ACCELERATOR RELIABILITY WORKSHOP
4-5-6 February 2002
Grenoble - France

Reliability of cryogenic facilities
A preliminary approach

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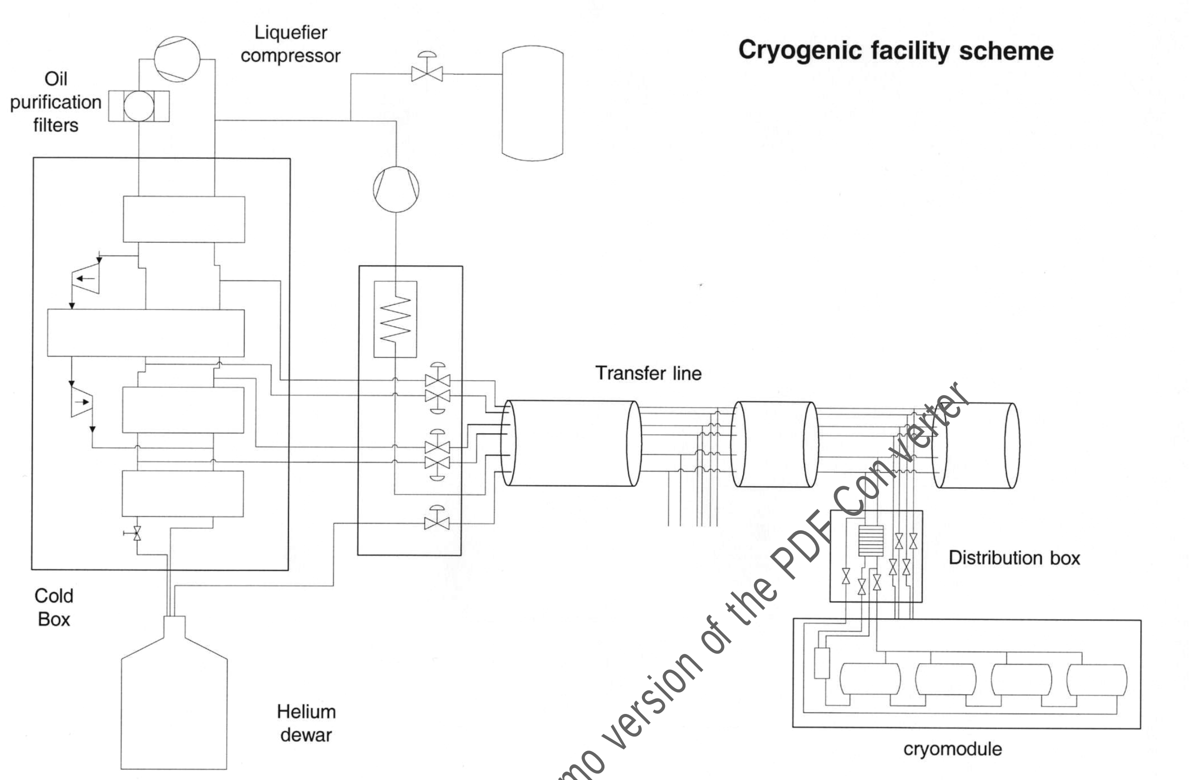
The development of new particle accelerators is mainly based on superconducting technology. The future of such accelerator for industrial purpose is dependant of the reliability of the associated cryogenic facility.
This paper will give a first analysis of the present reliability for the major cryogenic components used to keep cold superconducting cavities. This overview will highlight the points where this reliability as to be improved. A first approach of the ways to increase this reliability is examined.

Introduction

The development of new particle accelerators is mainly based on superconducting technology. The future of such accelerator for industrial purpose is dependant of the reliability of the associated cryogenic facility. It's all the more important that cryogenic refrigeration induce very long delay to recover the stability after shutdown. It is usually allowed that for a short cryogenic shutdown (less than 10 hours) the complete recovery time is 4 time longer the failure duration. It is yet 2 times for long failure period.

Components of a cryogenic facility : reliability review

This simplified scheme shown the major component of a cryogenic facility necessary. We will now detail each component from the reliability point of view.



Cold box

The main component of the helium liquefier, itself compose of several sub-system..

- Turbines

This is the most sensible element. The very high rotating speed (3000 to 5000 Hz) and the necessity to minimize by-pass flow for efficiency reason lead to a very precise mechanical construction. As the working temperature is low, any impurity became a solid pellet which can damage the turbine wheel. So, the important point for the turbine reliability is the impurities level control in the helium flow. This control is also important for others components. A continuous impurities measurement system is an essential component for such facilities. In parallel, a periodic regeneration of the cold box is needed to avoid impurities accumulation.
An other important parameter for the turbine reliability is the number of shutdown and restart. It is a risky period for the wheel suspension system, a very precise high pressure gas system keeping the wheel in position during rotation. As this cryogenic facility is supposed to work for long period, this is a less relevant parameter in our case.

- Thermal exchangers

These are static elements, the reliability is in principle very good. Usually, the defaults come from un-seen problems during the construction. Most of them appeared along the commissioning phase. But there is few examples of leaks appeared after several working years. A periodic cold box vacuum control can be used to detect this type of failure.

- Cryogenic valves

It is the other element very sensible to the impurities level. As the flow path is small, solid impurities can easily block the valve. The only way to solve this trouble is to warm-up the cold box and proceed to a complete regeneration, for which a cold box shutdown is necessary.

- External fluid control

I include in this chapter all the elements external to the cold box and used to control the helium flow during the different phases of operation. That is for example, solenoid valves, manual valves, non-return valves, filters, …
As, these are standard industrial components, the reliability is directly connected to the component choice done by the manufacturer. One can pay attention to include in the call for tender some specifications related to the reliability of these equipments to avoid any bad surprise limiting the utility life of the cold box. One can also pay attention to the quality of the tubing connections (type of connectors, seals, etc…). Leakage can appears more or less easily according to the quality of theses connections.

Compressors & Oil purification system

- Compressor

Screw compressors are usually used for such plant. This type of compressor was choose with respect too its better reliability compare to reciprocating ones. As rotating system, they are submit to wear, so a periodic maintenance as to be schedule every 10000 to 15000 hours.
To get an idea of the behaviour of the compressor, a simple but efficient control is to analyse an oil sample. The results gives information on impurities contamination but also parts wear. It's also a good way to know if an oil change is necessary or not.
An other way to detect any possible degradation of rotating equipments is a vibration surveillance program. Vibration data are collected on periodic basis and compare against a base line. Any deviation indicate an expected trouble.

- Oil purification system

A screw compressor needs oil to be lubrificate and to get a good gas cooling but only ratio less than ppm value are acceptable in the cold box helium flow. So, a severe oil purification must be done at the compressor exhaust. These systems are now well known but periodic maintenance interventions are necessary to keep the purification efficiency at a high level, as replace the filters adsorbents once a year.

Storage dewar, transfer lines & distribution boxes

The storage dewar stay at cryogenic temperature all along is utility life. As there is no thermal cycling, the dewar reliability is one of the best of all the components. It’s usual to find dewar with more than 20 years useful life.
The other components (transfer lines, distribution boxes) are submit to regular thermal cycling. This can induce mechanical stresses and lead to vacuum leaks. A periodic vacuum control of these elements is necessary to survey leakage appearance. But if the construction is done according to the book, the average reliability is excellent.

Others equipments

These are the different equipments used to recovery and store the helium gas during the different phases of the facility operation (recovery lines, recovery compressors, HP purifiers, HP reservoirs, etc…). These components must be installed with the same attention than the other major components, even if the working conditions seems less difficult (working temperature is room temperature). To reach the wanted high degree of reliability, a periodic maintenance program must be followed especially for compressors, purifiers and any systems with moving parts.

External utilities

Usually attention is concentrated on the main component, but we also have to well supervise general utilities. Cooling water, compressed air, electrical supply equipments must be designed and installed keeping in mind a needed very high reliability. Incredibly, in the present working cryogenic facilities, the number of shutdown due to utilities failures is comparable with cryogenic ones and even higher sometimes. As these equipments are standard ones, it’s probably possible to reach a better value.
For the cooling water, the quality is also an important parameter to survey. Any default can lead to corrosion in the exchanger and in the end to leakage. As we have seen before water impurities even at low level are not acceptable in the helium circuit.

Control system

The use of industrial PLC as the first level of the control & command system is essential to get a good reliability. That low level systems are programmed to control their associated component even in case of shutdown at a upper level. For the supervisory control and data acquisition system, several industrial products are available and a good solution to minimise the work and man power needed to maintain such important software. One constraint is the availability off these products for long period. The constructor steadily update there systems and with the time compatibility problems can appear.

The reliability in the design phase

Redundancy

One of the conclusion of this inventory of the components behaviour is the necessity, during the utility life of the plant, to shutdown some of them for maintenance reasons. To provide the necessarily continuous cooling capacity, redundancy of the major equipments is essential. Cold box, compressors, oil purification system and gas recovery system are the main components to be duplicate. Fortunately in big installations the production capacity is divided into several plants, the redundancy doesn't mean to double the refrigeration capacity but only a part of it. A way to minimize the economic effect of the redundancy.

Specific Design

To ensure the needed level of reliability, the job begin in the design phase. With the redundancy of the major components, the cooling capacity of the different cryomodules as to be guarantee even in case of one component shutdown. The transfer lines and helium recovery system will be designed in accordance with that constraint, by adding separation valves and by-pass lines at the right position.
In the standard design reliability is already present. For example, one can imagine to connect directly the liquefier to the cryostats. But the usual design include a liquid helium dewar in between the liquefier and the cryostats. The main reason is to get the possibility to provide uninterruptible supply of cryostats during some hours if the liquefier suddenly shutdown. Such principle has proved to be efficient for minor repairs.

Reliability example of some facilities

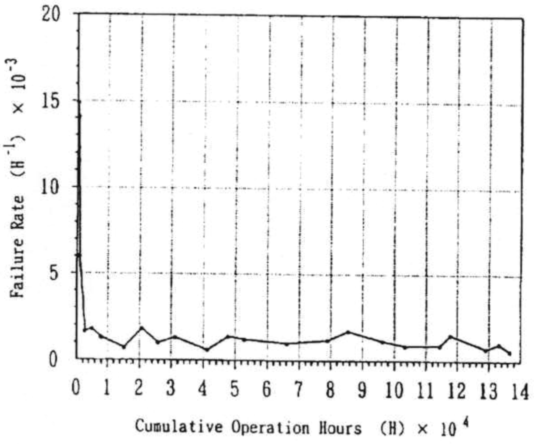
KEK [1]

Cryogenic facility

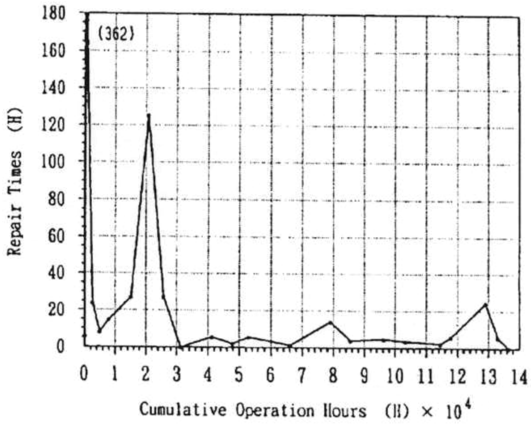
The reliability study is related to 3 helium liquefiers associated with the 3 superconducting coils of the detectors (VENUS, TOPAZ, AMY) of the TRISTAN electron-positron collider. The cooling power of each plant is 300 to 500 W at 4K.

Reliability factors

The cumulative operation time is 137000 hours over 10 years (1985-1995). The total number of failures is 169 of which 114 failures relate to the refrigerator system, 38 to utilities services and 17 to the superconducting magnet system.



Failure rate of the He refrigeration systems



Repair times during every operation period

The analysis of these failures show a first period (early failure period) when reliability is increasing (5000 hours/plant) and after that a "constant" failure rate with an average value of 99.2%.

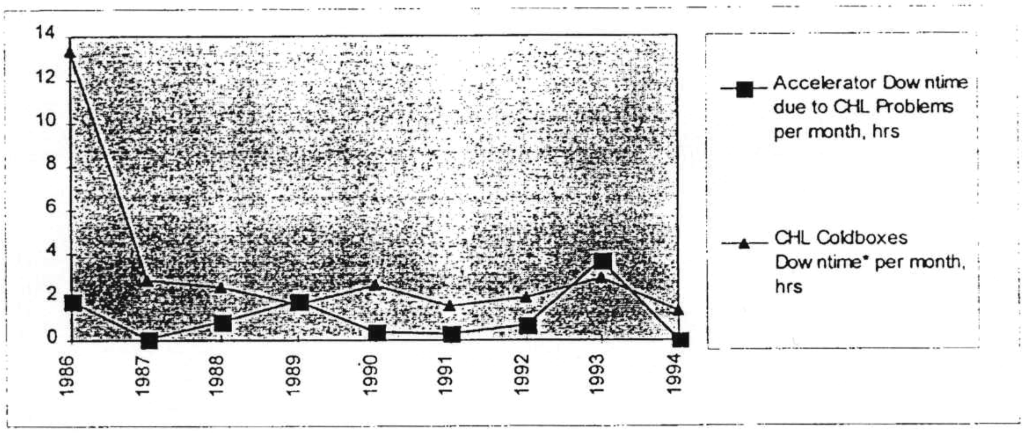
FERMILAB [2]

Cryogenic facility

The Tevatron superconducting proton-antiproton collider helium supply is done by the Central Helium Liquefier (CHL). It consist of 4 parallel reprocating compressors and 2 independent cold box of 4000 l/h and 5400l/h.
The collider superconducting magnets are feed by 24 satellite refrigerators through 6.5 km of transfer lines.

Reliability factors

The operation history is recorded on 76000 hours from 1980 to 1994.



CHL Reliability vs Availability for Fermilab Accelerator Physics.
Average monthly downtime (*during scheduled operations, not related to power glitches)

A first period of roughly 20000 hours showed an average reliability of 97% with an average accelerator downtime of 20 hours/month. In 1987, CHL has introduced numerous upgrades and improved control system and operator training. This has greatly improved the reliability to an average value of 99.5% (average accelerator downtime of 4 hours/month).
The most important impact on the reliability come from problems with un-adapted discharge valves on the reprocating compressors . The valve modification has shown MTBF of 2.7 times higher than the previous situation.

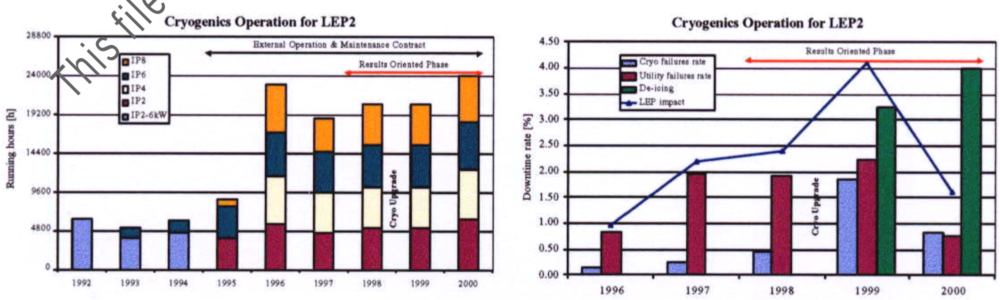
CERN [3]

Cryogenic facility

The LEP refrigeration system for the superconducting cavities was divide in 4 cryoplants of 12 KW equivalent cooling power at 4.5K. Installed and operated from 1993 to 1998, they were upgraded in winter 1998/99 to 18 kW and operated in this new configuration until 2000.

Reliability factors

A total of 120000 hours were accumulated by the 4 cryoplants.



Accumulated running hours and downtime rates for LEP2 cryogenic system.

The average reliability value for cryogenic failures is 99.3 % (7 hours downtime per 1000 hours). If we add utility failures the average reliability value decrease to 97.8 %. The peak value in 1999 is related to the upgrade modifications.
In 1999 and 2000, a specific problem was observed on 2 plants : a turbine filter clogging. Periodical de-icing was required to assure sufficient cooling capacity but had a negative effect on the reliability.

Conclusions

From these reliability examples, one conclusion is the observation of a first period (estimated 5000 hours) to improve the global reliability of the cryogenic facility. This period is needed to find and repair the problems related to the fabrication and installation of the system but, also, to accumulate training for the operators about the distinctive features of the specific installation. After that period the reliability reach a stable value if a well defined maintenance program is applied.
The present reliability factors of the main worldwide cryogenic facilities are pretty good, usually higher than 99%. Reach an higher goal will need a complete examination of the way to reduce the failures for each component. Furthermore, the present experience is accumulated on 10 to 12 years of working facilities. For longer useful life (20 to 30 years) some others difficulties can appears.
A detailed reliability study must be started at this phase of the superconducting cavities accelerators R&D to specify which components developments must be undertake to reach the wanted reliability factor.

References

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