

Dual chamber vacuum furnace for Low Pressure Carburizing (LPC) and High Pressure Gas Quenching (HPGQ)

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Dual vacuum furnaces with separated heating and cooling processes are providing several advantages when compared to single chamber vacuum furnaces. This includes faster heating up, less energy consumption, more quenching severity and less maintenance. Accordingly a new, "second generation" of dual vacuum furnace for low pressure carburizing and high pressure gas quenching, DualTherm®, was developed using proven technologies from the ModulTherm® series of vacuum furnace systems. The first furnace was recently installed at a commercial heat treater and is now in three-shift-operation.

Introduction

Single atmospheric heat treating furnaces that separate the heat process from the quench process have been available since the first atmosphere based internal quench furnaces were introduced in the mid 1900s. Similarly, vacuum furnaces that separate the heating processes from the oil quench processes have been on the market for decades. It is only in recent years, since the viable commercial development of acetylene based vacuum or low pressure carburizing, that the technology reaffirmed a 1994 ALD development by incorporating high pressure gas quenching into the two chamber vacuum furnace scenario.

This two chambers or "cold chamber quenching" concept titled DualTherm® (Fig. 1), integrates the benefits of vacuum processing and high pressure gas quenching however takes each to its logical conclusion by applying three basic rules:

- When at vacuum and at temperature, stay that way.
- When quenching, quench only what you need to quench.

- Load movement mechanisms don't belong in either process environment.

Intuitively, it makes sense to separate the processes of heating, cooling and load movement. Having a specific design to accommodate the unique

requirements of each function provides the best opportunity for to get the most from each function.

Staying at steady temperature and vacuum provides numerous advantages including:

- Workloads can heat up as fast as the materials are able to absorb the heat
- Energy is applied to heat the load, not the hot zone and insulation for each cycle
- No thermal cycling of the hot zone means it will last years beyond that in a conventional batch vacuum furnace
- Much higher efficiency hot zone designs can be employed since no cooling system is required



Fig. 1: Dual chamber vacuum furnace, type DualTherm®

- Hot zone is not stressed by high-pressure/high-speed gas flow during quenching process resulting in significant extension of life-time of hot zone
- Lower energy levels are required due to higher efficiency hot zones

Cold chamber quenching advantages include:

- Greater cross sections of lower alloyed materials can confidently be quenched
- Ultimate control of gas distribution for a more uniform quench
- Simplified baffling system enables alternating gas flow paths for quench distortion control without interference from load handling or load heating equipment
- Fastest backfill speed to maximum pressure is possible without fragile hot zone concerns
- Separated load movement mechanism advantages include:
 - Mechanism sees hot zone temperature only when loading/unloading heat chamber.
 - Mechanism does not provide obstacles for quench gas flow paths.
 - Motors and switches are located outside the vacuum environment

When comparing to standard, single chamber batch vacuum furnaces, DualTherm® furnaces stand alone. Focusing the entire quenching effort on the workload enables quenching of comparatively lower allowed metals. Concerns of imploding hot zones are

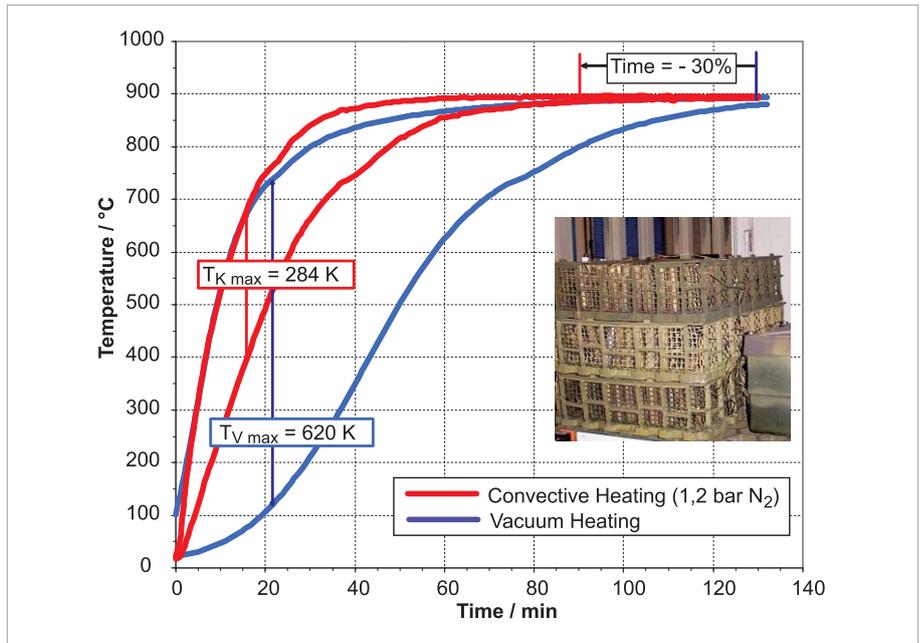


Fig. 3: Comparison of Heating-up characteristics using vacuum and convective heating processes

eliminated making a 3 second backfill to 20 bar routine thereby getting the quench speed “ahead of the curve”. Further, the hot zone insulation erosion problems due to high velocity cooling gas flows don’t exist in this configuration. Naturally, this significantly reduces routine hot zone maintenance and eliminates the “grit blasting” of the workload during quench.

Further, while LPC is possible in a standard batch vacuum furnace, it is only a matter of time before the heat exchanger behind the hot zone is plugged with soot. Then of course the

quench motor is also susceptible to carbon soot. Not to mention the carbon soot (being blown around within the hot zone) will cause vacuum leaks in the door seal. Is soot finding its way into the quenching motor? How long will it take until 30 or more heating element supports short to ground? These furnaces, by nature must include cooling gas paths within the hot zone for cooling gas flow. It is well known that the carbon from the LPC process builds up on these “cold spots” within and around the hot zone. These furnaces also require a more complex heating element arrangement and support systems that are prone to electrical shorting. Some manufacturers are actually endorsing “air burn-outs” of graphite hot zones. Surprisingly, it’s the same manufacturers that have cursed air in graphite hot zones since their inception. Endorsed by the manufacturer or not, this will significantly limit hot zone life.

The latest generation of DualTherm® was developed using proven technologies from the ModulTherm® series of vacuum furnace systems. With more than a hundred treatment chambers in operation worldwide, these “system modules” have withstood the test of time and proven their abilities.

Plant assembly

As said, the DualTherm® vacuum furnace is a two-chamber vacuum heat

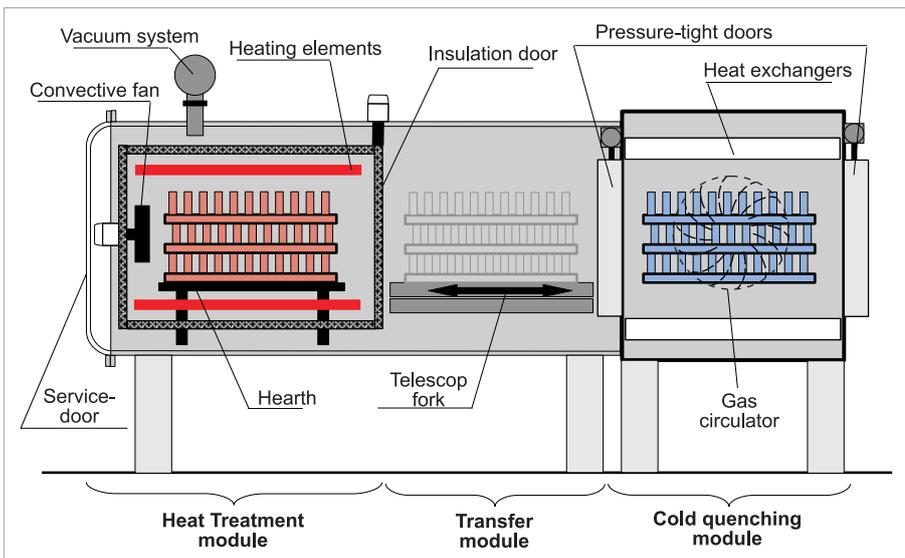


Fig. 2: Schematic sectional view of DualTherm®

treatment system. A schematic sectional view of the system is shown in **Fig. 2**.

The heating chamber is equipped with a "tight" hot zone (no cooling paths needed) encompassing multiple layers of graphite/ceramic insulation. The graphite heating elements are arranged around the sides of the workload ensuring fast and uniform heating of the workload to a guaranteed $\pm 5^{\circ}\text{C}$ uniformity. Naturally, all modern day vacuum furnaces provide the option for convection heating and DualTherm® is no exception. For this purpose, after evacuation, a carrier gas (nitrogen) is fed into the heating chamber; this is circulated during heating.

Convective heating offers several advantages including:

- Lower temperature gradient on individual components and within the workload
- Faster heating rates; particularly effective on densely packed workloads
- Uniform heating throughout the heating event

Fig. 3 shows a comparison between vacuum and convective heating processes. A densely packed load of bolts with 25 mm Dia. was heated to 890°C . Heating curves were recorded by means of a furnace tracking system using thermocouples in the core of bolts, equally distributed within the load. The heating curves for bolts with maximum and minimum heating rate were recorded for both heating technologies. As shown in **Fig. 3** convective heating leads to a significant improvement in heating uniformity while the total heating time could be reduced by 30%.

The treatment chamber hearth is of silicon carbide (SiC) featuring high wear resistance even at very high temperatures. There are no moving parts in the heating chamber, apart from the convection fan (made of CFC material) for the convective heating option.

For transporting workloads within the DualTherm® a set of telescoping forks are housed in the transport area. The drive mechanisms and sensor units as well as the transport system sensor guides are all located outside the vacuum environment for maintenance ease.

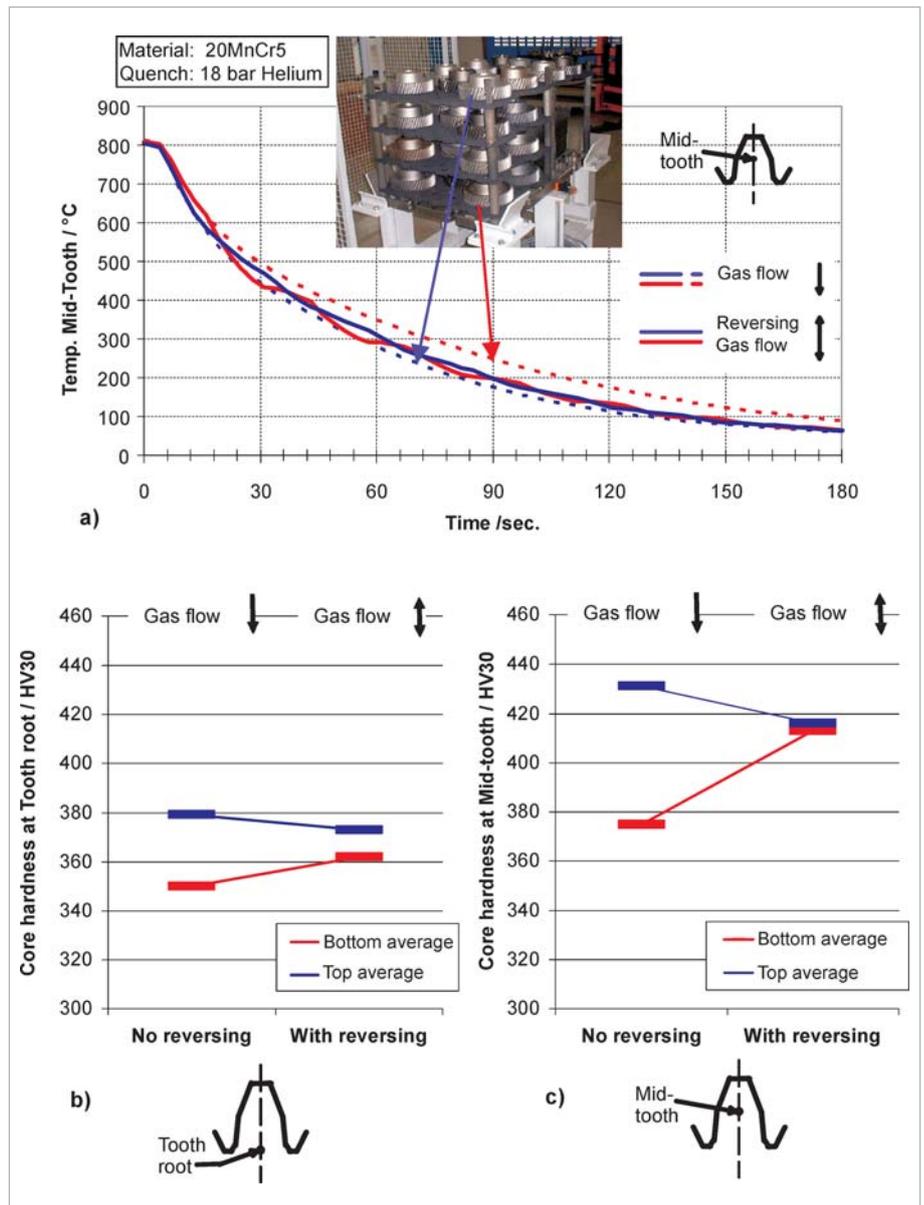


Fig. 4: Comparison of different gas quenching technologies and resulting hardness distribution in a load of truck gears

For quenching the workload a modular chamber was developed; capable of being adapted to the requirements of the specific customer components. The quenching chamber can be operated at pressures up to 20 bar.

Quench gas circulation is accomplished to the specific needs of the user. The process needs are identified and the quench system configuration is determined using:

- One or two quench fans
- One or two heat exchangers
- Dynamic quenching capabilities
- Reversing gas flows, particularly useful in distortion control for part weights in excess of 1 kg

- Variable fan speeds

These options provide a means to specifically provide the system required to meet the process needs. And of course, these capabilities can be retrofitted later as the user's needs evolve.

An example for the positive effect of reversing gas flow technology is demonstrated in **Fig. 4**. A load of truck gears was gas quenched from 820°C with 18 bar Helium by using gas flow from top to bottom and alternatively by using reversing gas flow. The cooling curves determined in the mid-tooth of gears located in the top and in the bottom of the load are shown in the upper graph (a). Being quenched from top to bottom the gears in the top layer showed a



Fig. 5: Gas quenching of a load of gear parts in the cold quenching chamber of DualTherm® a) shortly after the start of the gas circulator and b) 5 s later

faster cooling rate as compared to parts in the bottom layer, as one would expect due to the heating of the gas passing the load from top to bottom. By using reversing gas flow technology the cooling was much more uniform showing almost no difference between gears in the top and bottom layer of the load.

The different cooling characteristics resulted in different hardness distributions in the tooth of the gears as shown in the lower graphs in Fig.4. By using reversing gas flow technology the tooth root hardness spread of the gears (b) improved from 29 HV to 11 HV. For the mid-tooth hardness (c) there is almost no difference between top and bottom loaded gears as would be expected by the cooling characteristic shown above (a).

For high productivity maximum load size and load weight is of importance. DualTherm® offers an increased load height of 750 mm as compared to the 600 mm standard size, which can be used for additional 25% more load or to allow for especially long parts, i.g. gear shafts. While the standard load weight of this furnace category is limited to 500 kg, DualTherm® offers to load optionally up to 1000 kg.

Plant operation

The DualTherm® heating chamber remains at the user defined process temperature during operation and, except during convection heating, is always under vacuum. Shutdown is easily initiated by disabling the heat and leaving the unit under vacuum (either pumping or off). When needed, heat up to temperature is achieved in approximately 30 minutes.

At the start of the process the quenching chamber is used as a "vacuum lock", in which the air (it's been opened to atmosphere) is removed by simple evacuation. Then, via the transport mechanism, the workload is charged into the treatment chamber for its user defined thermal process.

Following heat treatment, the transport mechanism retrieves the workload from the treatment chamber and places it in the quench chamber. This transport is accomplished very quickly to ensure minimal workload temperature loss prior to quench. Once in the quench chamber, high pressure gas quenching takes place as controlled by the applicable recipe (**Fig. 5**). In addition to maximum quenching, it is also possible to use staged quenching, known as "Dynamic Quenching" where the circulation fan speeds as well as the chamber pressure are controlled during quenching.

Following high pressure gas quenching the components are clean, dry and bright and need not be cleaned.

Processes

The DualTherm® can be used for annealing at temperatures up to 1250°C as well as for low pressure carburizing up to 1050°C. When equipped with multiple quench gases (i.e. nitrogen, helium, argon) it is also possible to treat tool steels, rapid machining steels or Powdered Metals (PM) in addition to low alloyed tempering steels and case hardening materials.

The DualTherm® is also capable of:

- Vacuum brazing processes

- Annealing under convection up to 950°C
- Annealing with a partial pressure up to 1250°C
- Hardening at temperatures to 1250°C with different gases and with a maximum quenching pressure of up to 20 bar
- Low pressure carburizing with high pressure gas quenching
- Low pressure carbonitriding
- Vacuum brazing with subsequent fast cooling

System control and operation

For "operating and observing" the DualTherm® includes a swing arm mounted panel PC conveniently positioned near the workload entry door. At this PC, all treatment recipes are entered, stored and executed. Often required, user specific data (load number, part numbers, quantities) can be entered for each specific workload.

The PC is also the storage facility for all historical data including process parameters and fault messages. Naturally, process information can be viewed in real time and historical trends via the graphical user interface.

Finally, the PC can be networked to most factory systems. The information can also be backed up to a CD/DVD drive. As would be expected, all furnace movements and functions are PLC controlled.

Maintenance and service

The DualTherm® designers placed particular importance on maintenance ease. All components to be serviced are presented for easy access. For internal maintenance a service door is provided at the rear. After the heating chamber as cooled down, and following the subsequent release to atmosphere, the service door can be opened providing easy access to all hot zone components.

Additionally, without the repeated thermal cycling (up and down) required of a single chamber furnace, the hot zone has to be maintained far less. One more nicety is that the fragile hot zone is isolated from the operator. There is no more risk of damage due to an operator error.

The vacuum pump set is fitted directly to the furnace chamber. The pump oil is filtered allowing long intervals between oil changes, even for carburization processes.

Summary

The compromises required to own and operate single chamber vacuum furnaces are now being fully appreciated. This is a result of the needs for higher quenching pressures and the growing industry requirements of vacuum carburizing (LPC).

Separations between cooling and heating processes provide the best opportunity for the highest performance. Specific designs for each function enable this peak performance.

When considering utilities, it's far less expensive to maintain a furnace at operating temperature than reheat the entire

hot zone and insulation pack with each cycle. Also, when quenching one can get as much as possible from the quench gas chosen. This can best be done with a chamber designed specifically for quenching workloads. The design results in a significant reduction of quench gas consumption. Both are solid reasons making the DualTherm® concept far more environmentally friendly.

This new, "second generation" DualTherm® was first installed late in 2007 at Härte- und Oberflächentechnik Chemnitz, Branch Works Hohenstein-Ernstthal. In this plant, in three shift operation, gears and pinions for hydraulic transmission systems are carburized at low pressure and hardened by high pressure gas quenching.

The DualTherm® is easily integrated into the production environment further advancing it as the vacuum furnace design for the future. ■



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