxidation-reduction potential.On completion the vessel contents are analysed and if acceptable contamination levels are achieved, the solution is transferred to the effluent plant. The treatment of the destruct solution through pH adjustment and polymer flocculants, prior to release, significantly reduces the discharge of heavy metal contaminated waste.

MAGAZINE STORAGE: DD6 CELL 2

Figure 7: Cell 2 Magazine and Staubli Robot

The design of the 2kg magazines, applicable to Cell 2 and Cell 3, is based on a solid cast, then machined stainless steel chamber with a pneumatically operated steel door. Blast modelling predicts the design withstanding a 2kg TNT equivalent event, with no sympathetic reaction to product, either in transit or in storage. The storage area of Cell 2 has six 2kg magazines, with the robot manipulator providing the movement to and from the Cell 2 magazines or through the transfer hatches to Cell 1 and Cell 3.
The PLC determines and stores the weight, identity and status of the product within Cell 2, Cell 3 and Cell 4 magazines, with five status options:

- Quarantine
- Awaiting results
- Passed
- Rejected
- Requires re-sieve

MAGAZINE STORAGE AND BLENDING: DD6 CELL 3

The storage area of Cell 3 has six 2kg magazines, with the robot manipulator providing the movement to and from Cell 3 magazines or through the transfer hatches to Cell 2 and Cell 4. Cell 3 handles 2kg and 100gm storage pots. Product stored in 2kg pots is remotely dispensed and weighed into 100gm pots in Cell 3, then transferred to Cell 4 for storage, sample dispensing or blending. The weigh scales in Cell 3 and Cell 4 are managed by their respective robot controller, via the ethernet, allowing closed-loop control of pouring operations to take place with accuracies of ±50mgms.

The blending of primary energetic material can be conducted both in Cell 3 or Cell 4. The selection of the product through the HMI and SCADA generates a DD6 Manufacturing Record Sheet, detailing ingredients and quantities required in the jelly mould mixing of blend. The weighing, addition and transfer of all inert ingredients to the jelly mould mixer is a manual process, and acknowledging the control room SCADA prompt to close Cell 3 door commences the automated cycle of the robotic selection, weighing and dispensing of the primary energetic material/s. The PLC controls the addition sequence, the blending duration and the dispensing to a 100gm storage pot. On completion of blending the product is transferred to Cell 4 for storage or sample dispensing.

MAGAZINE STORAGE, BLENDING AND DISPENSING: DD6 CELL 4

The design of the 100gm magazines, applicable only to Cell 4, is also based on a solid cast, then machined stainless steel chamber with a pneumatically operated steel door. Blast modelling predicts the design withstanding a 100gm TNT equivalent event, with no sympathetic reaction to product either in transit or in storage.


Figure 8: Cell 4 Blending (Jelly Mould Mixer)

The storage area of Cell 4 has ten 100gm magazines, with the robot manipulator providing the movement to and from Cell 4 magazines or through the transfer hatches to analytical, production or Cell 3. Cell 4 robotically handles 100gm and 7gm storage pots.

Product stored in 100gm pots is remotely dispensed and weighed into 7gm pots in Cell 4, then transferred for analysis or production, with selection of product and quantity being determined by HMI input to the SCADA. Product can be dispensed as single samples for assessment by analysis or article proof testing, or dispensed up to a maximum of ten 7gm samples as a production 'campaign'.

The blending of primary energetic material can be conducted in Cell 4, with the detail as discussed in Cell 3 above.

HMI, SCADA, PLC AND SAFETY CONTROLLER: DD6 CONTROL ROOM

The interface at the HMI-SCADA and PLC has been kept to a minimal level of layering, with the majority of activities accessed and started at two levels or less. The displays are simple, clear and intuitive, keeping commitment to training at a minimum requirement.

Significant activities available on the SCADA, outside the precipitation, destruct, blending and dispensing, include the capability to:

- Operate modular remote recovery sequences
- Transfer destruct liquors to the effluent treatment facility
- Assess magazine contents in compliance with Control of Explosives Regulations
- Re-sieve product
- Re-mix blended product
- Access and operate valves, switches, motors, etc, for maintenance and/or recovery

It is impractical to identify and list all the safety checks and interlocks associated with the range of programmes and their activities, but the principal function of the modular Omron Safety Controller is the operation of safety output devices the monitoring of emergency stop buttons, door switches, etc. The storage and transfer hatches within the cells are checked for open or closed position using four reed switches, two for open and two for closed, with each pair working as a dual-channel redundant circuit. The access doors to the cells are checked for the closed position by a pair of non-contact safety switches, while the pneumatically activated door shot pins have engaged sensors, which are monitored in pairs by the safety controller. The closed signal confirmation can only be given when the reed switches, contact switches and shot-pins are all made, ensuring that when bulk product is in process or transit, the relevant magazines, cell doors or transfer hatches remain closed.

In order to comply with the requirements of the machinery directive to protect personnel from motion hazards, the safety controller commands the robot manipulator emergency stop function, ensuring that whenever the respective cell access door is open the robot manipulator arm power is disabled. The safety controller also prevents other moving parts, such as vessel tipping, vessel stirring, lift tables, etc, from operating with the relevant cell door open.

BREAKDOWN AND RECOVERY: DD6 HAZARD STUDY

The conduct of a detailed hazard study questioned the design of the facility and the opportunity for remote intervention in the event of electrical, mechanical or other failures. Where appropriate the hazard study findings, along with resultant actions, have been applied to the design of the facilty and the software programming.

At any stage in the precipitation, should there be processing concerns, it is possible to carry out a chemical destruction within the vessel or discharge the reactants to destruct and complete the chemical destruction within this 300litre vessel. All valves, heaters, stirrers and pumps are operable through a supervisor controlled manual screen, allowing the remote addition of destruct solutions or the use of deionised water valves for flushing or washing purposes.

The Cell 1 product handling processes of filtering, sieving and weighing can be aborted and product remotely tipped by the robot manipulator, either into the 2kg storage pot for subsequent processing or transferred directly to destruct. The decontamination vessel is used to wash and flush traces or greater quantities of primary energetics into the destruct vessel, with the capability to visually monitor the containers contamination level on the CCTV before transfer to the laydown area. Any destruct sequence can be conducted at this stage, by supervisory control of the SCADA for reagent addition from the solution preparation vessels, stirring and TCU heating. This ensures complete chemical destruction, confirmed by analysis, prior to transfer and effluent treatment.

Any product that is analytically non-compliant, through purity, particle size or contamination can be remotely returned, from Cell 2, Cell 3 and Cell 4 through the selection of a programmed destruction sequence and chemically destroyed in Cell 1. The destruction sequences also provide the option, at 100gm level only, to remotely desensitise by addition to oil, before transportation for burning.

The programming of modular remote sequences ensures that a recovery option is available at any point within a movement or process, allowing the robot manipulator to be automatically returned to its original home position through the selection of one or more sequences. Only the selection of compatible sequences is permitted by the PLC and SCADA programming.

TIMELINE

- Design and HAZOP commenced June 2009
- Commencement of civil works January 2010
- Inert commissioning of plant October 2011
- SCADA and PLC programming commenced March 2012
- First live precipitation March 2013

'TAKE HOME MESSAGES'

- Are your personnel exposed to significant hazards from energetic materials?
- With the benefits of PLC driven remote operation, do your processes have risks to personnel that can be considered to be ALARP
- Can automation remove your personnel from the immediate hazards posed from energetic materials?
- Automated methods or robotics, don't need to be prohibitively expensive and can be replaced or repaired
- Robots don't have dependants!

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