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I&C accelerated aging and I&C re-engineering

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I&C accelerated aging and I&C re-engineering

- Introduction
  - Delivery times in safety related nuclear I&C are very long and replacing a whole I&C system or even just field devices can take up to many years.
    - It is important to know the condition and spare part status for each installed I&C system and field devices at the plant so that needed actions (e.g. repair, replace or renewing tasks) can be started on time.
  - This presentation discusses I&C accelerated aging project and I&C re-engineering studies that have been carried out in Fortum.
- Agenda
  - Accelerated aging project inside Fortum
  - I&C re-engineering studies inside Fortum

I&C accelerated aging

Board type	Pcs
Siemens Teleperm-C M74004-A111	7
Siemens Simatic-P Z24	6
Siemens Simatic-P B22B	6
Siemens Simatic-N 71458-A527-A1	6
Siemens Transidyn TS721-V32828	7

- Idea of I&C accelerated aging is to accelerate the aging of electronics, polymers and other materials so that within months the aged I&C component would resemble as much as possible the same component in used operation environment after normal traditional aging without acceleration.
- Accelerated aging can be done for example in product development phase, in component type testing or for already aged components to gain a better view of the components' remaining life-time.
- Fortum performed accelerated aging tests for 4 different legacy Siemens I&C systems recently (Teleperm-C, Simatic-P, Simatic-N, Transidyn). Test setup consisted of 3 racks and 32 I&C boards in the racks. Racks and boards had electricity switched on during testing for selected inputs but there was no PLC logic etc. programmed to change the states of inputs and outputs. Electricity was only cut during interim measurements which were performed many times during the testing in order to know whether boards still functioned properly.
- Tested board types were selected so that they represent the most used board types at the plant. Tested boards also contain components that are used in many other boards as well.
- For the testing, worst case temperatures in the I&C cabinets were recorded and those defined the length for testing. Expected lifetime was selected to be 30 years (262800 h).

I&C accelerated aging

- Arrhenius' equation has been around for decades for accelerated aging. It is used for defining the temperature dependent fault frequency of tested components.
- $AF = \frac{t_1}{t_2} = e^{\left(\frac{Ea}{k}\right)[\frac{1}{T_1} - \frac{1}{T_2}]}$

* t_1 = lifetime expected in temperature T_1 [h]
* t_2 = test time in temperature T_2 [h]
* E_a = activation energy for aging [eV]
* k = Boltzmann's constant 8,617385 x 10^{-5} eV/K
* T_1 = normal environment temperature [K]
* T_2 = aging temperature [K]
  - Aging temperature 80 °C was used and activation energy 0.7 eV for electronics and 1.0 eV for polymers on boards (polycarbonate, polyamide, and various polyester compounds). Used activation energy depends on the materials. There is more discussion of the accelerated aging theory e.g. in IEC 62582-1, edition 1.0 2011-08. Finding correct activation energies can be hard if there are many different materials on I&C components or the materials are not well known.

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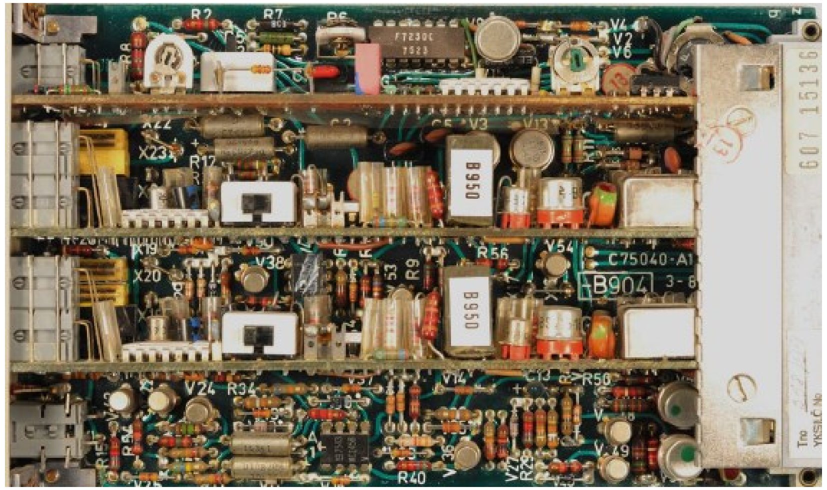
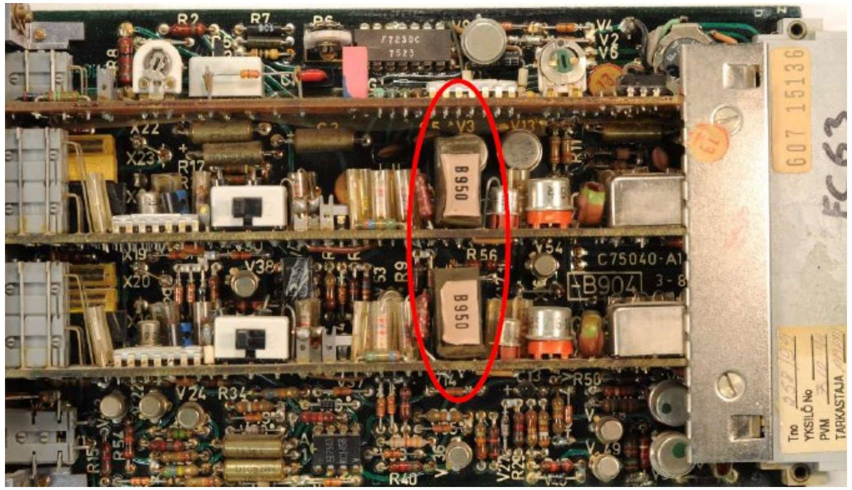
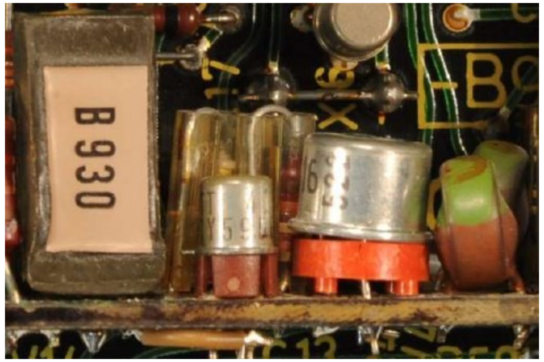
- Visual results: wiring between boards and racks aged much faster than the boards itself. Also, polymeric parts got more fragile during testing and got broken more easily when bent.
- I&C board faults: Faults occurred on Teleperm-C boards a lot more than for other board types (6/7 boards failed during the tests, transformer short-circuits, transistors in short-circuit states, broken relays, optocoupler, trimmers)
  - ReliaSoft Weibull++ software was used and calculated average life-expectancy for Teleperm-C boards at 35 °C was 19 years and 12 years at 40 °C (normal worst case environment temperatures on boards despite the room/cabinet air conditioning).
  - On the left Teleperm-C board before aging. In the middle after 9160 hours aging at °80C (simulates board at 35 ° for 30 years) we can see deformation of plastic enclosures circled in red. On the right, plastic mounting brackets seem to be very brittle after aging.







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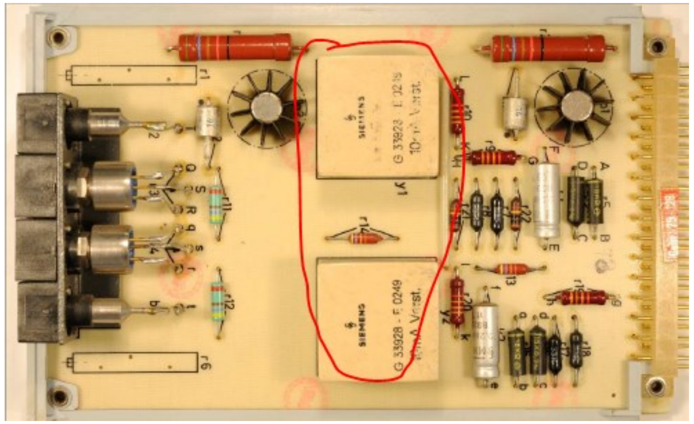
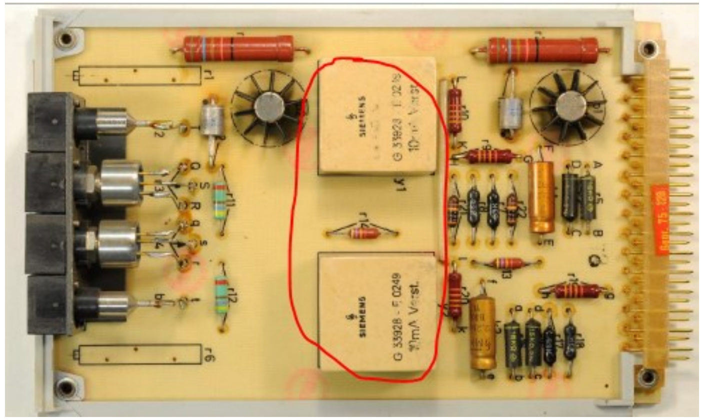
- Plastic enclosures of amplifiers got broken during testing (not visible in the photographs)
- The plastic frames of the cards were broken on some cards even before aging but after aging no additional fractures were found.
- The plastic card guides in the test racks were also partially broken even before the test. During interim tests also couple more card guides got broken.
- Support structures and connectors in test racks and circuit boards were deciphered to be polycarbonate, polyamide as well as various polyester compounds. Activation energies of these polymers in literature are generally 1.0-1.2 eV. 1.0 eV was used and aging at 80 °C for 9160 hours equals 127 years in normal 35 °C. The test racks and their plastic parts were already aged before the tests so in general polymeric parts on boards and racks withstood very well long testing time.
- But as said earlier, wiring between boards and racks aged much faster than the boards itself and softeners on conductors evaporated so that wires got very brittle.





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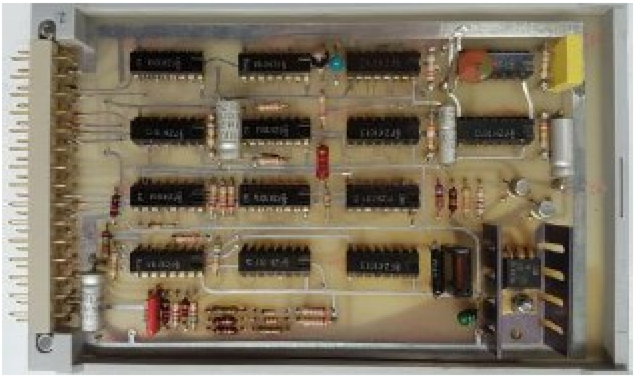
I&C re-engineering

- There are many possible strategies for the I&C re-engineering. One possibility is to re-engineer just the most critical components as spare parts. It is also possible to re-engineer whole racks or I&C cabinets at once. Intellectual Property rights need also to be checked from the OEM before the re-engineering process can be started.
- A design basis must be gathered for the I&C components selected to be re-engineered. Existing specimen, OEM documentation and user manuals, system drawings, schematics, plant operation and maintenance procedures, existing and requested environmental conditions (needed especially for the qualification) and other possible documentation helps with the requirements for the re-engineering. Re-engineering can also be started from the scratch meaning that there is no documentation available for the component to be re-engineered but only the existing specimen (reverse engineering or black box engineering).
- I&C re-engineering company needs to have a Quality Assurance Program that is approved by the regulator in order to supply safety classified components. V&V activities need also to be designed in the re-engineering project. As much as original testing procedures exist, the better. If little or none OEM documentation exists, then detailed circuit analysis is needed for determining each input and output and tolerances for those. This is of course more time consuming than in situations where the original OEM documentation exists and OEM documentation can be treated as acceptance criteria.
- A manufacturing tester machine can also be designed and built together in the re-engineering project so that manufacturing testing can be made on a factory level also for bigger batches for the products. After the re-engineering project, this new tester can also be procured for the plant's own I&C maintenance department for the repair work carried on by license holder itself.
- I&C re-engineering process for one item from the requirements to manufacturing first batch takes typically from 6-12 months. First article to be manufactured includes inspection, testing and measuring of specimen mechanical design, electrical design, test procedure development and part ordering. After first article has been finished and approved (by license holder and regulator), a re-designed I&C component batch can be manufactured according to agreed quality management programs and shipped to a customer.
- I&C re-engineering is usually the last option after other possibilities such as repairing or replacing the I&C components. The more I&C component types there are to be re-engineered the worse the solution can be economically. Based on interviews with the companies in re-engineering business, whole digital I&C system upgrade can start to be more feasible economically when amount of boards to be re-engineered exceeds 20-50 different board types.
- Main I&C re-engineering benefits are that obsolescence issues can be dealt with individually without the need to upgrade whole I&C system (e.g. when there still are enough spare parts for the other components).

I&C re-engineering

- As a sample trial, we selected couple non-safety turbine I&C boards for re-engineering. Selected boards are simple and it makes also sense to re-engineer those from the spare part view.
- Functioning of the new boards will be kept the same as the old ones including board dimensions and connectors.
- New component selection for the new boards takes some time since exactly similar components for e.g. logic circuits do not exist anymore. Long reliability for the new components is also crucial. A Finnish company for the job was selected.
- Because selected boards are non-safety, industry standards such as IEC 61508 and ISO 9001 can be used.
- Surface mounted components will mainly be used because that is a more reliable way for manufacturing with automated production lines. Anyhow, couple components need to stay as changeable and these will still be made with through stacked components.
- Work includes gathering of requirements, design of circuit diagrams, circuit board design, mechanical design for the plastic parts with 3D printing (separate molds would be used only if quantity of remanufactured boards was higher), parts list, test planning and testing and reporting of the tests. Work itself is scheduled to take ~20 weeks for the selected boards.



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