Failure analysis and lessons learned on crate and power supply equipment

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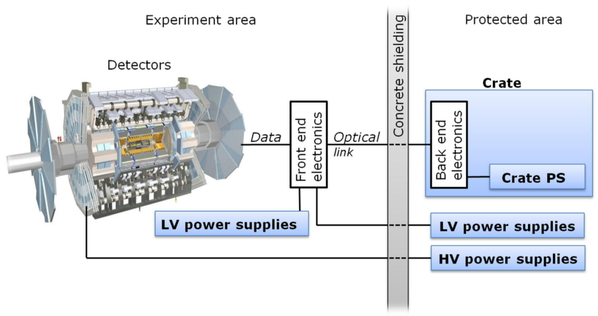
Power supply and crate service

Introduction

Large quantities of high and low DC voltage power supplies (PS) and crates are used to house and power sub-detector electronics in the LHC experiments (Atlas, CMS, Alice, LHCb, TOTEM).



Powering configuration in LHC experiments

Service activities

The PS and crate service in the EP-ESE group supports this equipment for over 20 years and manages a set of long-term maintenance and purchase contracts with the manufacturers.

- **Technical support** to CERN users .
- **Testing** on delivery and around manufacturer interventions.
- Managing the purchase and maintenance **frame contracts**.
- Logistics and maintenance **tracking**.
- **Evaluating** new equipment.
- Maintaining up to date **technical documentation**.
- **Repair** of CERN manufactured equipment.

Service facilities

- Technical **database**.
- 5 **Test benches** including 2 automated ones.
- User reception provided by the **electronics pool**.
- Two **labs** made available to manufacturers for on-site service.

Equipment supported

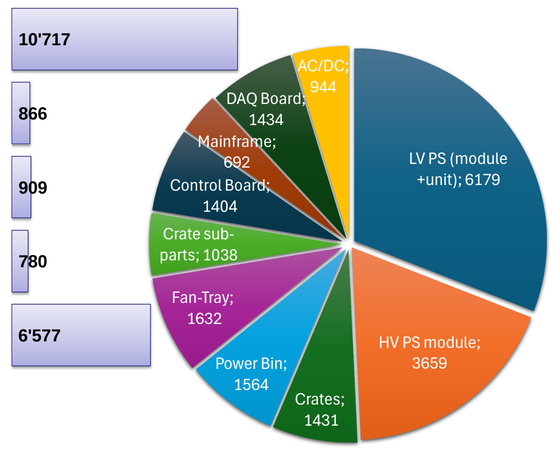
Four manufacturers and CERN provide different equipment types divided into ten main categories.

The indicated numbers are ordered quantities. The current number of items in operation is not precisely known.

Caen item quantities are estimated, as nearly half were neither purchased nor recorded centrally through the service. The estimates are based on database info, Caen sales data, and user feedback.

Key numbers

Total items	Estimated value	Avg. repairs per year	Mean time to repair	Avg. tests per year
19'849	> 50 M€	500	48 days	498



Statistical failure analysis

Abstract

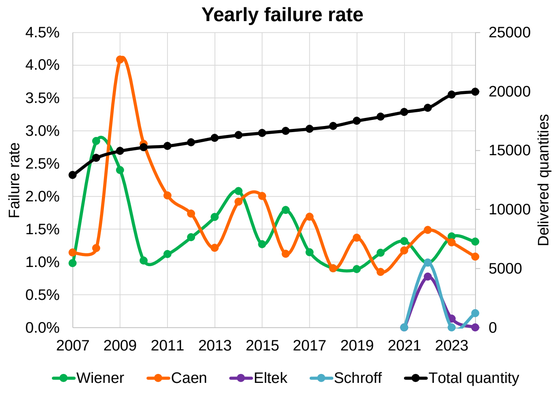
The PS and crate service monitors equipment during maintenance activities such as verification, calibration, preventive maintenance, and repairs. A technical database centrally manages all operations, recording detailed maintenance histories, analysing failure rates, identifying weak components, and tracking intervention types. Collaborations with manufacturers and users are established when needed to better understand the causes of failures and find solutions.

Failure rate analysis

The first equipment was delivered in 2002. However, the failure tracking (fault report) only started in 2007. The yearly failure rate is based on the actual failures (fault report leading to a repair) versus the delivered quantities.
CERN made equipment is subject to a dedicated section below.

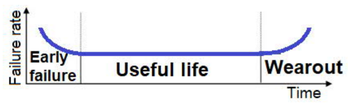
Main observations:

- Average yearly failure rate: < 2%.
- Failure rate decrease tendency, thanks to the contribution of the preventive actions carried out.
- Most Eltek and Schroff equipment bought since 2021 is in storage and will be installed during LS3.



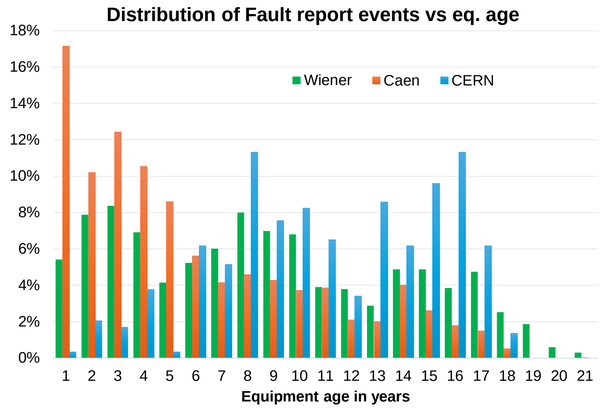
Operating time before failure

Considering the theoretical bathtub curve below, the time before failure intends to estimate the failure phase the equipment is currently in.

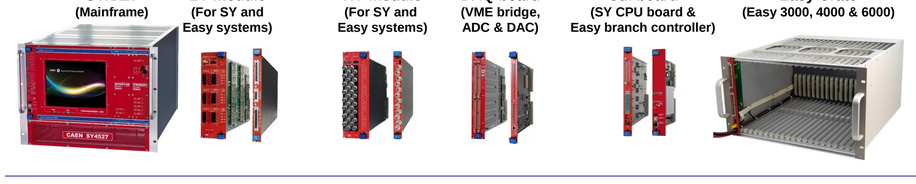


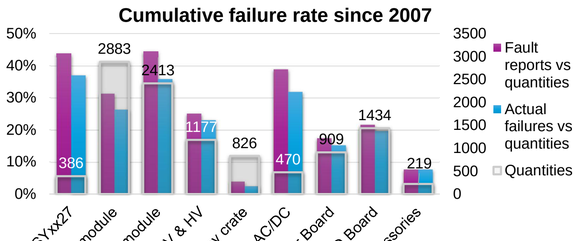
Main observations:

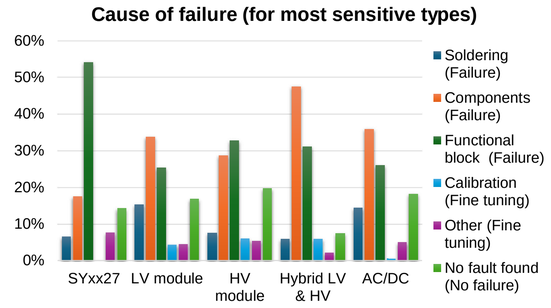
- For the CAEN equipment, the first 5 operating years could be considered as the early failure period.
- The CERN produced equipment is showing signs of aging.



Focus on CAEN equipment







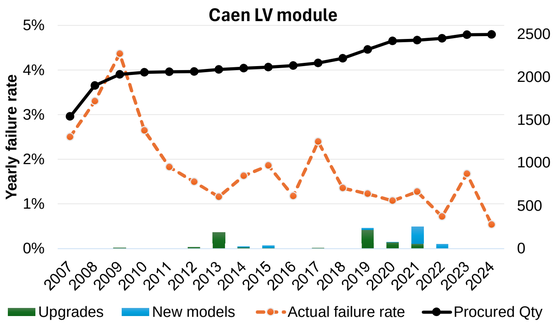
Main observations

- The SYxx27 shows the highest failure rate. This poor result is largely due to the old non-modular mainframes, which have been discontinued since 2013.
- The power converters (LV&HV modules and the AC-DC) have a cumulative failure rate of 23% to 36%, which is considered acceptable given their power density and channel count.
- The functional block failure encountered on the SYxx27 is due to the fragility of commercial PC components the old SYxx27 mainframes are based on.
- For the other devices, the failure cause is relatively distributed.

Upgrade approach

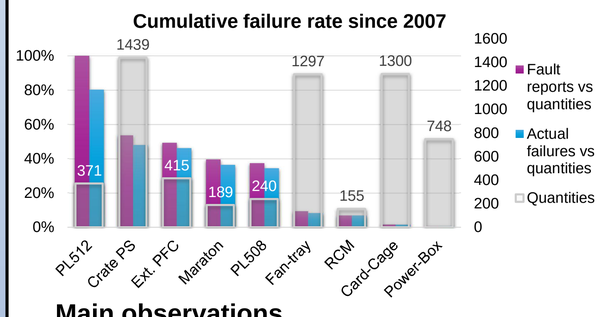
Caen has adopted an upgrade strategy focusing on improving performance and reducing failure risk. Over the last years, many items have been modified and new models have been introduced to replace the legacy ones. The example on the right shows the failure rate decrease of LV modules, probably due to the combination of modifications and the gradual ordering of new and more efficient models.

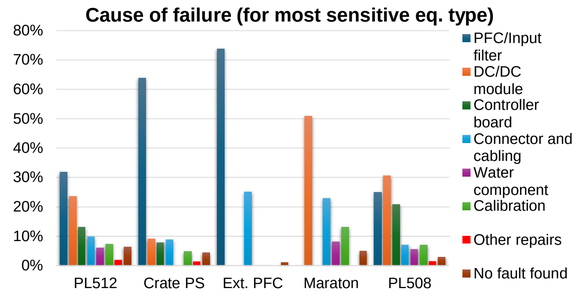
The table below provides examples of operated upgrades.



Incident / identified risk	Upgrade	Benefits / Results
A3000NF (Filter for AC/DC) Two incidents in Atlas. Smoke came out of the A3000NF filter.	**Nov. – Dec. 2023** Internal capacitors replaced and overheating protection added.	**47** out of 59 units refurbished.
SYxx27 mainframe  High failure rate impacting all inserted modules.	**Since 2013** New generation of mainframe	**Modular SYxx27 mainframe**  Reduced failure impact on the entire system.
LV & HV modules Risk of component obsolescence and module wear out.	**Since 2019** 68 new models gradually added to the catalogue.	Gradually contributing to reduce failure rates, enhancing performances and ensuring long-term repairability.

Focus on WIENER equipment



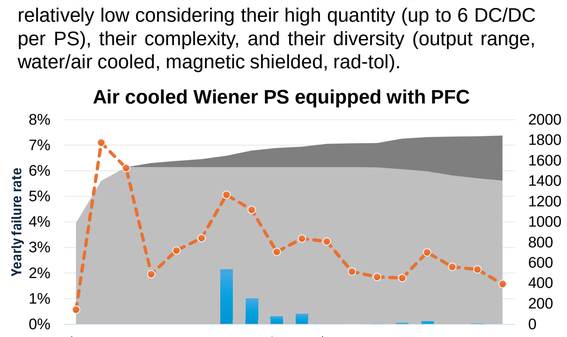


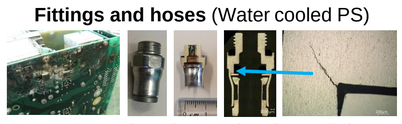
Main observations

- The PL512 failure rate largely dominates the other equipment families. This may be due to the limited and late preventive maintenance performed and/or the operating conditions of these devices.
- The PFC is the major failure cause of all devices equipped with it.
- The number of failures attributed to the DC/DC modules is relatively low considering their high quantity (up to 6 DC/DC per PS), their complexity, and their diversity (output range, water/air cooled, magnetic shielded, rad-tol).

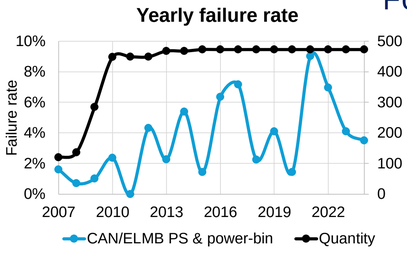
Preventive maintenance approach

Wiener opted to recommend preventive maintenance to lower failure rates and extend product lifespan. For instance, the curve on the right illustrates the yearly decline in failure rate for PFC-equipped power supplies (Crate PS and Ext. PFC). This decrease is likely due to preventive measures, such as fan and capacitor replacements and diode addition, along with the gradual rollout of the PFC version A. Since 2018, the PFC version A is systematically replaced with version B during repairs.
The table below gives some examples of preventive maintenance carried out on Wiener equipment.

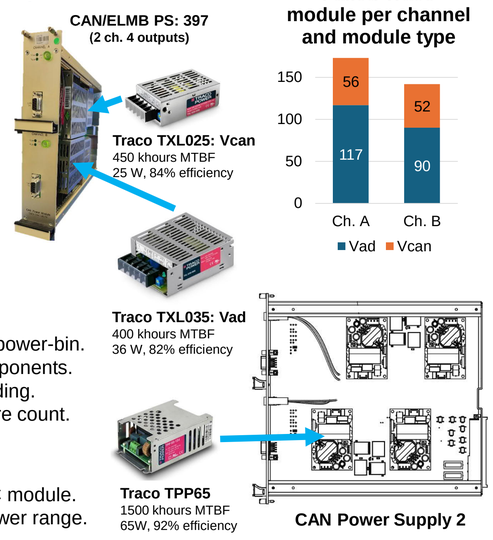


Incident / identified risk	Preventive maintenance	Benefits / Results
Fans (Crate PS, Ext.PFC & Fan-tray) Risk of overheating with fans exceeding their MTBF.	**2013 – 2014** Fan replacement campaign for air cooled PS and fan-trays.	**772** items refurbished. Contributing to keep the failure rate at a low level.
Fittings and hoses (Water cooled PS)  Stress corrosion observed on brass fittings. High risk of water leakage in experiments.	**2016:** For 446 PS, the elbow fittings and CPC blocks are exchanged for stainless steel. **2021:** Internal straight fittings and hoses are exchanged on 289 PS.	 No leakage reported from the experiments since then.
PFC (Crate PS, Ext.PFC & air cooled PL512) High failure rate observed since the first PS deliveries.	**Since 2009** New air-cooled PFC (ver. B) released and systematically exchanged since 2018.	About a quarter of PFC replaced, positively contributing to reducing the failure rate.

Focus on CERN equipment



CAN/ELMB PS failure mode	
No fault found	1.72%
Adjustment	3.45%
Other	0.99%
Current transducer	0.99%
LED	2.46%
Traco AC-DC module	86.21%
AC fuse	4.19%



Main observations

- The yearly failure rate tends to increase. This combined with the time before failure plot, shows that the equipment is dramatically aging.
- The CAN/ELMB PS accounts for 96% of fault reports, with 14% from the power-bin.
- The commercial Traco AC/DC modules are identified as the weakest components.
- The Vad internal module has a higher failure rate due to frequent overloading.
- Channel A is less well cooled by the airflow which explains its higher failure count.

Recommendations

- Upgrade the CAN/ELMB PS to the new design with highly efficient AC-DC module.
- Optimize the cooling airflow and ensure the load remains in the output power range.

Conclusion

Lessons learned

- Failure rates have decreased over time and remain low, likely due to targeted preventive maintenance campaigns and gradual replacement of aging equipment.
- Failures related to the PFC still significantly dominate the Wiener equipment that uses it.
- The Wiener PL512 is showing signs of aging, with its failure rate on the rise. The gradual preventive maintenance campaign started in 2021 has not yet yielded significant results.
- Almost half of the Caen equipment used at CERN was neither bought via the frame contract nor registered in the service database, affecting traceability and data analysis. However, nearly all maintenance requests are processed through the service.
- The CAN/ELMB PS failure rate is clearly increasing. This can be explained by the aging effect, the lack of preventive maintenance, the quality of the Traco AC-DC modules and the operating conditions, particularly the cooling quality.

Recommendations for the HL-LHC phase

- **Traceability** by using the tools and procedures of the power supply and crate service to easily manage procurement and maintenance requests, keep history of events related to the items, manage warranty durations and perform statistical analysis based on reliable data.
- **Preventive maintenance** is crucial to prevent failures and extend lifespan of the equipment.
- **Adapted warranty** requires to be carefully negotiated depending on the equipment type. For example, in view of the results of this study, a long initial warranty period or the option to extend it should be favoured.
- **Spare** quantity should be dynamically planned for critical equipment. The repair turnaround time needs to be taken into account.
- **Cooperation** between users, manufacturers, and the PS and crate service allows all parties to stay informed, gain valuable experience, and develop a global view that benefits all.