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Retrofit concept for small safety related stationary machines

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Abstract. More and more old machines have the problem that their control electronics' lifecycle comes to its intended end of life, whilst the mechanics itself and process capability is still in very good condition. This article shows an example of a reactive ion etcher originally built in 1988, which was refitted with a new control concept. The original control unit was repaired several times based on manufacturer's obsolescence management. At start of the retrofit project the integrated circuits were no longer available for further repair of the original control unit. Safety, repeatability and stability of the process were greatly improved.

1. Introduction

Retrofitting is especially interesting for companies who want to keep their old machines for backup purposes or for production of small quantities at today's quality standards.

This raises interest equipping old machines with new controllers, refitting to up-to-date safety regulations and, regarding modern industry concepts, to add connectivity and remote supervision functions. The considered equipment was a reactive ion etcher model 1540-S RIE/PE from VacuTec AB. At the time of the retrofit the machine played a central role in the production process working in three shifts at sixteen hours machine operation time per day. Manual operation was necessary, since the old control did not support automated processing, what was required in this special case. Small interferences on almost any electric line caused an immediate shutdown without logging process parameters and product data of processed material. Finding the failure without knowing the cause of the shutdown was a difficult task. Documentation of the processes was done manually and the set points for the processing media (different gas flows) and vacuum pressure were done by ten-turn adjustable potentiometers. Today's safety needs were missed (e.g. starting pump down at open process chamber might damage the pump). As the machine was operated manually [1] an operator had to survey the machine at all times.

2. Goals of the retrofit

Three top priority goals of the retrofit were identified: First to meet the up-to-date needs of safety regulations.

Second to improve reproducibility and accuracy of the processes.

And third to save operator time by automating the processes as far as possible. Another intended benefit was to stay independent of certain component manufacturers and allow the exchange of components independent of a specific supplier.

3. Working principle of the machine

Reactive ion etching (RIE) is used as a method to chemical and mechanical etch the surface of a masked material. Adequate gases like SF_6, CHF_3 and O_2 are set in a state of high frequency plasma at low pressure.

A DC-offset voltage accelerates free radicals out of the plasma. Now two different processes happen in parallel:

Firstly the chemical etching process: accelerated radicals impinging the surface of the substrate intended to be etched, react chemically with surface parts and the gaseous reaction products (usually fluorine compounds, sulfuric compounds and oxidized photoresist molecules) are pumped out of the process chamber.

Secondly the mechanical etching process: some of the accelerated ions are less reactive, e.g. carbon or argon. These ions crash into the surface and sputter out small parts of the surface.

Due to incomplete reactions the gases pumped out are noxious.

4. Analysing the machine structure and primary conclusions

The lack of accurate documentation and the fact that many undocumented changes to the machine were done by the owner made it necessary to analyze the complete technological structure and measure the connections of each single wire. As a result an accurate wiring diagram and a set of structural representations of the machine were determined:

- The vacuum system consisting of the process chamber, Valves and two pumps in line, a pressure controller and control valve
- The high frequency system consisting of Electrodes in the process chamber, wiring, a matching network and a Radio Frequency (RF) generator,
- The gas inlet control system consisting of several valves and mass flow controllers,
- A set of sensors consisting of Vacuum gauges, control component feedback signals, set point generators and actual flow feedback from the mass flow controllers.
- Some signal changing components, e.g. magnetic valves to control the pressurized air operated gas flow on-off valve and larger vacuum valves as well as voltage to frequency converters to read back the actual value input.
- The safety circuits, including a main relay, cooling water flow-switches, emergency-power-off button, relay logic.
- The (original) CPU-500 control unit.
- Power supplies

The analysis showed that several components are likely often to be replaced by spare parts of different manufacturers, like the turbo pump and its controller, or the pressure controller. Other components are, in this case, technologically obsolete. E.g. the voltage-frequency converters. Some components have already been replaced by newer and more accurate models, like the mass-flow controllers.

5. Safety analysis

Regarding the components of the machine, the process itself, and the handling of the machine by the operator, the main risks were identified and the according measures were derived.

The main risks are:

- Contact of the operator with reaction products
- Contact with high frequency/voltage at the electrodes
- Rotating masses getting out of control (turbo pump)
- Getting body parts crushed in the lid-mechanism of the chamber

An analysis according to IEC 61508 [2], [3] came to the result that Safety Integrity Level (SIL) 2 is required to keep the rotating masses under control and SIL1 is required for the other main hazards.

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6. Things we considered about standard PLCs in Retrofit constellation

Standard programmable logic controllers used in retrofits, have certain intrinsic risks:

Adding input/output modules can rapidly become very expensive and bears the same risk of "getting outdated" as the original controller. When the version of a PLC changes, software can be hard to be "re-used". When machine components wear out and are replaced, often new communication standards are required and PLCs need new or additional communication modules.

Procurement is often time-consuming and when PLCs get older, these modules are no longer available which may end up in an unexpected early next retrofit.

The Cycle-time of standard PLC does not necessarily meet the reaction times required for certain processes.

7. Conceptual approach

The concept is based on five main ideas:

- Stacking of three medium sized mobile electronic control units (ECUs) with safety capabilities interconnected safely by CAN-Bus and signaling lines.
- Parameterization by a standard-PC via CAN-Bus.
- To ensure that the PC does not lock up the processes the control routines run entirely on the control units.
- Running the safety-critical considered software-functions completely on the individual controls, independent of the other control units and independent of the PC ensures that at least two of the three controllers shut down safely if one controller fails. In case of a more important failure, the hardware-logic will shut down the failed controlling unit safely.
- Programming the Control units in "C", using the provided multitasking environment of the manufacturer allows short reaction times in the range of 1-6 milliseconds [4].

This concept is shown in Figure 1. The black arrows indicate the CAN-Bus.

To allow PC-independent process step control, a direct communication between the control units via CAN bus, indicated by the green arrows is realized.

Black and green colored lines show functionality. Both are realized on the same single physical CAN bus.

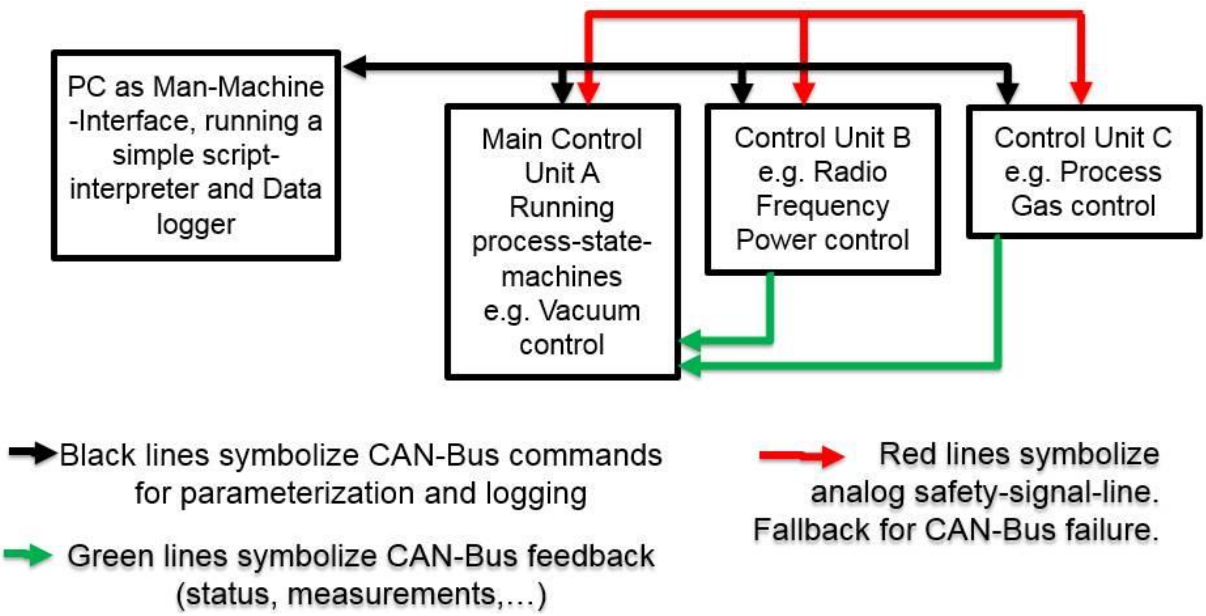

Figure 1. Communication architecture of the new control design

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According to ISO 13849 [5] a second path as a very simple fall back communication was implemented, indicated by the red lines in Figure 1. Any of the three control units can pull this signal low to indicate a detected fault state. This results in a controlled shutdown of the other two controllers. Non-answering to a CAN-Bus command within a timeout is also detected as malfunctioning and triggers this mechanism.

While the CAN-Bus is operating in normal mode, all expected and unexpected events will be logged. In case of a failure the process engineers will have a chance to find out the reasons that led to a shutdown or process interruption.

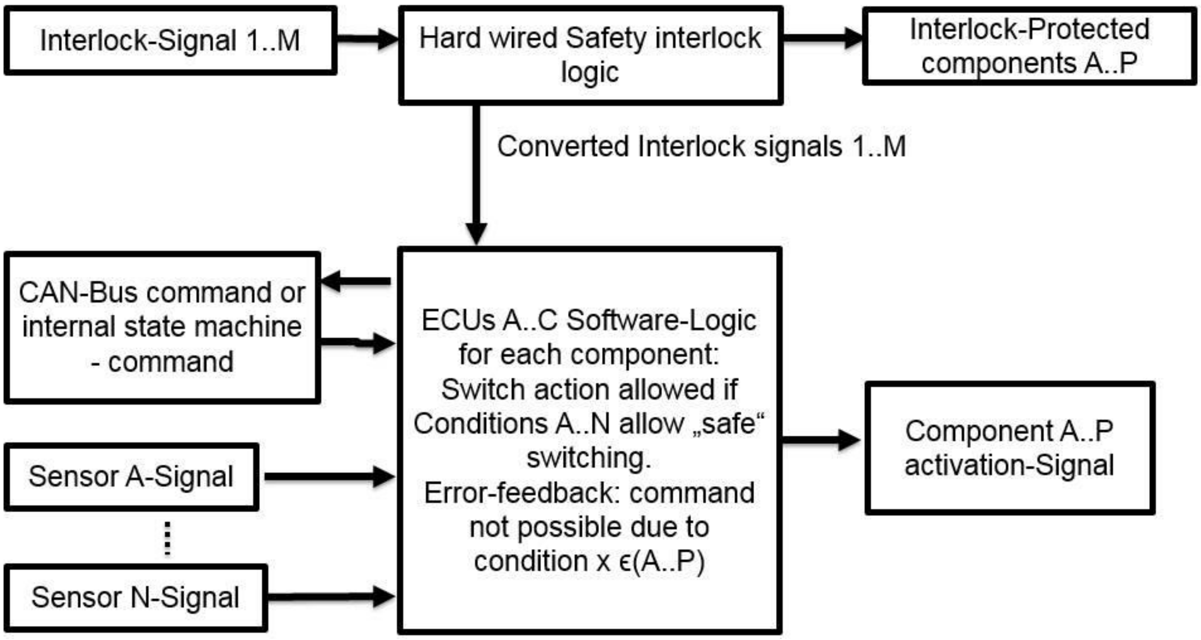

Figure 2. Safety mechanisms by design

To avoid the machine getting into hazardous states, before each switching action certain checks are performed as shown in the lower part of Figure 2.

Figure 3. Machine before retrofit

Figure 4. Machine after retrofit

8. Conclusions

- It is possible to successfully use Electronic Control Units of the type “ESX 2, by STW” that were built and intended for use in 16-32V mobile machine environments, as well as in stationary machines. All three controllers and their power supply fit into a standard nineteen inch rack case, as shown in the upper left corner of the machine in Figure 4. For comparison the machine before the retrofit is shown in Figure 3.
- It is possible to implement safety relevant control functions with Electronic Control Units independently of their intended usage.
- In this case it was possible to achieve the required levels of safety without the need of safety-software or safety control units. The safety paths for critical signals are provided in hardware logic.
- The much more rugged construction of mobile controls performs a lot better in harsh electromagnetic interference (EMI) environments than the original industrial standard control.
- The “worst case” considered crash happened unexpectedly after the retrofit. Nobody was injured, the machine had no further damage. The safety concept has been proven to be successful.
- Reproducibility and accuracy of the processes were greatly improved. Failure rates of the processes are almost zero, as long as the operator starts the correct process.
- Operator time is greatly saved. Once started, the machine runs a process fully automated.

9. Outlook

The machine is in operation since its retrofit without serious failures. No further developments concerning the retrofit or safety, are planned yet.

References

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