Lifetime testing results and diagnostic performance prediction of linear coolers at Thales Cryogenics

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ABSTRACT

Thales Cryogenics (TCBV) has an extensive background in delivering long-life cryogenic coolers for military, civil and space programs. During the last years many technical improvements have increased the lifetime of coolers resulting in significantly higher MTTF’s. Lifetime endurance tests are used to validate these performance increases. An update will be given on lifetime test of a selection of TCBV’s coolers.

MTTF figures indicate the statistical average lifetimes for a large population of coolers. However, for the user of IR camera’s and spectrometers a detailed view on the performance of an individual cooler and the possible impact of its performance degradation during its lifetime is very important. Thales Cryogenics is developing Cooler Diagnostic Software (CDS), which can be implemented in the firmware of its DSP based cooler drive electronics. With this implemented software the monitoring of the main cooler parameters during the lifetime in the equipment will be possible, including the prediction of the expected cooler performance availability. Based on this software it will be possible to analyze the status of the cooler inside the equipment and, supported by the lifetime knowledge at Thales Cryogenics, make essential choices on the maintenance of equipment and the replacement of coolers.

In the paper, we will give an overview of potential situations in which such a predictive algorithm can be used. We will present the required interaction with future users to make an optimal interaction and interpretation of the generated data possible.

Keywords: Cryocoolers, Cooler Diagnostic Software, Maintenance, Reliability, cooler degradation, Cooler Drive Electronics, DSP technology, MTTF.

1. INTRODUCTION

Thales Cryogenics has an extensive background in delivering long life cryogenic coolers for military, civil, and space programs. During the last years many technical improvements have increased the lifetime of coolers resulting in significantly higher MTTF’s. Recent publications have for instance shown the new advances in compact long-lifetime coolers [1]. These new coolers have not only significantly reduced the typical dimensions of linear coolers, but also increased the expected lifetimes to significantly higher levels than in comparable coolers of previous generations [2].

Several methods exist of presenting cooler lifetime data. Depending on the method used for the statistics, and the cooler lifetime definition, different numbers can be used. In any case, MTTF numbers represent statistically average numbers. These are only valid for large numbers of coolers in certain environmental conditions. It will present a customer with average lifetime expectancy of its installed cooler base. It will enable the prediction of cost of ownership on an average level.

These average numbers do not include the performance of individual coolers. Lifetime prediction of individual coolers can significantly differ from the statistical average, depending on the deviation in the statistical population. This thus also means that the cost of ownership per product can differ significantly per product with respect to the average.

If maintenance on camera level means replacing a worn-out cooler, several strategies are possible. In case a preventive strategy is followed, it means that many coolers will be replaced before they are actually on the end of life. On the other hand, if the maintenance strategy is reactive, it means that maintenance will be necessary on unplanned moments, and camera downtime will be inevitable.

In this paper we will present a novel approach to lifetime prediction in linear coolers. This prediction algorithm will allow lifetime prediction of individual cooler-dewar combinations, thus enabling users of linear coolers in optimizing
their maintenance schedule to minimize system downtime and maintenance costs. The algorithm has been implemented in existing hardware which will be presented. The next step is to use it in practical situations. An example of such an application is given, together with its challenges and requirements for future interaction with customers for further optimization. Also, in chapter 2, we will present the updated lifetime test data.

2. COOLER LIFETIME DATA

Previous cooler lifetime data was presented at the SPIE conference in Orlando, 2010 [2]. The updated results for the same selection of coolers are shown in Table 1 below. A few coolers have been added to the selection. Not all lifetime coolers are mentioned in the selection below. Newer coolers are e.g. not mentioned yet as they do not have a significant amount of running hours yet.

Table 1: Selection of cooler lifetime results, summarized

<table>
<thead>
<tr>
<th>Cooler type</th>
<th>Description cooler</th>
<th>Running hours</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSF9088</td>
<td>Moving coil flexure cooler</td>
<td>75814</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9188</td>
<td>10 mm Stirling coldfinger</td>
<td>83947</td>
<td>Still running, Worn out displacer replaced at 69.000 hours</td>
</tr>
<tr>
<td>LPT9110</td>
<td>500 mW Pulse tube</td>
<td>79311</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9320</td>
<td>20 mm Stirling coldfinger</td>
<td>66494</td>
<td>Still running, New displacer bearing material after 20,000 hours</td>
</tr>
<tr>
<td>LSF9320</td>
<td>20 mm Stirling coldfinger</td>
<td>61092</td>
<td>Still running, New displacer bearing material after 15,000 hours</td>
</tr>
<tr>
<td>LSF9330</td>
<td>20 mm Stirling coldfinger with flexure bearings</td>
<td>62999</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9330</td>
<td>20 mm Stirling coldfinger with flexure bearings</td>
<td>64189</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9330</td>
<td>20 mm Stirling coldfinger with flexure bearings</td>
<td>49848</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9330</td>
<td>20 mm Stirling coldfinger with flexure bearings</td>
<td>50022</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9597</td>
<td>¼” IDCA cold finger</td>
<td>4456</td>
<td>Failed, experimental displacer liner material</td>
</tr>
<tr>
<td>LSF9597</td>
<td>¼” IDCA cold finger</td>
<td>6694</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9597</td>
<td>¼” IDCA cold finger</td>
<td>13975</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9597</td>
<td>¼” IDCA cold finger</td>
<td>13979</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9597</td>
<td>¼” IDCA cold finger</td>
<td>17705</td>
<td>Still running</td>
</tr>
<tr>
<td>LSF9997</td>
<td>¼” IDCA cold finger</td>
<td>4467</td>
<td>Still running</td>
</tr>
</tbody>
</table>

3. LIFETIME PREDICTION USING DIAGNOSTIC ALGORITHM

3.1 Background and principle

Cooler lifetime or MTTF numbers that are often mentioned are only a statistical representation of expected lifetime of a cooler. These numbers are based on a large statistical population. For instance, if the Weibull distribution is used, the lifetime definition is the time after which 63% of the population has reached end of life.
Lifetime data mentioned in cooler specifications is based on various tests and field data. One of such tests is lifetime testing, where a representative number of coolers is placed in endurance test and performance is monitored over time. As a result of the wear mechanisms present in coolers, cooling power will degrade over time. Once the cooling power has dropped below its specification value a cooler is declared end-of-life, despite the fact that there is no mechanical failure; the cooler is still producing cooling power. The average of these tests determines the average cooler lifetime or MTTF.

Instead of using only the end-of-life point for cooler lifetime prediction, also the degradation itself over time can be used. Typical curves for different cooler families are shown in Figure 1.

![Figure 1: Cooling power degradation over time for different cooler families.](image)

Different cooler families show different degradation of performance over time. Conventional contact-seal compressors (UP) show faster degradation than flexure bearing (LSF) series Stirling coolers. Pulse-tube coolers (LPT), as well as Stirling cold fingers equipped with flexure bearing suspension, show a significantly different degradation of performance over time. The wear mechanisms responsible for these degradation curves, (see e.g. ref [3]) are different for each cooler family.

Further analysis of individual cooler degradation curves show, however, similar behavior as shown in Figure 1. The degradation rate could be different for individual coolers, but the overall trend appears very reproducible. This trend can thus be used to estimate the expected life expectancy of individual coolers, and thus predict the remaining lifetime of individual coolers.

The main mechanism behind this lifetime prediction algorithm is based on the known cooler degradation behavior and measurement of actual performance data. The coolers performance in a particular application is measured and logged over a long time interval. The measurement data over this interval is then used to predict remaining lifetime.

The lifetime prediction extends beyond the linear regime shown in Figure 1. The solid lines show the ‘end-of-life’ definition based on a maximum performance degradation of 20%. When used in a practical application, the end-of-life definition could be completely different. The margins between maximum and required cooling power are usually much larger than this 20%. Therefore, we need to consider also the degradation beyond the –20% point, up to the point where wear-out and random failures become dominant. Based on existing lifetime data, the degradation will continue to degrade nearly linear beyond the –20% point, indicated by the dashed lines in Figure 1. However, further on during the coolers lifetime the degradation rate increases.

The prediction of remaining lifetime is based on the entire performance degradation of the cooler, including the non-linear wear-out region. The degradation is approximated by an empirical relation. The diagnostics algorithm uses measured and logged data during the life of an application to fit the coefficients of this empirical relation. With the determined fit coefficients, the remaining lifetime can then easily be calculated.
3.2 Cooler Drive Electronics enabling diagnostics

The new generation of cooler drive electronics (CDE) was introduced approximately 2 years ago. It consists of two different models, each with a different maximum output power. Both models are shown in Figure 2.

![CDE models](image)

Figure 2: The HPCDE2465 and MPCDE2450 DSP based cooler drive electronics.

As presented before [4], this new family of cooler drive electronics uses Digital Signal Processors (DSP) as the main control element. The DSP that was selected has spare storage and calculation capacity. This additional capacity is used to implement the new diagnostics capability without any physical changes to the existing hardware. This thus also allows retrofitting existing hardware with this functionality.

3.3 Challenges and solutions in implementation of the Cooler Diagnostics Software

The diagnostics capabilities were added as new functionality into existing electronics hardware. All the requirements were to be realized using existing hardware. From a hardware point of view, this means the following restrictions:

- Computational capacity should not impede with other control functions, such as the temperature control loop.
- The algorithm should thus not influence the temperature stability specifications;
- Communication of diagnostics and alarm data should take place over the existing communication ports;
- Storage of data should be nonvolatile, i.e. diagnostics data should remain available even if power is switched off;
- Limited storage is available. Storage should be done efficiently to optimize data logging capacity;
- Time data should be available to analyze the data. However, no real-time clock is available on the existing hardware;
- Stored data should be consistent. Any anomalies in data should be detectable because otherwise incorrect predictions could be made. Additionally, if inconsistent data is found, it should be possible to reconstruct the data so that the maximum amount of data is available for analysis;
- The trends that are to be observed change on timescales of hundreds of hours. This means that averaging or smoothing of data should also take place over similar time scales. This should not interfere with available data storage capacity.

There is sufficient calculation capacity available in the DSP. In order not to interfere with other control mechanism, the diagnostics algorithm is programmed with the lowest priority in internal execution. This can be done without any limitations to the algorithm itself, as only very long-term effects are observed. Also, the update speed of diagnostics data can be very slow; lifetime predictions are expected to change on timescales of hundreds of hours, instead of milliseconds that other mechanism show.

Diagnostics and alarm data should be communicated with the user. Currently, two methods of communication are present in the converter. First of all, an RS232 port can be used for changing settings, reading data, etc. Furthermore, a hardware line is present, the ‘cooler ready’ output, that is currently used to indicate that the cooler has reached set point temperature. These two communication lines are also used to communicate diagnostics and alarm data. The RS232 bus can be used to change settings and read all relevant data. Using serial communication in situ is not always a preferred
solution as this requires active polling of the converter data. Therefore, the cooler ready line can be programmed to provide a dedicated alarm output. There is only one device available in the existing hardware that allows non-volatile storage of data. This is the device that also stores settings and parameter data for the other functions in the CDE. The remaining storage capacity in this device is used for diagnostics data. A circular data buffer is used to infinitely store data. The oldest data point in the buffer (see Figure 3) is overwritten by the newest data. In the example in Figure 3 only eight points are available, in the implementation 25 points are available.

Figure 3: Graphical representation of a circular data buffer. The oldest data point is automatically overwritten by the newest data. In this example, the last 8 points are always available.

As mentioned before, no real-time clock is available to generate time data. It is possible, however, to generate elapsed time data, due to the accurate time standard present in the CDE. This elapsed time data is stored in the same circular buffer. It also used to determine the oldest data point in the buffer. The circular buffer also plays a role in the averaging of data. Averaging is done the digital interpretation of a linear first-order low-pass filter (Figure 4). The output of this filter consists partly of the newest sample \( x \) and partly of the outcome of the filter the previous calculation

\[
y_n = (1 - \alpha)x + \alpha y_{n-1}
\]  

(1)

By using this filter for averaging of data, only the last data point has to be available. This means that averaging timescales of several hundreds of hours are possible without having to store many data points during that period. It should be noted, however, that the filter constants cannot be chosen too long, as this will result in loss of time resolution or delays between actual trends occurring and the logging of these trends.

The filter parameter \( \alpha \) should match the typical time scales that occur in the system. The following should be taken into account:

- A typical lifetime of an LSF cooler is several tens of thousands of hours;
- The available amount of data points is 25;
- The amount of time that should be covered in the data set used to store the diagnostics data should cover a significant part of the lifetime;
- The time periods that a cooler is active can be different for different applications;
- Data points (samples) are available at sample rates of once per second or faster.
The output of the filter consists of the sum of part of the most recent sample data $x$ and the previous results of the filter $y$.

The time span to be used for diagnostics data and the available data points result in typical intervals of several hundreds of hours. This means that there is a huge difference between the sample rate and storage rate. The low-pass filter coefficients should thus be very small. The value of $\alpha$ should be so close to ‘1’ that calculation using standard 16 bit accuracy or even extended 32 bit accuracy will not have sufficient resolution.

A challenge is related to the storage of intermediate data directly after sample is taken, and the typical time intervals that a system is powered. The output of the low-pass filter is stored in volatile RAM. After the interval is passed, the value is stored to the circular buffer. However, if the power is switched off before the interval passed, the data is lost. A further consequence is also that the total elapsed time will not be incremented, and the total elapsed time will be inaccurate. Intermediate storage in the circular buffer is possible but the high sample rate of raw data could quickly lead to device failure, because of the maximum write cycles specified for the storage device. Intermediate storage should thus also be carefully considered.

The solution to the above-presented inconsistency in time scales is solved by using two cascaded filters and two buffer intervals. The first filter uses RAM as intermediate storage. After the first interval is passed, the data is stored in the non-volatile memory. The output of the first filter is used as the input of a second filter. After the second interval has passed, the output of this filter is stored in the circular buffer. This method of buffering is further shown in Table 2, where intervals of 30 minutes for intermediate storage and 100 hours of data point storage is assumed.

<table>
<thead>
<tr>
<th>Elapsed time</th>
<th>Action</th>
</tr>
</thead>
<tbody>
<tr>
<td>0:00</td>
<td>Start logging</td>
</tr>
<tr>
<td>0:30</td>
<td>Intermediate storage in location $n$</td>
</tr>
<tr>
<td>1:00</td>
<td>Intermediate storage in location $n$</td>
</tr>
<tr>
<td>...</td>
<td></td>
</tr>
<tr>
<td>100:00</td>
<td>Final data point storage in location $n$</td>
</tr>
<tr>
<td>100:30</td>
<td>Continue intermediate storage in location $n+1$</td>
</tr>
</tbody>
</table>

The use of two cascaded filters eliminates the problem of resolution. The first storage in RAM eliminated the problem of maximum write cycles. The intermediate storage in nonvolatile memory eliminates the problem of data loss if power is switched off before the next data point is stored in the circular buffer.

The filter constant of the first interval should match the intermediate storage interval, as for the second interval and filters. The filter constants and time intervals are user adjustable, as they depend on the application, variations in environmental conditions, cooler types, etc.

As mentioned before, the diagnostics functionality is now based on existing hardware. In the future, hardware redesigns could be made to further expand the functionality. Such design changes could be for instance an extension of the storage capacity, inclusion of a real-time clock, and the use of bi-directional communication busses such as CAN-bus for more extensive communication between CDE and application.

### Stored data and diagnostic capabilities

The data that is stored and used for diagnostics is determined by the available data in the CDE. Currently, from the available data the following subset is used for diagnostics

- Elapsed time;
- Ratio between actual output voltage and maximum output voltage;
- Ratio between actual sensor voltage and sensor voltage set point;
- Power supply voltage;
Ambient temperature.
The output voltage ratio and sensor voltage ratio are the main parameters used for logging and lifetime prediction. Power supply voltage and ambient temperature are used in the offline interpretation and analysis of data. So not all the available information is stored; this is done to efficiently use the available data storage capacity and the necessity of these parameters for lifetime prediction.
A typical evolution of performance data during a coolers lifetime is shown in Figure 5.

![Figure 5: Performance evolution of a cooler in an application during its lifetime assuming steady-state operation. Cooling power will decrease over lifetime. The performance has been logged in several data points, from which the remaining lifetime is predicted. If the application continues to operate under the same circumstances, the performance will further degrade, until the output voltage ratio reaches 100% and the diode set point can no longer be maintained.](image)

The data in Figure 5 only considers steady-state operation. Transients during cool down are filtered out. During the main lifetime of the cooler, the user will observe a steady decrease in cooler performance, observed by a steady increase of CDE output voltage. At a certain point, the maximum output voltage will be reached and the available cooling power will be less than required. As a consequence, the temperature set point cannot be maintained. The detector temperature will increase.

The shape of the performance degradation will be different for different cooler types and families. This was also indicated in Figure 1. A linear Stirling cooler of the UP series will degrade faster than a cooler of the LSF series. An LPT cooler will degrade differently again, as there is no ‘wear out’ regime in these coolers. Their degradation will remain for a much longer period of time.
The degradation profile is also determined by the combination of cooler and detector. If the detector also shows degradation, for instance due to a slow degradation of the vacuum, there could be an acceleration of performance degradation. Furthermore, the initial ratio between actual and maximum output voltage determine the shape of the curve.

Furthermore, there can be different criteria to determine ‘end of life’. In extreme cases it could be the moment that a cooler mechanically fails. In more practical cases, it could be the moment that sensor set point can no longer be maintained. In applications less demanding on temperature stability, it could be the moment where the difference between temperature and set point exceeds a certain value. In the current implementation the prediction of remaining lifetime, however, can only be made for the situation where ‘end of life’ means that the cooler is operating at maximum power.

The goal of the diagnostics prediction algorithm is to alarm the user of a potential problem with the cooler. It allows the user to intervene before the problem actually occurs.
To accommodate each of the above-mentioned scenarios, the following alarm triggers are available, all indicated in Figure 5:

- The remaining lifetime of the cooler, as predicted by the evolution of output voltage, is below a certain amount of hours;
- The output voltage of the CDE exceeds a certain pre-set maximum value;
- The diode voltage ratio is below a certain value.

Enabling of the alarms, as well as the levels used for the alarms depend on the type of cooler and application and are therefore user selectable.

**Application specific use of the cooler diagnostics algorithm**

As mentioned in the previous part of this paper, many parameters used in the algorithm can be adapted to specific applications. The following parameters are available:

- Low pass filter coefficients (or time constants);
- Data storage intervals;
- Alarm trigger levels for:
  - Remaining lifetime;
  - Maximum output voltage ratio;
  - Maximum sensor voltage ratio.
- The enabling of each of the alarm triggers.

The settings of the parameters will be different depending on the cooler type, environmental conditions, detector type, etc. A camera running an LSF type of cooler would require significantly longer data storage intervals than a UP series cooler. A stationary application such as an observation camera will be subjected to significantly lower transients than an application such as a tracking pod. Also, an observation system will be less sensitive to variations in sensor temperature than a spectrometry application.

Adaptation of the diagnostics method to these specific applications will have to be done in close cooperation between Thales Cryogenics and customers. Every application will be different, with its own specific variations, time scales, requirements, etc. This is thus also an important aspect in further developing this diagnostics function.

In the next section, an example situation is presented, indicating the importance of this interaction with end customers.

**Application example**

The application used for this example is that of a stationary observation camera. The new LSF9997 linear Stirling cooler is used. The observation system is placed outside, and thus subjected to variations in ambient temperature due to day-night cycle and seasonal temperature variations. The assumed ambient temperature variation is shown in Figure 6 below. The local climate has hot summers and relatively cold winters.

Ambient temperature variations are the most important cause for variations in cooler input power. The next reason is the degradation of the cooler itself. We assume that this particular cooler has a degradation of approximately 20% over 20,000 hours, a typical average MTTF for this type of cooler. After 20,000 hours, we assume a slightly increased degradation rate.

The system is designed such that the average input power begin of life is approximately 60% of its maximum at 23 °C. As the output of the CDE is measured in voltage, this roughly corresponds to 75% of its maximum output voltage.

The required cooling power varies with ambient temperature. For this example, we assumed a required heat load of 300 mW at 23 °C, combined static dewar loss and detector dissipation, with a sensitivity of 2.4 mW/K in ambient temperature variation. We further take into account that the maximum drive voltage of a cooler also depends on ambient temperature.
Figure 6: Average, maximum, and minimum temperature during the year to which the observation system is subjected.

With these input data, we can estimate the evolution of output voltage ratio $V_{AC}/V_{AC,MAX}$ over time. In a similar manner as the climatic ambient temperature variations, we can also plot the ‘climatic’ output voltage ratios. This is shown in Figure 7.

The ‘flattened’ tops and apparent lower variations at peak temperatures are caused by the ambient temperature correction of the maximum output voltage $V_{AC,MAX}$. The variations between the ‘maximum’ and ‘minimum’ lines occur on timescales of typically one day. Furthermore, there is a timescale of 12 months indicating the change of seasons. The third timescale visible is that of the degradation itself, which can be seen as a progressive increase over the typical timescale of several years.

Figure 7: Output voltage ratio caused by variations in ambient temperature and steady cooler degradation over time.

The graph also shows the difficulty in determining the ‘end-of-life’ moment of a cooler. From a cooler specification point of view, this moment is reached after 20,000 hours, when degradation is 20 %, and the cooler will no longer meet the specified minimum cooling power. However, in this particular example, there is still sufficient cooling power, and the detector will maintain set-point temperature. After approximately 39 months, the output voltage ratio reaches 100% for the first time. This is the moment where the set point will be lost for the first time. From this particular application point of view, this could be the ‘end-of-life’ moment.
The approach used for the diagnostics capability for this particular application is then based on the following key points:

- The remaining lifetime prediction should be based on the longest-term variation only;
- No false alarms should be generated because of short-term variations;
- No alarms should be missed because of over-aggressive filtering;
- ‘End-of-life’ is defined where output voltage ratio reaches 100%. Cooler should be replaced before that moment;
- Seasonal variations should be included in the prediction.

We therefore choose the following settings:

- Alarm 1: Remaining lifetime less than 1 season (4000 hours);
- Alarm 2: Warn when the output voltage ratio is above 90% ;
- Filter constant low-pass filter: 200 hours for averaging out daily variations and damping seasonal variations;
- Logging interval: 1000 hours.

With a logging interval of 1000 hours, the diagnostics buffer holds approximately 25000 hours of data. The diagnostics data after the first 20000 hours, the specified MTTF for this cooler, is shown in Figure 8. The logged output voltage levels are lower than the trip level of 90%. Furthermore, the diagnostic fit shows a remaining lifetime far in excess of 4000 hours. In this situation, the cooler can be left to run unattended; no alarms will be given yet. As seen before, in this particular application the lifetime of the cooler will be longer than the interval shown.

In Figure 9 the situation after 35000 hours is shown. In this situation, diagnostics will be giving warnings about system performance.

At approximately 23000 hours, the output voltage range exceeds the 90% threshold level. The subsequent alarm is an indication for the user to observe the system and analyse the data. In the analysis of data the environmental conditions should be taken into account. The conclusion in this stage would be that the system is running at relatively high power due to the fact that it is peak summer. It is expected that the ambient temperatures during winter will decrease, resulting in a lower required drive voltage. The conclusion is thus that in this stage there is no necessity to immediately replace the cooler.

The next alarm will occur at approximately 27000 hours. Analysis in this stage would lead to the conclusion that the cooler is subject for replacement somewhere during the summer season, as further increase in drive voltage is expected. Finally, at 31000 hours, the remaining lifetime will be less then the threshold of 4000 hours, indicating the need of cooler replacement. It should be noted that the cooler will have incidentally been running at 100 % during peak summer temperatures. This has been predicted by the 90 % voltage ratio alarm. The remaining lifetime alarm warns for the moment where the output voltage will be at 100 % structurally.
In the case mentioned above, quite a few assumptions have been made. The validity of these assumptions will have to be evaluated for each particular case. There is no ‘ready made’ solution for the diagnostics function, and further development of the algorithm and related trends is necessary to further build confidence in the capability. Field data will be very important in this analysis, which means that further development can only be done in close cooperation with the (end) users of coolers and associated systems.

Figure 9: Stored data after 35000 hours.

4. CONCLUSIONS

In this paper, we presented the new diagnostics functionality in our cooler drive electronics. This diagnostics functionality can be used to monitor the performance of a cooler in an application during its lifetime, to predict remaining lifetime, and to provide warnings to the user that maintenance could be necessary. This functionality allows the end user to better plan maintenance on systems. The availability of an application can be maximised and maintenance can be scheduled efficiently, both optimising cost of ownership. Using a practical example, the potential of the algorithm was demonstrated. It was also indicated that there is no ‘ready-made’ solution is available. Implementation and optimisation always has to be done in close cooperation with (end) users, to adapt the parameters to specific applications.

Up to now, the functionality has been implemented. The next step is to test it in an actual application. Such field data will be used to gain experience in the process and further optimise the algorithms and application adaptation.

REFERENCES