The Remaining life of Vacuum Interrupters

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- Basic Introduction
- Contact Wear & Mechanical Life
- Vacuum Life
- Service Experience and Investigations

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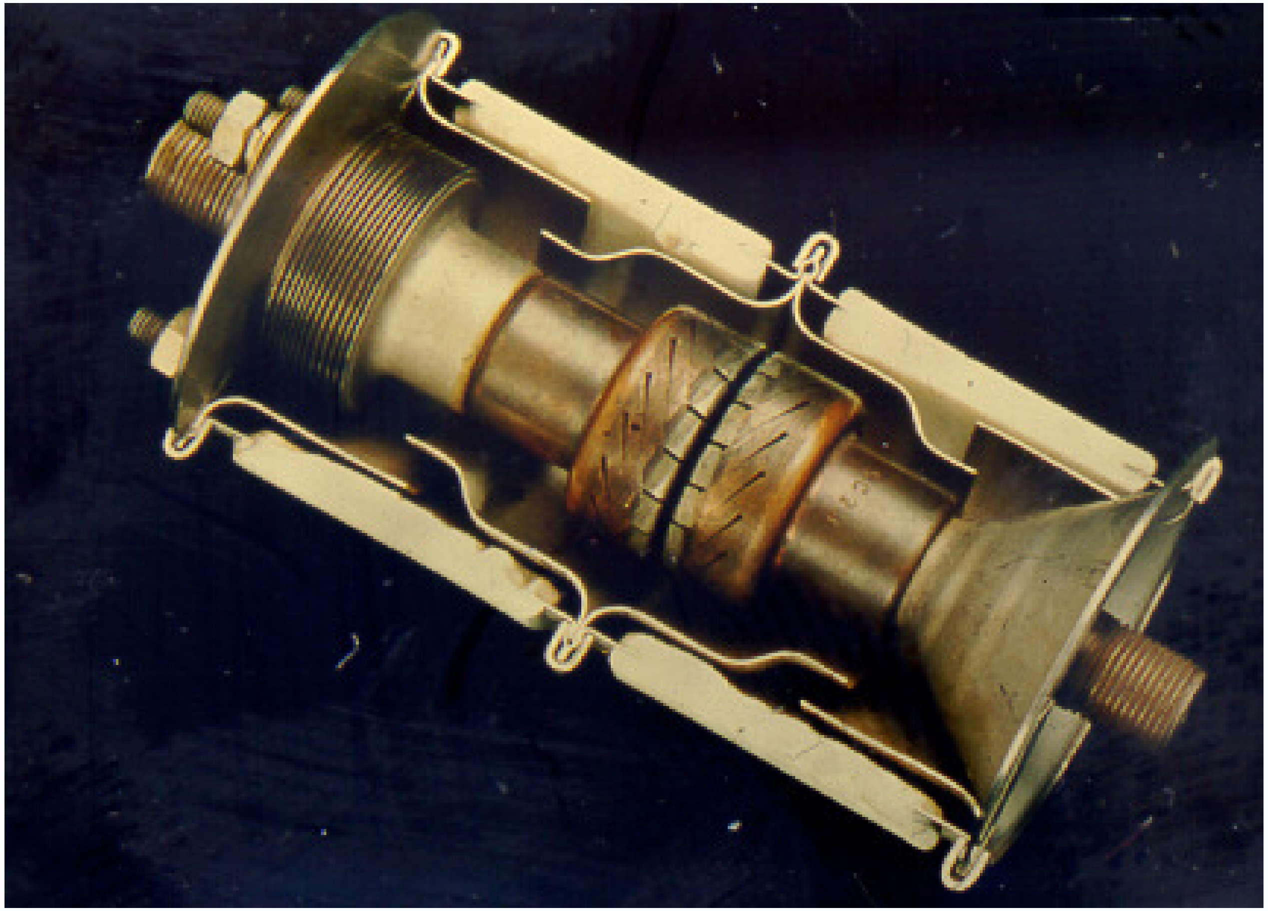
Introduction

Classic Vacuum Interrupter Design



V8 1213, VIL Finchley 1970's.

The photo shows a V8 interrupter from the 1970's.

This shows the basic design and main components of a Vacuum Interrupter.

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Introduction

Manufacturing -One Shot Seal Off

V204 interrupters being loaded into the furnace for seal off.
South Africa 1990.

This shows V204 vacuum interrupters being assembled in a clean room in South Africa. After assembly the interrupters are loaded into a vacuum furnace and brazed and sealed at the same time " One Shot Seal Off".

The components are chemically cleaned and then assembled in Clean Rooms to reduce contamination and "Virtual Leaks"

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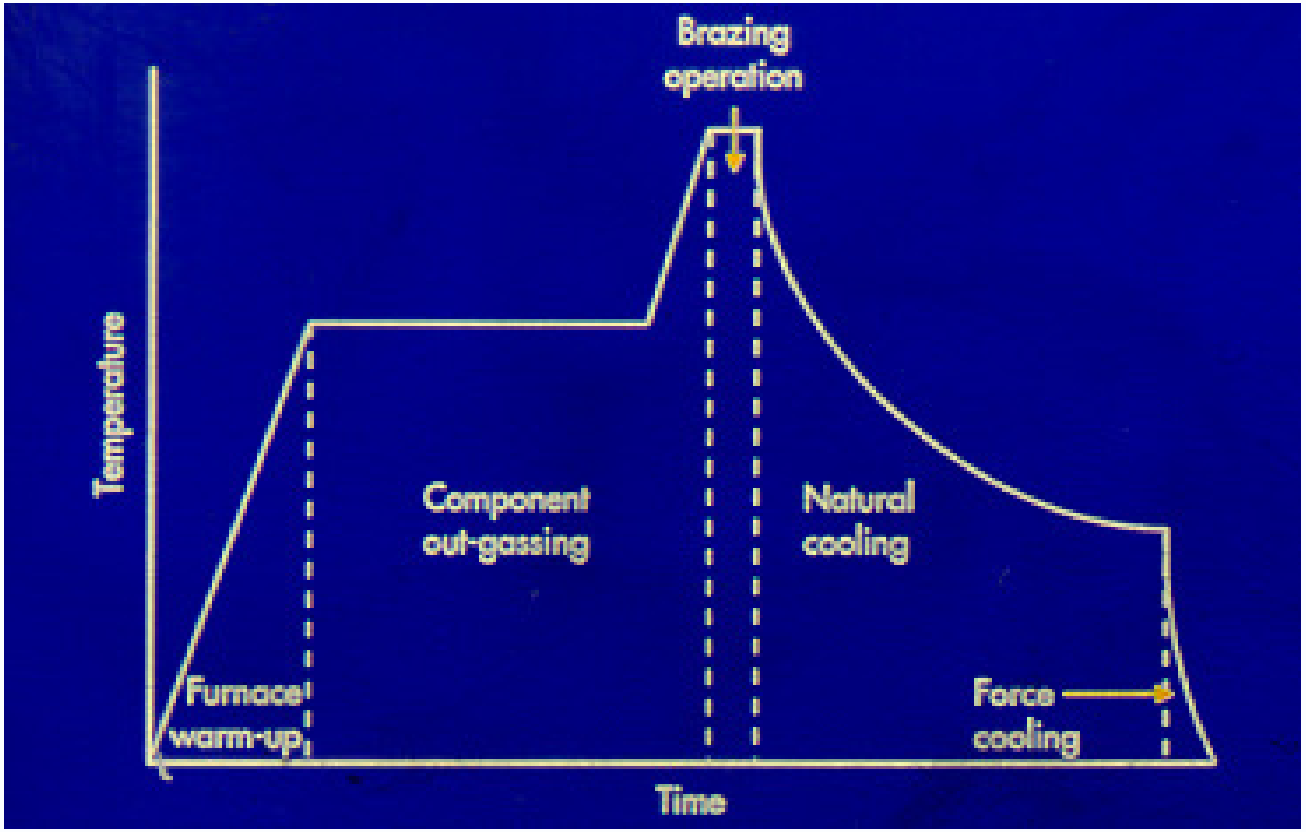
Introduction

Manufacturing -One Shot Seal Off



This shows the One Shot Seal Off furnace cycle.

Seal off takes place only at the highest temperature, after all components have been outgassed for several hours during the cycle.

The Outgassing temperature is over 700'C.

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Introduction

Technology & Size

Family of 20kA@12kV interrupters from 1975 to 1995. Showing their respective contacts

The change in size of the arc control system allowed significant changes to the size of the interrupters.

The photo shows four interrupters ranging from a V5 of 1975 to a VI 100 of 1995. All of these are production devices and are rated at 20kA@12kV. The smallest being only 60mm in body dia., and with a 32 mm dia. contact.

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Interrupter Contact wear

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Sealed for Life Concept

Vacuum Life Specified by Manufacturer (Datasheet 1987)

Vacuum Interrupter

Type V801

17.5kV; 20kA; 1250A.

Typical performance ratings

The specified ratings are for guidance and apply to interrupters installed in properly designed and manufactured circuit-breakers operated under the 'Typical' conditions recommended above.

For performance ratings under conditions other than those specified, please consult the manufacturers.

Minimum withstand voltage	50/60 Hz, 1 minute	50kV rms
	Impulse	95kV crest
Normal current		1250 A rms
Maximum dissipation	– at 1250 A and 27kgf added contact force	100 W
	– at 1250 A and 170kgf added contact force	50 W
Short circuit current	Symmetrical	20kA rms
	Asymmetrical (50% d.c.)	43kA peak
3 second through current		20kA rms
Making current		50kA peak
Mechanical life		50,000 operations
Storage life		20 years
Minimum electrical life	– at rated symmetrical short circuit current	200 operations
	– at rated normal current	20,000 operations

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Contact Wear

Basic Principles

- The arc energy in a vacuum interrupter is relatively low due to the low arc voltage.
- The arc control systems (both RMF and AMF) both work to minimise the melting and effective wear of the contacts.

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Contact Wear

Basic Principles

- During arcing the metal vapour tends to remain within the contact gap and the vast majority of metal vapour recondenses back onto the contacts even at short circuit levels
- The arc is naturally diffuse below c9kA peak and so extremely large numbers of load current switching operations are possible

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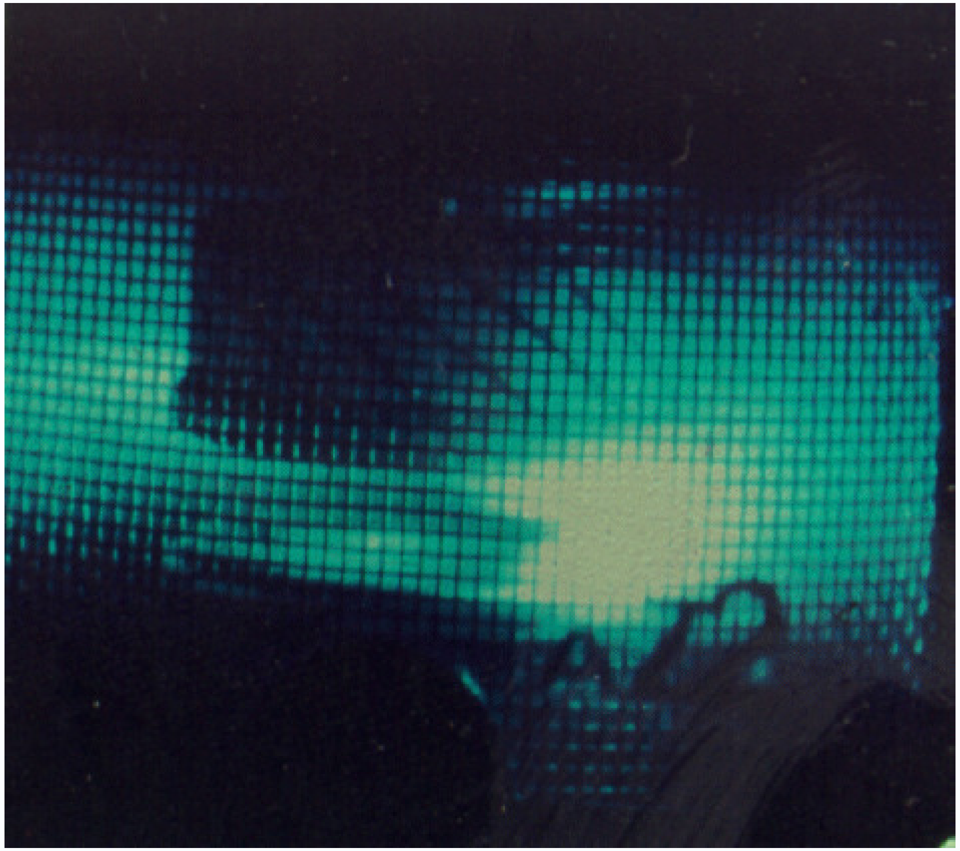
Contact Wear

Arc Control: Radial Magnetic Field (RMF) Contact Geometry



Still from HS film @ 5,000 pps showing 55mm diameter RMF contact interrupting 31.5kArms @12kVrms.

This works by using a self induced Radial Magnetic Field to make the arc move over the contact surface, reducing local heating, shown by the "Contrate" geometry here.

The contact material must allow the arc to move freely over the surface.

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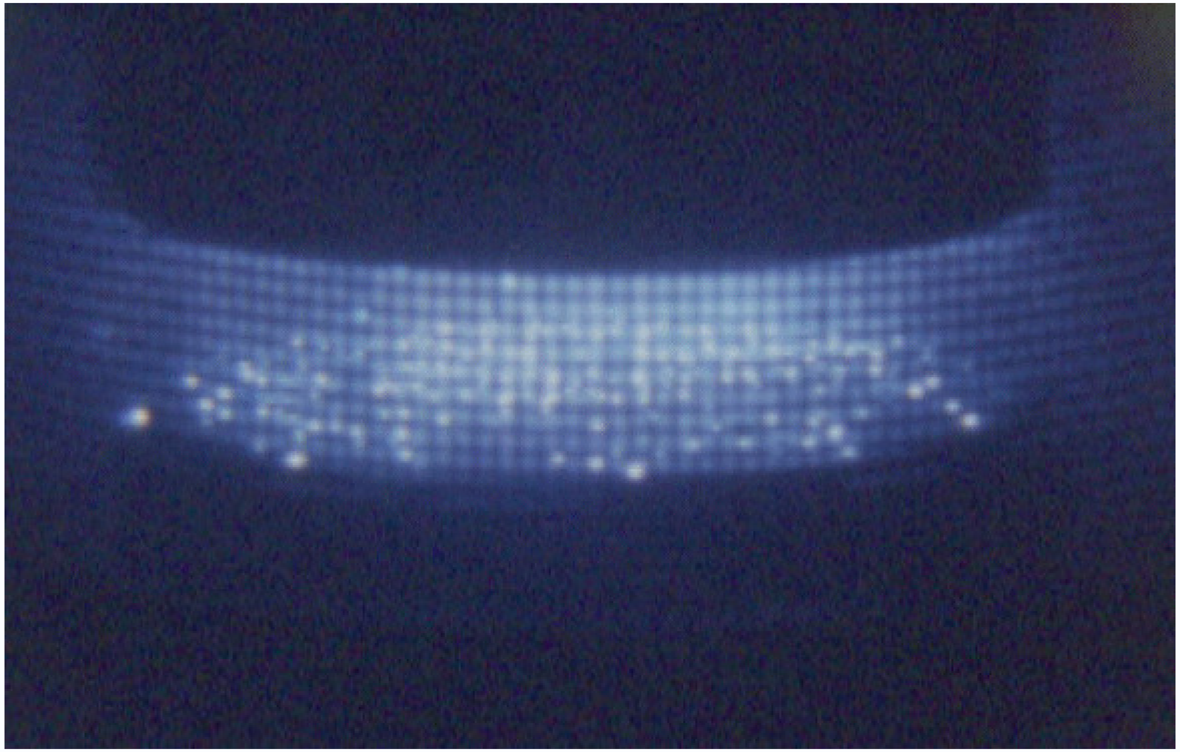
Contact Wear

Arc Control: Axial Magnetic Field (AMF) Geometry



Still from HS film @ 9,000pps showing an AMF contact interrupting 40kArms @12kVrms.

This works by using a self induced magnetic field in the axis of the arc which prevents the arc from constricting and reduces local heating by spreading the energy over the surface.

The contact material does not have to allow the arc to move freely.

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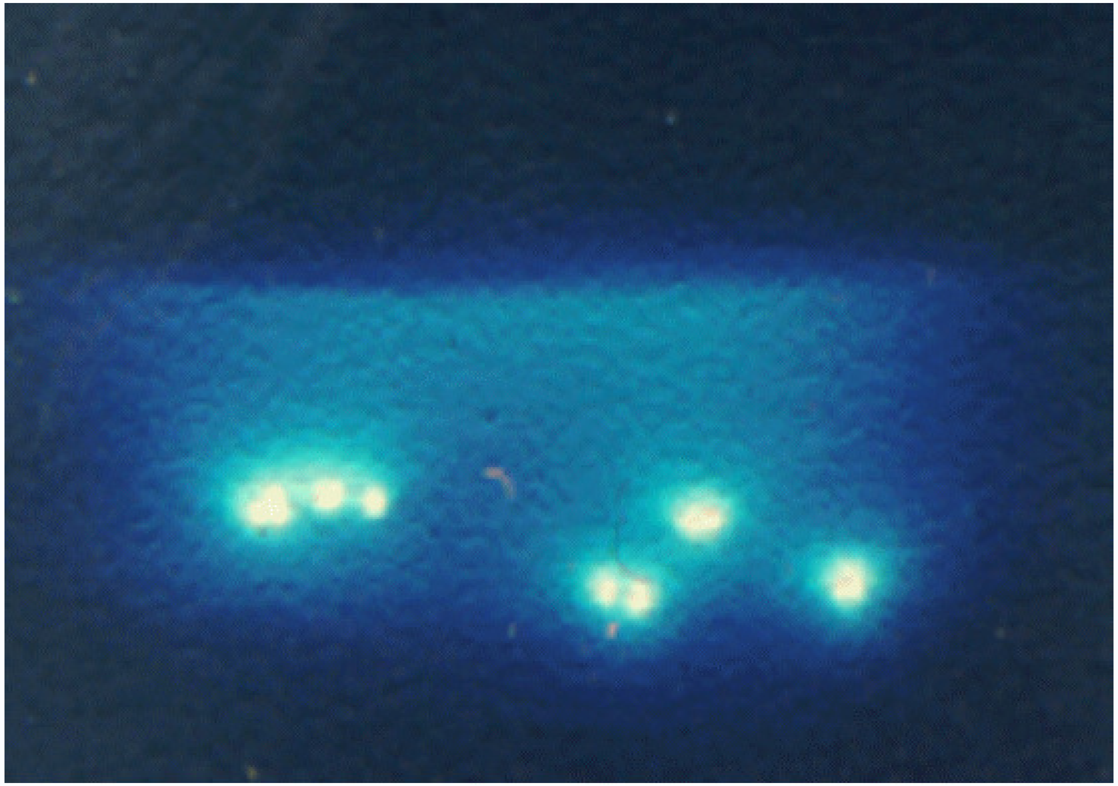
Contact Wear

Arc Control: Natural Diffuse Mode: Plain Contact Geometry



A plain butt contact can interrupt up to ~ 9kA(pk) without any arc control.

The arc is split naturally into a number of cathode spots which repel each other and spread the energy over the contact surface.

Still photo from High Speed film @ 10,000pps
showing cathode spots on plain contact geometry
(55mm diameter disc) CLR carrying @200A

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The Sealed for Life Concept

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Sealed for Life Concept

Vacuum Life Specified by Manufacturer (Datasheet 1987)

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	Asymmetrical (50% d.c.)	43kA peak
3 second through current		20kA rms
Making current		50kA peak
Mechanical life		50,000 operations
Storage life		20 years
Minimum electrical life	– at rated symmetrical short circuit current	200 operations
	– at rated normal current	20,000 operations

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Sealed for Life Concept

What does “Sealed for Life“ mean?

- A sealed vacuum device such as a Vacuum Interrupter has a shelf life determined by the manufacturer.
- The shelf life is calculated based on three things;
  - 1) The maximum pressure above which the device is said to have lost vacuum.
  - 2) The pressure in the device
  - 3) The maximum Leak Rate of the device

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VIL Sealed for Life Concept

Determining the Storage Life (Vacuum Life).

- The Paschen Curve (maximum pressure)

  This defines the physics of electrical insulation in vacuum and shows that for vacuum the dielectric strength is almost 40kV/mm but also that there is a sudden rapid decrease in dielectric strength to "Paschen minimum" as pressure increases.

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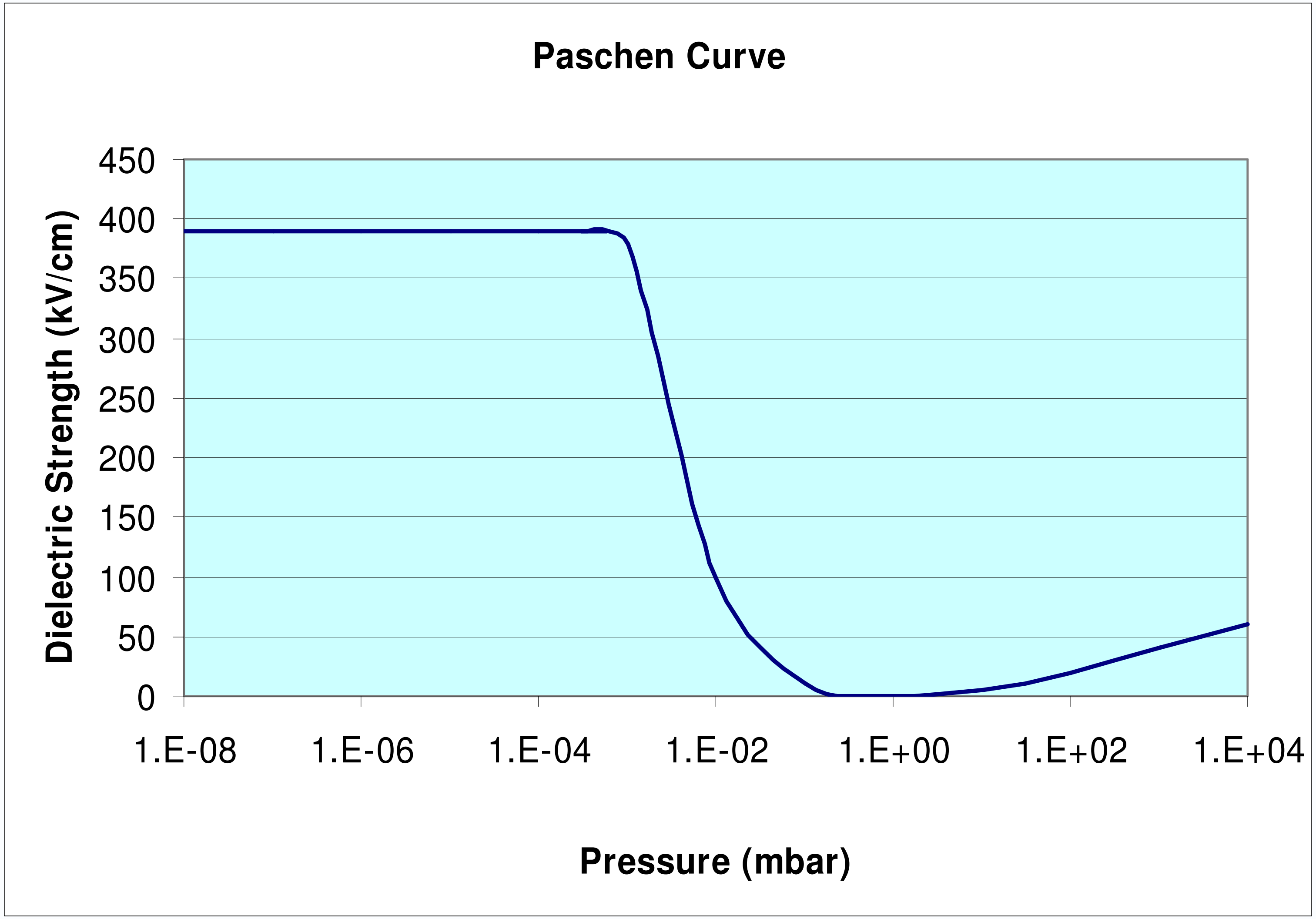
Sealed for Life Concept

Vacuum Physics



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Sealed for Life Concept

Determining the Storage Life (Vacuum Life).

- Pressure Measurement (Inverse Magnetron discharge)

  The determination of pressure in a VI is essential to the manufacture and is achieved by using the interrupter as its own gauge. When fitted to a specially designed suitably calibrated pressure measuring machine an accurate measurement of pressure down to 10-7 mbar or less can be made.

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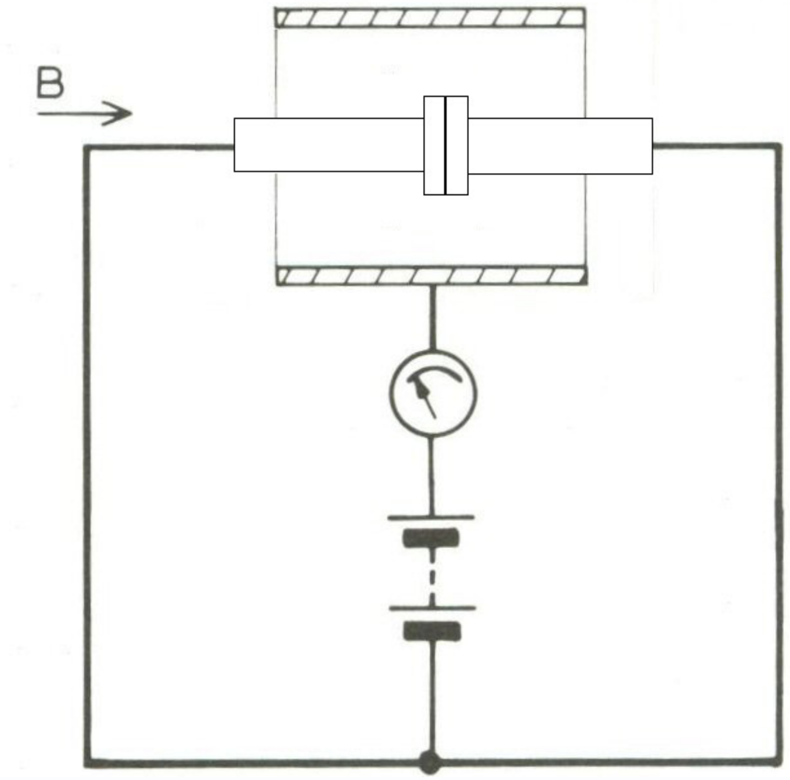
Sealed for Life Concept

Pressure Measurement - Single Inverse Magnetron



This schematic shows the principle of operation of an Inverse Magnetron crossed field vacuum gauge (Magnetic Field Coil omitted) applied to a sealed VI. Voltage is applied between the closed contacts and the shield in a large magnetic field.

A very small discharge occurs between the shield and the closed contacts in the VI , and the current carried is proportional to the pressure.

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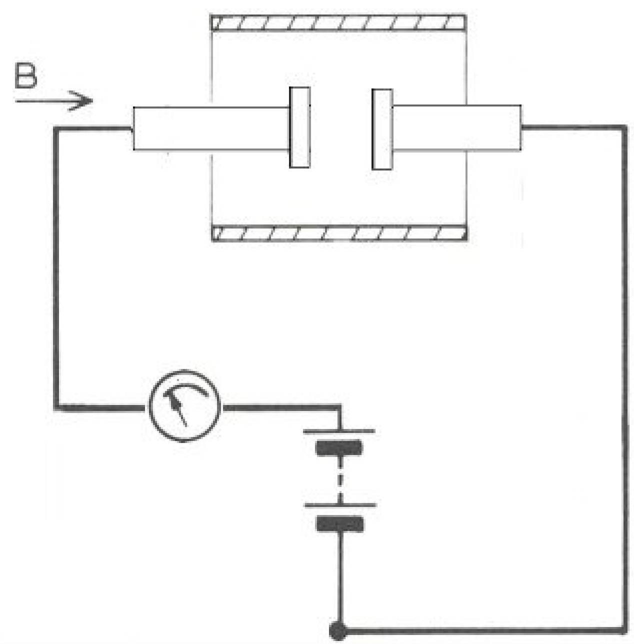
Sealed for Life Concept

Pressure Measurement - Double Inverse Magnetron



This schematic shows the special Pressure Measuring circuit for measuring the Vacuum within Sealed Vacuum Interrupters with a concealed centre shield (Magnetic Field Coil omitted).

In this case it is not possible to make an electrical connection to the shield and so a voltage is applied between open contacts in a large magnetic field. A very small discharge then occurs between one of the contacts and the shield, and a second discharge then occurs from the shield to the other contact. Again the current carried is proportional to the pressure.

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Sealed for Life Concept

Pressure Measurement

Real Leak

A real leak is a leak where gas enters the device from outside, and causes the pressure to rise within the device.

Virtual Leak

A virtual leak is where outgassing of surfaces or materials within the sealed device causes the pressure to rise within the device.

Although the mechanism is quite different, both Real and Virtual leaks can result in the pressure rising to the failure level.

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Sealed for Life Concept

Manufacturing – Pressure Measurement

V204 interrupter being loaded into the CUPE Pressure Measuring Machine. South Africa 1990.

This shows the operation of the special Pressure Measuring Machine for measuring the Vacuum within sealed Vacuum Interrupters as the key part of the quality control assessment determining the shelf life of the interrupters.

This machine is used to establish the pressure and thereby the leak rate of every interrupter. As it is a true measurement of pressure, this technique monitors both Real Leaks and Virtual Leaks.

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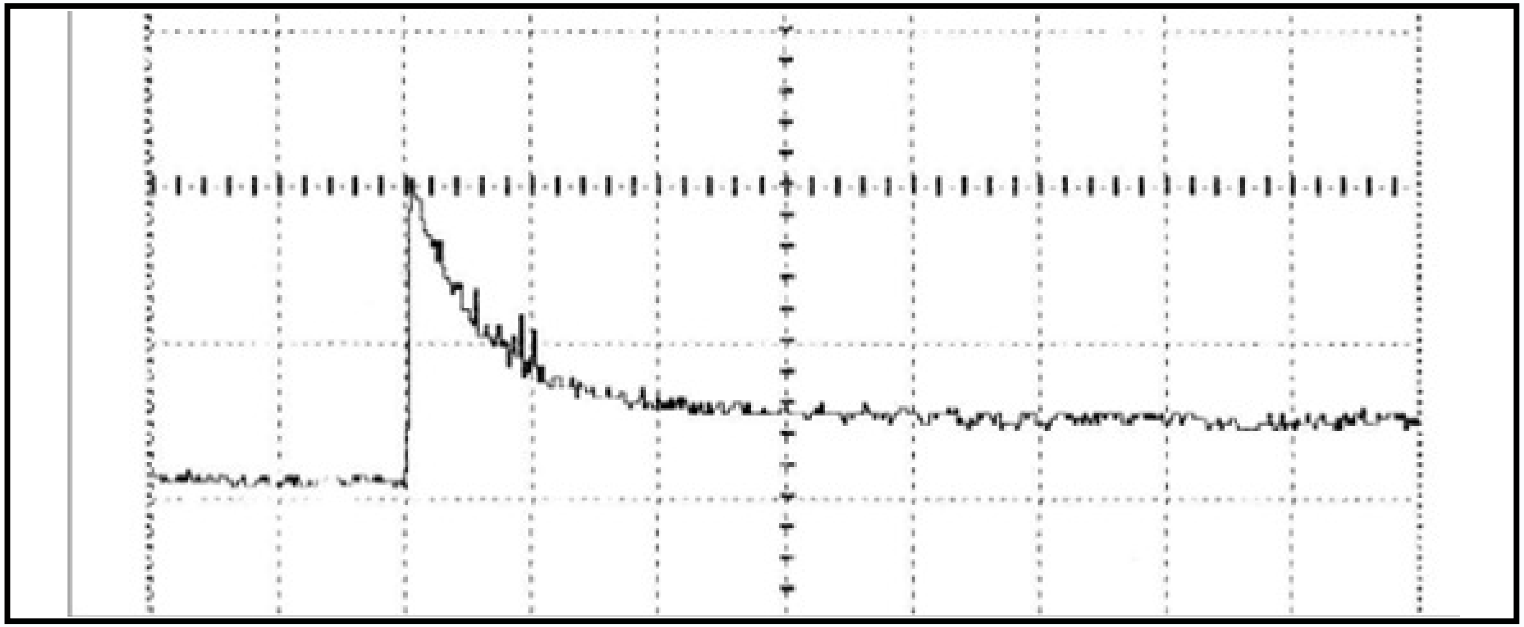
VI Magnetron Testing

Pressure Measurement



Typical magnetron pulse from an interrupter.
The Peak current is proportional to pressure.
Timescale is 200mS per division.

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Sealed for Life Concept

Determining the Storage Life (Vacuum Life).

- **Leak Rate Calculation (storage period)**

The following series of slides show the calculation for vacuum life graphically. Essentially we check the pressure twice with with a fixed time between, this enables a calculation to be made of the worse case pressure after 20 years. As Pressure is on a logarithmic scale, for clarity the Time is also shown as log days. The very good vacuum used at seal off allows the determination of leak rate over a very short storage period, in this case 7 days.

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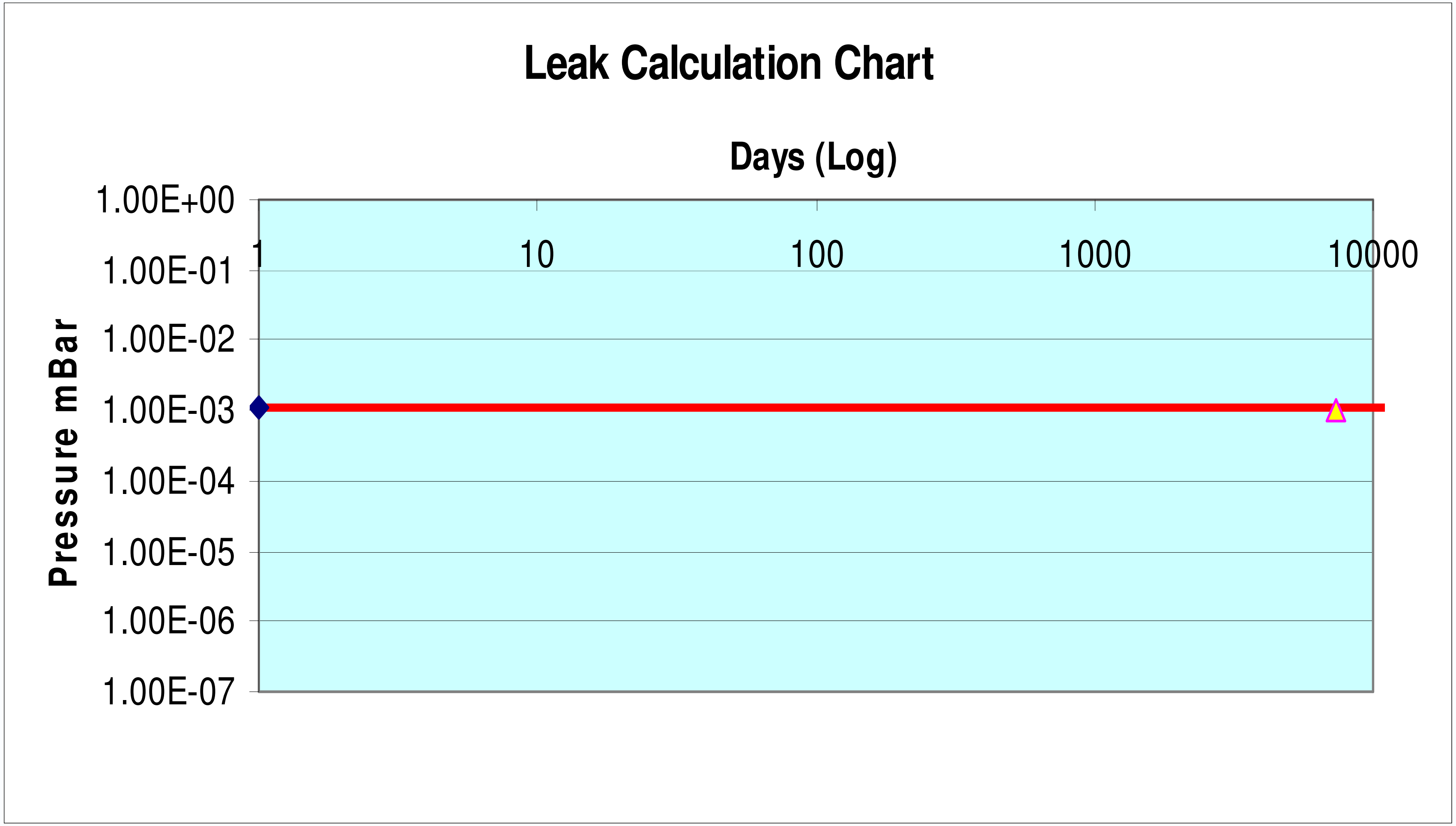
Sealed for Life Concept

Vacuum Life Determination – The red line is the Limit Pressure, the triangle indicates 20 years (7,305 days).



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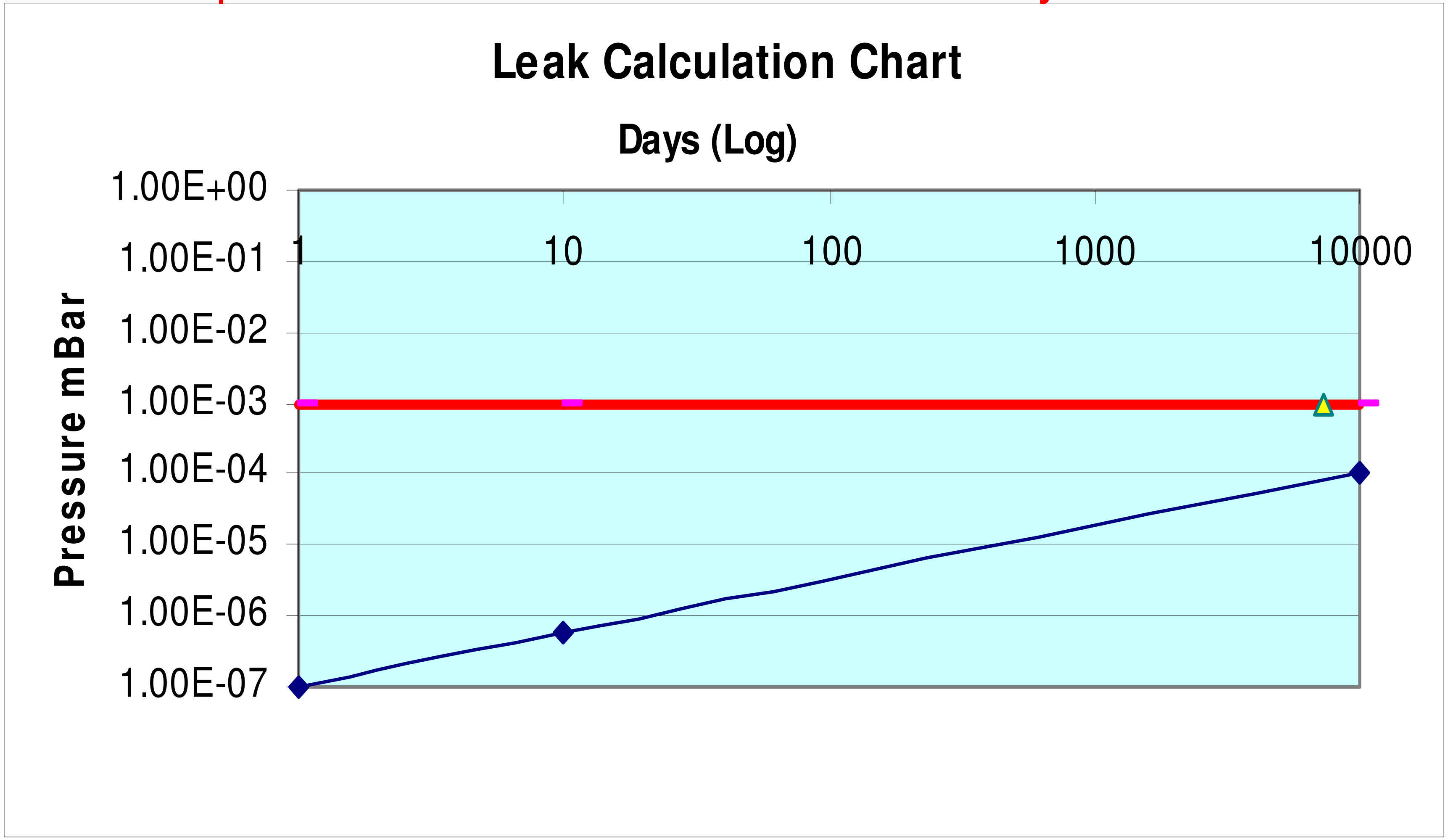
Sealed for Life Concept

Vacuum Life Determination – A “Good“ Interrupter with pressure better than the limit after 20 years.



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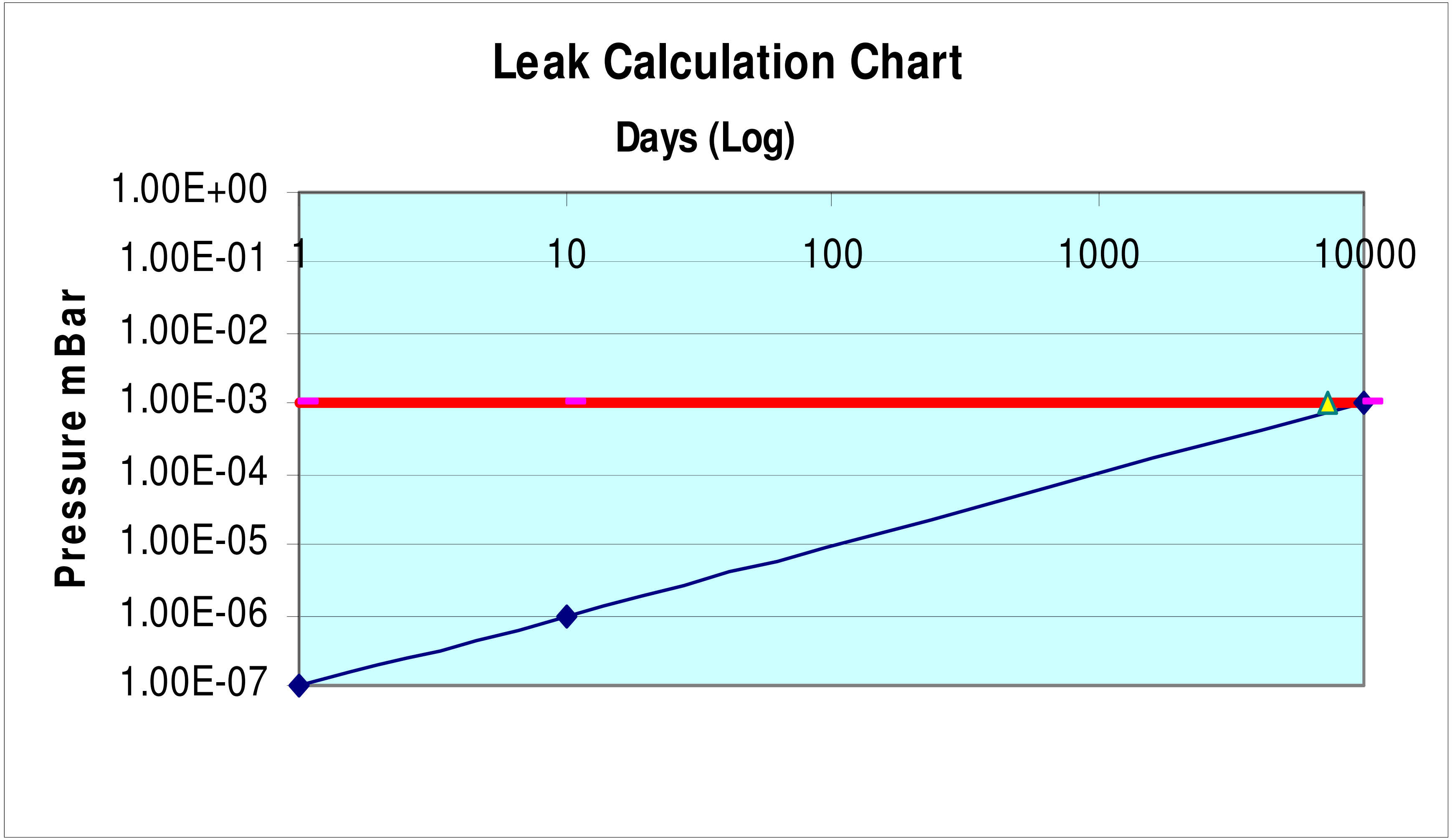
Sealed for Life Concept

Vacuum Life Determination – A “Marginal“ Interrupter pressure only just better than the limit after 20 years.



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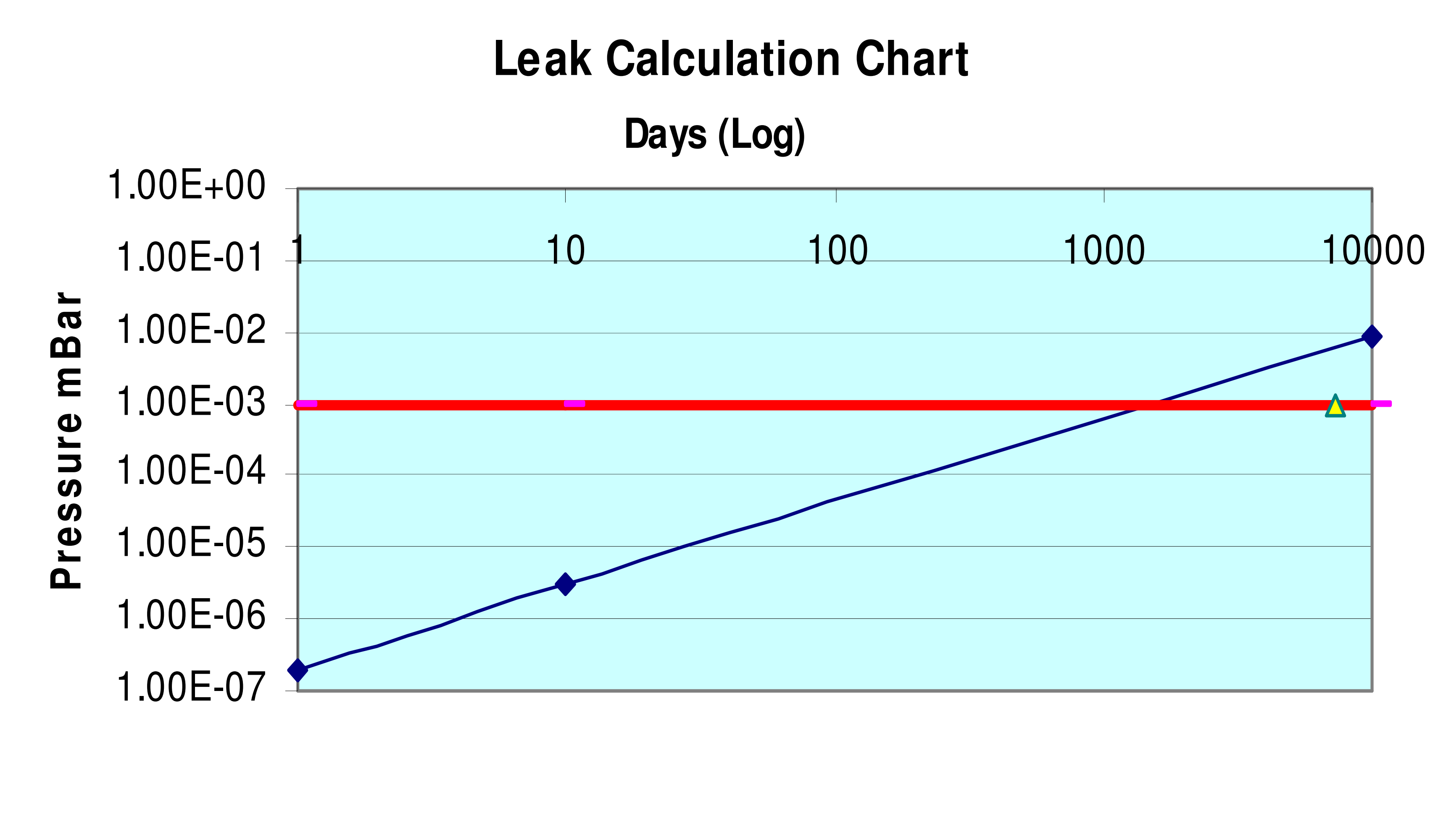
Sealed for Life Concept

Vacuum Life Determination – A “Bad“ Interrupter
pressure worse than the limit before 20 years.



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Storage Life

Causes of Loss of Vacuum

Assuming that the VI has successfully passed the Storage Life criteria then other effects can cause a loss of vacuum.

- Mechanical Damage
- Corrosion
- Design/Manufacturing Issues

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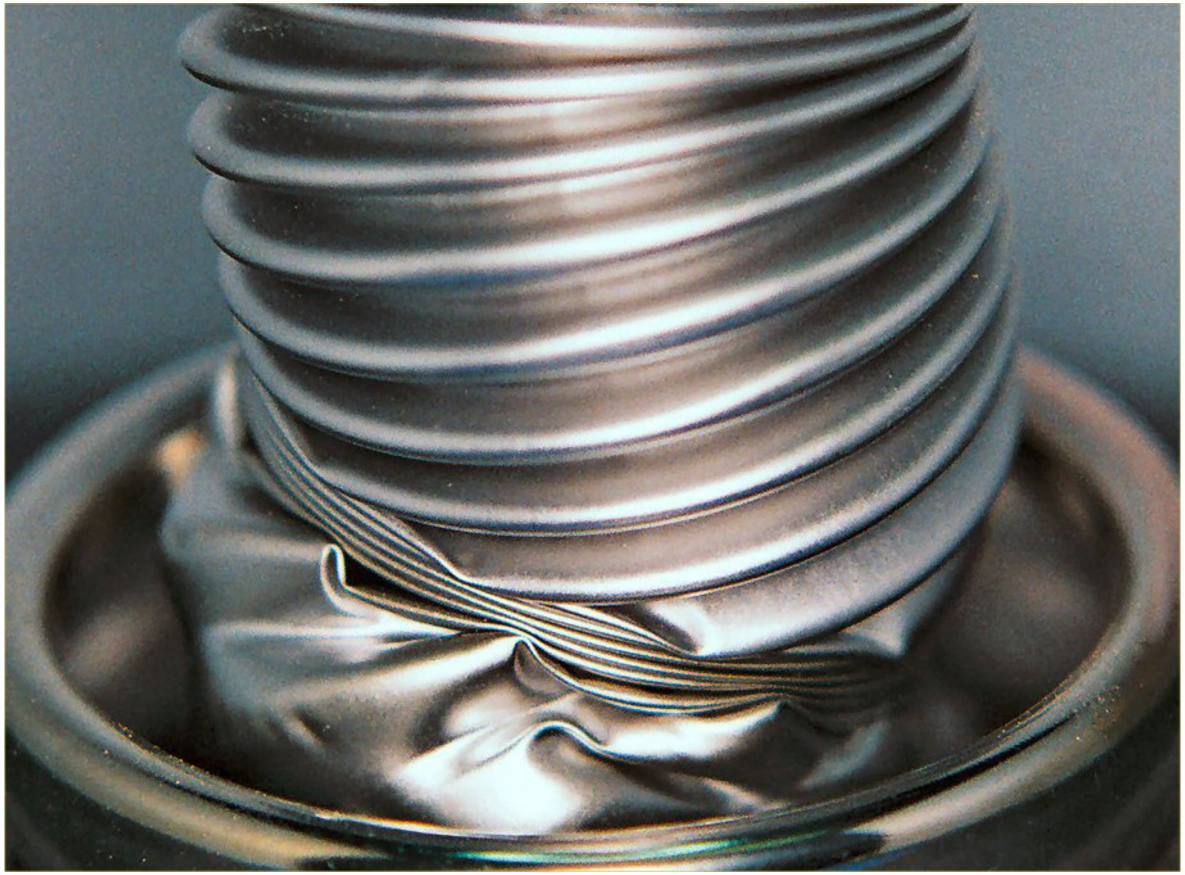
Causes of Loss of Vacuum

Mechanical Damage - Twisted Bellows



The bellows is the mechanically weakest part of the VI and is protected in different ways by different manufacturers

– this VI lost vacuum in service due to the bellows being twisted during installation of the VI in the circuit breaker

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Causes of Loss of Vacuum

Penetrating Corrosion

Although VI are generally corrosion resistant, in certain environments corrosion over a long period can be a problem.

– this VI lost vacuum in service after more than 20 years due to penetrating corrosion of the moving endplate/bellows joint

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Service Experience & Investigations to date

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Service Experience

Today

- There are tens of millions of vacuum interrupters in service worldwide

- Each year over a million vacuum interrupters are manufactured and put into service

- The MTTF of vacuum interrupters is estimated to be c 44,000 Interrupter-Years (within the normal Storage Life period)

- The industry standard for many manufacturers is a Storage Life of 20 years

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Service Experience

Today

- Generally VI do not wear out in normal applications

- Certain applications – arc furnace, rail traction, capacitor bank switching may result in significant VI wear after very large numbers of operations – normally related to the mechanical life of the bellows.

- The Storage Life is not directly related to useage and more data is needed to understand the true life and risk of loss of vacuum after the 20 years or so manufacturer‘s rated life.

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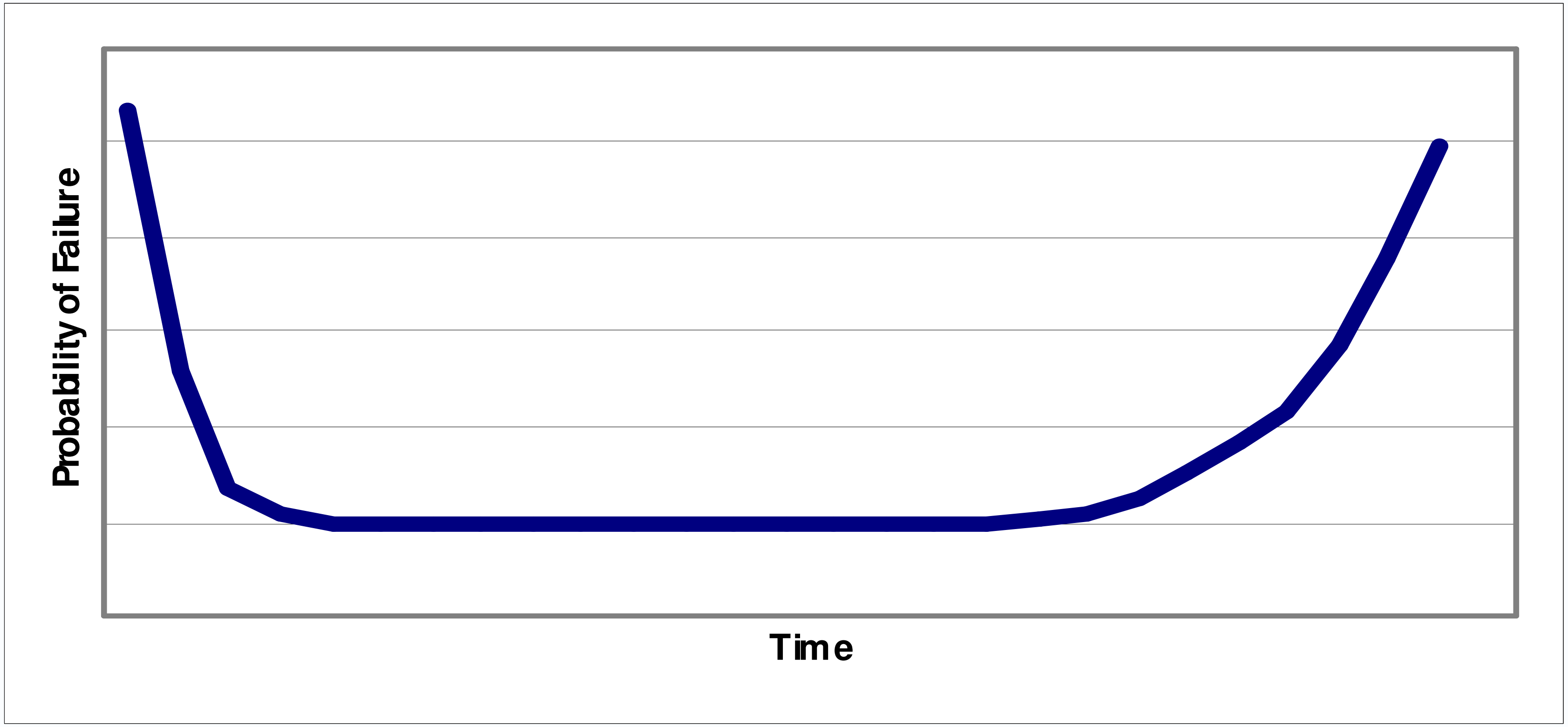
Storage Life

Summary



The classic “Bathtub Curve of Failure”. The difficult part with a new technology is to know where you are on the curve. The design life should be limited to the flat central part of the curve.

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VI Magnetron Testing

Summary of vacuum test results of 50 VI which were in service and were over 25 years old. These will all have had a pressure lower than $5x10^{-6}$ mbar at seal off.

No. Found	Pressure on first test (mbar)
2	10^{-7} or No Discharge
6	10^{-6}
7	10^{-5}
24	10^{-4}
10	10^{-3}
1	HT Failure (Paschen minimum)
Total 50	

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Vacuum Interrupter Life

Summary

- Vacuum Interrupters have extremely large mechanical and electrical lives and as such normally do not wear out in service.
- Vacuum Interrupters have proven to be extremely reliable during their service life of 20 years - However increasing numbers are now exceeding this life.
- Once we have sufficient experience we will be able to calibrate the bathtub curve and determine the risk level and probabilities of failure for VI with time.
- The one thing that is certain is that if interrupters are left in service indefinitely the vacuum insulation will eventually fail.

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Discussion

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