Heat Treatment

INDUSTRY

- Homogenisation
- Stress relieving
- Normalising
- Hardening
- Tempering
- Annealing
- Brazing
- Out-gassing
- Low pressure carburising

invensys EUROTHERM

The Vacuum Furnace Process

Application Note

Vacuum furnaces are widely used in heat treatment processes, and vary widely in capacity and size.

Equipment has consistently been improved over the last 30 years such that vacuum processing has become a widely used application in the Aerospace and Automotive Industry.

Vacuum is considered to be any pressure which is below atmospheric pressure and in industrial applications may be expressed as torr, microns or millibars.

Typical ranges for furnaces

Vacuum Range	mBar
Atmospheric (ambient)	10E+3
Rough to medium vacuum	10E+3 to 10E-3
High vacuum	10E-3 to <10E-7

Vacuum effects

The effects of treating components in a vacuum are two fold

1. In the medium-high vacuum region the partial pressure of the residual air in the furnace particularly O^2-H^2O is significantly reduced and will provide an environment to process components with little or no surface oxidation.

The reduction of residual Nitrogen (N^2) is also beneficial for materials, which would otherwise form nitrides.

2. Decomposition of existing oxides in the surface of components may occur depending on the temperature and material type.

Mechanical equipment

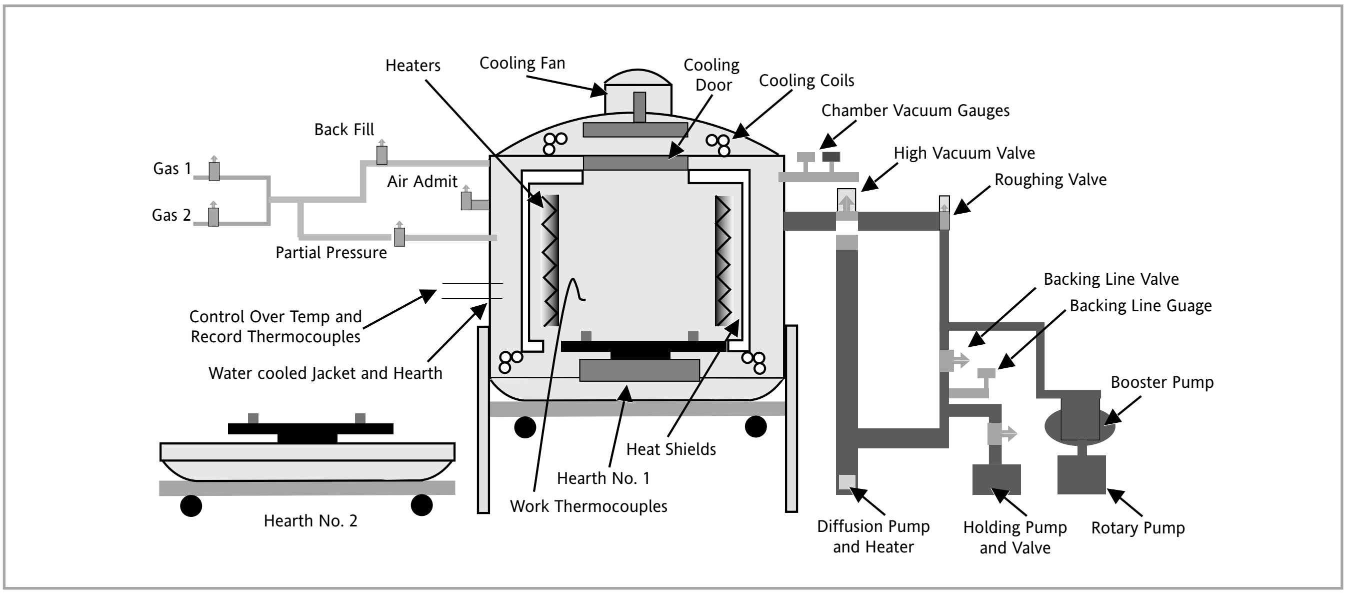
Vacuum furnaces take many different mechanical formats, designs include common components, such as;

- Work piece chamber or mutiple chambers usually with water-cooled jacket, loading and transfer mechanism
- Heat shields made of graphite board or high temperature material
- Furnace furniture constructed of graphite or other high temperature material
- Heating element often Graphite or alternatively Molybdenum or high temperature material for temperatures above 1000°C
- Vacuum pumping system
- Partial pressure control
- Optional fan assisted circulation systems for annealing processes
- Quenching vessels and/or gas/fan quenching system
- Cooling system
- Control system

The cellular concept of vacuum processing is becoming more widespread with multi-cell layouts used to integrate heat treatment into shop floor production and manufacturing.

A typical simple single chamber vessel furnace is shown in figure 1.

Figure 1 Typical single chamber bottom loading vacuum furnace



Control system

Each part of the process cycle calls for specific control features.

1. Furnace programmable controllers to accommodate sequencing and monitoring of digital actions and overall furnace interlocks.

2. Vacuum pump sequencing control system

The vacuum pumping cycle requires the control system to interface with multiple low, medium and high vacuum gauge types. The mechanical pumps and high vacuum vapour pump need to be sequenced in a controlled way to ensure that the furnace is properly evacuated without damage to the pumps or back streaming of oil into the work chamber. The sequence is processed by comparing the actual value of backing line or chamber pressure to series of pressure setpoints in the medium/high vacuum range. The sequence may also include, pump rate efficiency timers, leak rate testing and out gassing algorithms as well as furnanace process and heater interlocks.

Figure 2a
Pump startup sequence example

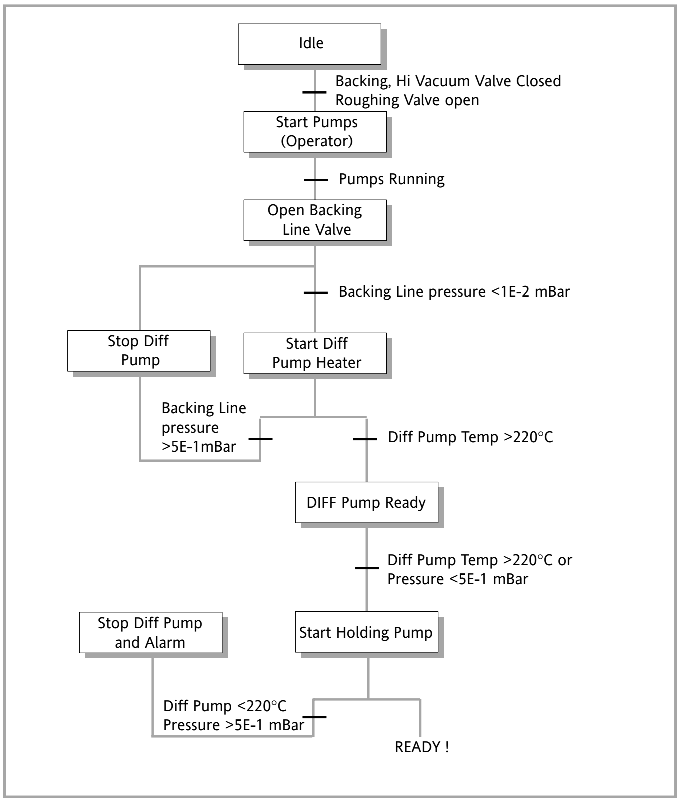
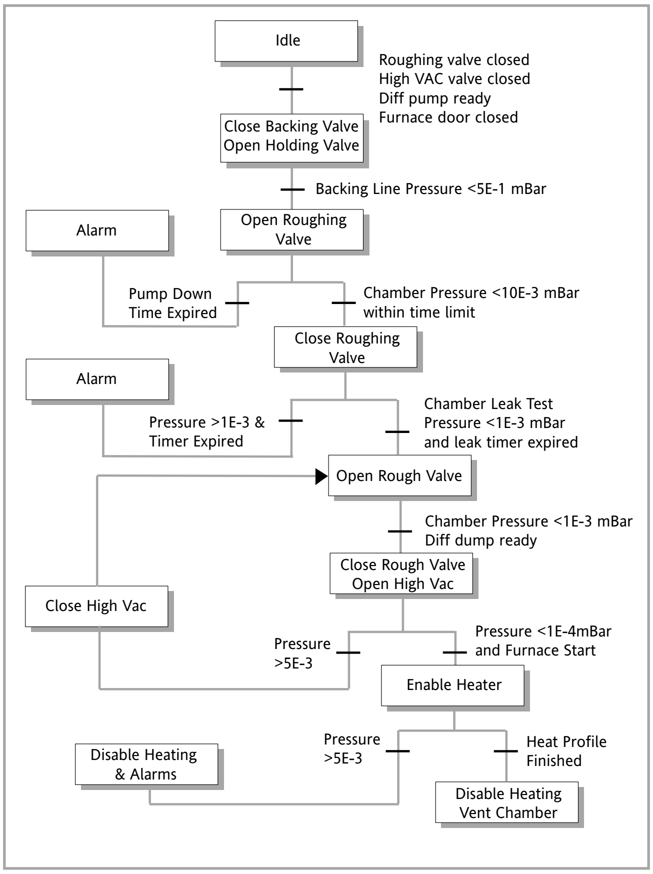


Figure 2b
Chamber pump down flow chart/sequence example



3. Heat treatment programming controllers

Vacuum heat treatment cycles are often complex and require multiple stage profiles. These profiles are defined against material and component specifications and are usually maintained against controlled recipes.

Temperature programming profiles are often carried out over multiple segments where accurate control needs to be maintained during both the black heat and radiant heat regions. The cycle will most often follow defined heating rates and dwell periods depending on the treatment process being carried out. Special control optimisation routines to automatically deal with the variation in process gain for large size furnace loads and the black heat radiant boundary, can lead to improved cycle times and product quality.

Since heat treatment is a scientific process it is important to ensure that the workload follows the defined profile and special mechanisms must be employed to eliminate over-shoot and to provide work piece thermocouple tolerance and compliance.

Partial Pressure may be contolled within the work chamber by adding a controlled flow of high purity inert gas. Since some materials have relatively high vapour pressures they will exhibit signs of surface evaporation at medium to high vacuum levels. The purpose of partial pressure control is to raise the pressure level of the work piece chamber to prevent this otherwise detrimental effect.

The Cooling process either, vacuum or aided cooling and Gas-Gas/Fan quenching routines are common requirements.

Most modern furnaces include highly efficient heat exchangers and rapid cooling fans to aid the cooling and quench process. Vessels are designed to operate at back fill pressures in excess of 10Bar and the sequence must provide control of this part of the cycle.

Some furnace cycles also make use of back filling with inert gas or the use of circulation fans during the heating process this is to aid heat transfer below the radiant heat range. For cellular installations optional oil quench systems may be built into the design.

A simple typical profile is shown in Figure 3.

4. Electrical Power Control

Vacuum Furnace heaters are made of Graphite, Molybdenum or occasionally other high temperature alloys, they usually operate at voltages lower than the available mains supply and are connected to the supply through a transformer or saturable reactor.

The element material must not be exposed to an oxidising atmosphere whilst it is at temperature and special pressure interlocks in the vacuum controller are employed to prevent this. Thyristor power controllers are used to give the best results when the heaters are coupled to the supply via a transformer.

5. Interface with vacuum gauges

Special consideration needs to be taken over the interface of the control system with various types of vacuum gauges which are available.

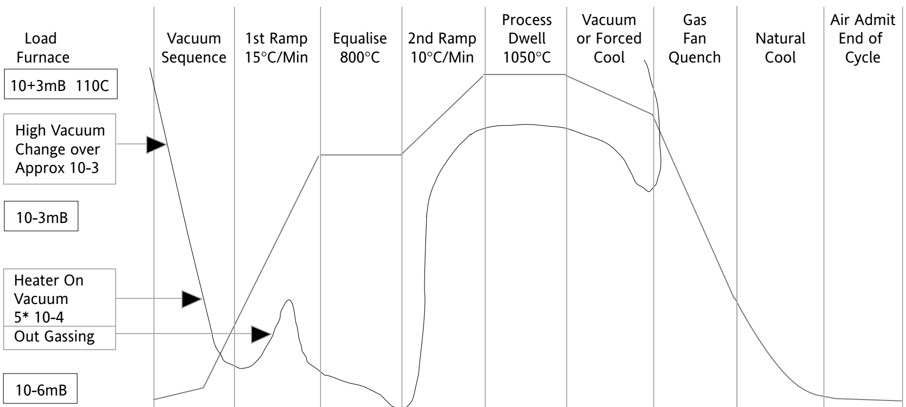
Modern gauges tend to be of the wide range or active type where the output span is scaled to coincide with a defined logarithmic range of vacuum. Eurotherm control solutions employ standard input linearisation to accommodate many industrial vacuum guages and where new ones are used a simple technique is available to recalculate the linearisation required.

Typical Active gauges are:
Atmosphere to medium vacuum 10E0 to 10E-4; Pirani gauges; Thermocouple gauges; and Strain gauges

Vacuums in the range 10E-2 to 10E-9, Ion gauges; and Inverted Magnetron Gauges.

Wide or Full range gauges employ more than one measuring technique but have a continuous output across the range 10E0 to 10E-9.

Figure 3 Typical profile



Furnace interlocks	Active	Active	Active	Active	Active	Active	Active	Active	Active
Vacuum sequence	Pump down	Monitor	Monitor	Monitor	Monitor	Monitor	Isol	Isol	Isol
Partial pressure				On	On	On			
Workpiece monitor			On	On	On	On			
Vacuum cool						On			
Forced cool						Choice			
Gas fan quench							On		
Natural cool								On	
Air admit									On

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