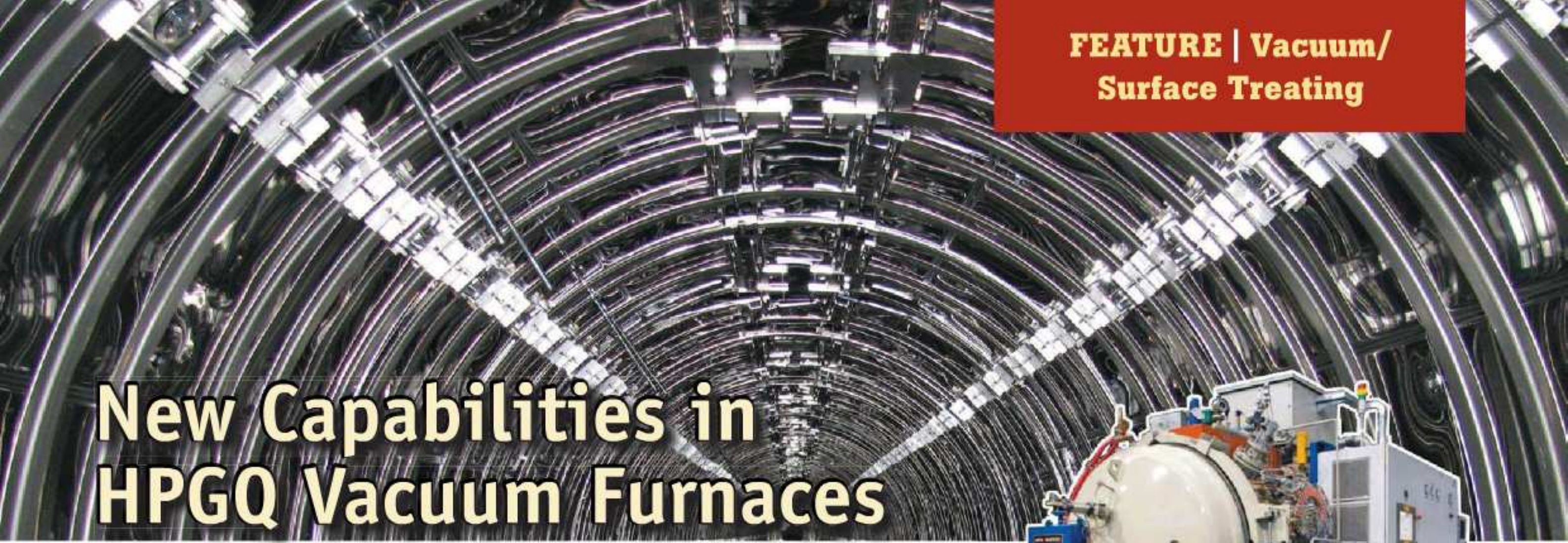

New Capabilities in HPGQ Vacuum Furnaces

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HPGQ vacuum furnaces are commonly used for heat treating high-, medium- and low-alloy steel tools, HSLA steel products and for individual applications of low-pressure (vacuum) carburizing (LPC) technology.

Fig. 1. Furnace 25VPT4035/36 (24 x 24 x 36 inch) 800-kg charge capacity

Vacuum furnaces are manufactured with 6- to 25-bar gas-cooling systems with nitrogen and occasionally helium being used as a cooling agent. These furnaces have 200 to 5,000-kg charge capacity, mainly with horizontal charge loading. Furnaces having larger charge capacity and larger heating chambers are generally designed for a specific technical purpose, whereas furnaces having smaller charge capacity and smaller heating chambers are suitable for various technological applications. It is now possible to adapt a furnace for hardening of tool steel and HSLA steel while also being able to low-pressure vacuum carburize (LPC) the majority of steel types, including the use of optimizing technologies such as FineCarb, PreNit, vacuum nitriding, etc. An emphasis on cost efficiency of the implemented processes is as important as always, and it also drives new opportunities.

Assembly Time of the New-Generation Vacuum Furnaces

When purchasing equipment, investors are interested in quick assembly and start-up time. A delivered furnace must be pre-assembled to the maximum possible extent in order to eliminate or substantially limit the required assembly work. Vacuum furnaces manufactured by SECO/WARWICK with 16 x 16 x 24 inch (400 x 400 x 600 mm) and 24 x 24 x 36 inch (600 x 600 x 900 mm) charge loading dimensions meet these requirements. At the same time, the furnace footprint is small. The assembly and start-up time of these furnaces is short. In many cases it is possible to limit start-up to three days, including operators' training. Figure 1 is an example where the furnace body, the equipment and control cabinet are mounted on one transport plate. The furnaces can be installed by means of forklift truck, overhead crane or transport rollers. The only elements disassembled for transportation purposes are the transformer and the pump system. Their re-assembly takes a maximum of 2-3 hours.

Energy-Saving Power Control System for HPGQ Vacuum Furnaces

At present, furnace evaluation involves technological capacities, efficiency, operational reliability and life of the systems (including heating chamber) in addition to minimization of the amount of used consumables and energy factors. Improvements in these variables can be achieved in many ways:

- By using more efficient components such as electrical motors
- By using transformers for heating elements
- By using heating-chamber insulation
- By reducing the number of components
- By means of suitable control systems

A typical HPGQ vacuum furnace has two major systems consuming electric energy in the process of heating and cooling. Each of them is traditionally equipped with an individual power control system. Thyristor drivers or a transductor are used in the process of heating, and a soft-start or a blower-motor frequency inverter is used in the gas-cooling process. Because of the fact that heating and cooling stages are always separated in the furnace operation sequence, only one power control system is on. This was the premise for designing a single, universal system that would control furnace heating power and its cooling rate alternately. The energy-saving power control system for vacuum furnaces developed by SECO/WARWICK *(US patent 7,193,188 and EU patent)* employs an inverter, which has a number of advantages

Fig. 2. Power control elements in a control cabinet; left – traditional, right – with inverter

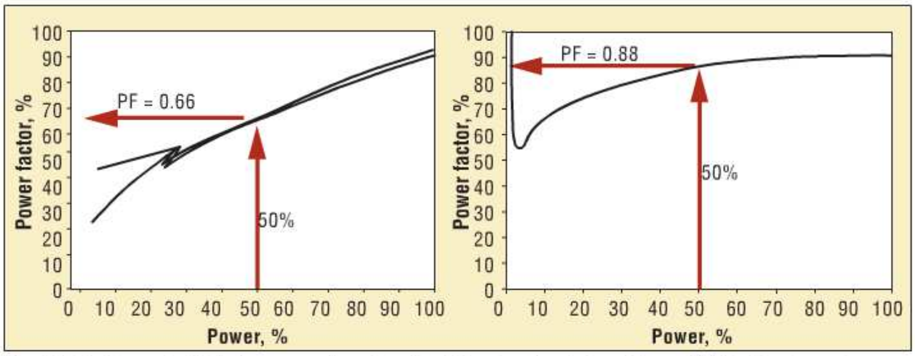

Fig. 3. PF characteristic in power function P; left – for thyristor driver, right – for inverter

over the traditional system and competing solutions:

- A very precise stepless regulation of heating power is assured while enabling a gas-cooling intensity regulation within the whole range of blower speeds. Previously, this was only possible for slow speeds.
- It is now possible to realize advanced processes with controlled cooling, including martempering and austempering.
- The cooling system can be easily adapted and optimized for using a variety of gases and their mixtures (N_2, Ar, He, H_2).
- The control cabinet is smaller (Fig. 2).

Very high performance parameters were achieved in the area of energy efficiency:

- The power factor (PF) of the heating system was increased in comparison to thyristor control.
- PF of the blower motor was increased in comparison to the direct power supply.
- Power network overload occurring during start-up (at the nominal electric current) was eliminated.

The power factor (PF) is defined as a ratio of active power P to apparent power S; PF = P/S. Power factor defines the portion of power consumed by P load in relation to the delivered power S and should be as close to 1 (100%) as possible. Every method of the stepless regulation of the power delivered to any receiver is associated with reduced energy efficiency of the appliance, which results in reducing PF. In order to illustrate this effect, PF of the standard 24 x 24 x 36 inch HPGQ furnace system was compared using power regulation by means of a phase-released thyristor driver and an inverter (Fig. 3). The diagrams prove that the higher the power reduction, the worse the power factor. The relation is stronger with thyristor control (SCR) than with inverter (INV).

At 50% of power (P), the PF for the thyristor driver is 66% (0.66), whereas for the inverter it is 88% (0.88). This demonstrates a strong advantage of INV (12% power loss) over SCR (34% power loss).

A test heat treatment was run in the 24 x 24 x 36 inch HPGQ furnace for both types of power control: a traditional one with the use of thyristor drivers and a new one with the use of inverter. Power and consumed electric energy were monitored during the process. The process involved heating the charge to 1000°C (1832°F) at the speed of 10°C/min, holding the temperature for the period of 3 hours and cooling the 600-kg (1,323-pound) charge in nitrogen at a pressure of 10 bar. Diagrams illustrate power and power-factor measurements during the process for SCR (Fig. 4) and for INV (Fig. 5) respectively.

The course of active power consumption (red) is almost identical for both processes and confirms that they are conducted in the same conditions, which is the basis for comparison. As expected, the most significant differences occur in the courses of passive power (blue) and of PF (green). The passive PV is much lower with INV, and PF value is much higher than with SCR.

Figure 6 illustrates the comparison of energy consumption, which can be the basis for estimating the cost of energy for

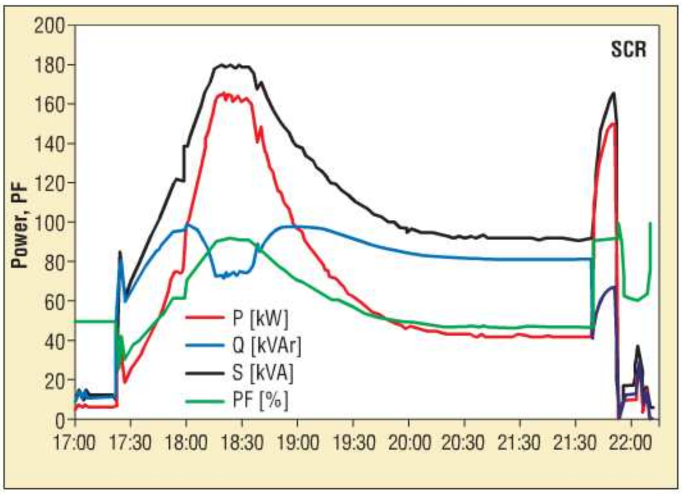

Fig. 4. Power and power factor in the referential process for traditional control (SCR)

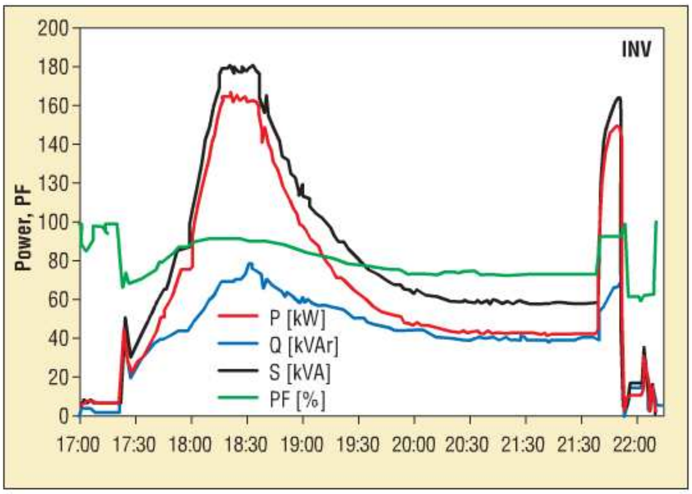

Fig. 5. Power and power factor in the referential process for inverter control (INV)

Fig. 6. Energy summary of SCR and INV

Energy consumption	SCR	INV	Savings	
Pt [kWh]	325	325	0	0
Qt [kVArh]	366	212	154	42%
St [kVAh]	489	388	101	21%
PF_{ay}	0.66	0.84	0.18	27%

both processes. The consumption of 325 kWh of active energy was accompanied by the absorption of 366 kVArh of passive energy for thyristors and only 212 kVArh for an inverter, which is 42% less. Data clearly indicates that an inverter energy-control system in a vacuum furnace improves furnace energy efficiency, reducing passive power consumption and the costs of electrical energy.

New Technological Capabilities of HPGQ Furnaces

Advanced process software solutions expand the scope of today's HPGQ vacuum furnaces.

HPGQ with Helium

The HPGQ cooling option, with up to 25-bar cooling-gas pressure (including helium), enables universal heat treatment comparable to quenching oils. The α factor of the achieved cooling speeds amounts to 1,800-2,000 W/m²K. Uniformity of cooling intensity within a furnace's total useful space fits into the range of +/-15%. The performance of a 25 VPT 4035/36 furnace (Fig. 1) was presented more thoroughly in the September 2009 edition of *Industrial Heating*. These furnaces can be equipped with helium recycling systems of up to 99.5% efficiency.

Interesting results were achieved during the most recent test of cooling a 16-inch cube of H13 steel, which was conducted according to GM-DC-9999-1 and NADCA specifications in the 24 x 24 x 36 inch furnace. Cooling speeds achieved at the side walls ranged between 200-250°C/minute (360°F/min), whereas the speed achieved in a typical 24 x 24 x 36 inch furnace with 10-bar nitrogen cooling system is 80°C/minute (145°F/min) with NADCA requirements of 28°C/minute (50°F/min).

Quench Simulator

Furnaces dedicated to heat treatment of tools, including hot-work steel tools, are presently equipped with a simulator that enables designing the cooling process for large parts and/or furnace loads and comparing actual results with the simulation. Thus, the heat-treatment process for expensive tools can be optimized to produce the highest-quality parts. Figure 7 shows the window of the G-Quench Pro simulator.

HPGQ with LPC

HPGQ VPT furnaces (<25 bar) are a very good and proven solution for LPC using FineCarb® technology. These furnaces can be used for a classic heat treatment of tools and HSLA steels or to carburize and harden a variety of alloy steels.

For carburizing processes, the furnaces are equipped with SimVaC® software – an advanced simulation program consisting of a vacuum-carburizing module, SimCarb, and a quenching module, SimHard

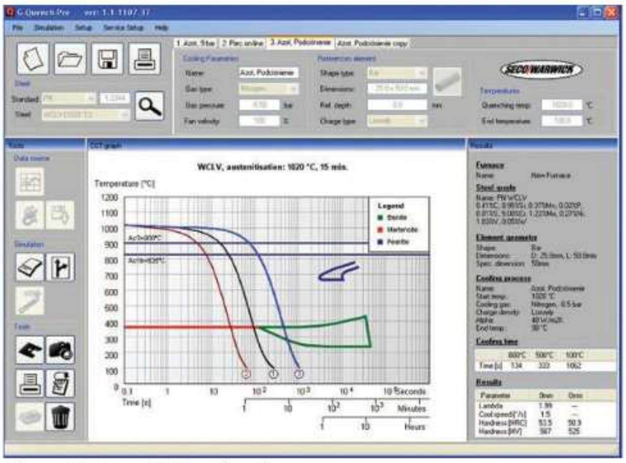

Fig. 7. G-Quench Pro simulator

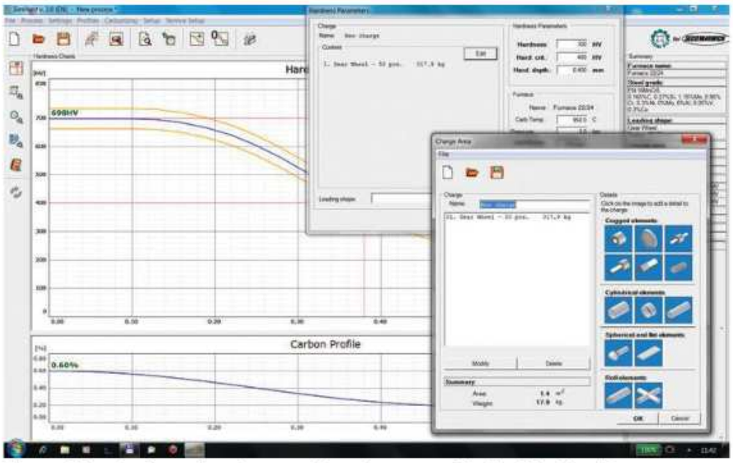

Fig. 8. Simulation of carbon and hardness profile by SimHard®

(Fig. 8). This software makes it possible to accurately predict process results. The process simulation predicts the carburizing-gas mix and presents the process result in the form of carbon profile and hardness depth profile. The simulation suggests the process based on a depth requirement.

The system takes into consideration the steel grade, shape and geometry of treated parts, charge surface size, surface carbon concentration, carbon depth requirement, carburizing temperature, boost and diffusion sequence. Also taken into consideration is the pre-cooling phase before hardening, the cooling-gas type and pressure, and the size of the furnace.

Simulation program SimVaC® is a necessary support for the technological functions of the furnace, predicting the results of the carburizing and quenching processes. The high accuracy of the simulation and its consistency with the real process results limits or even eliminates the need for conducting research and decidedly accelerates the process optimization.

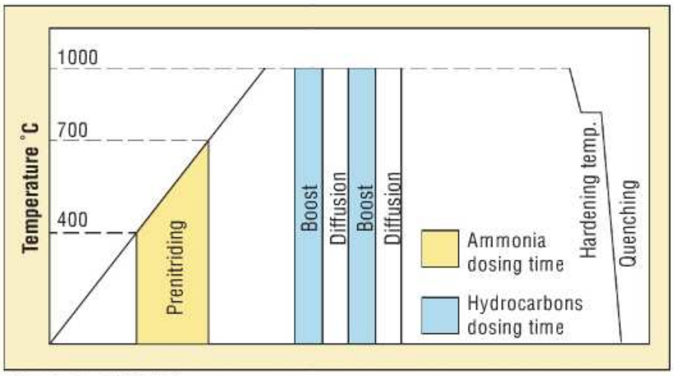

Fig. 9. PreNitLPC® process

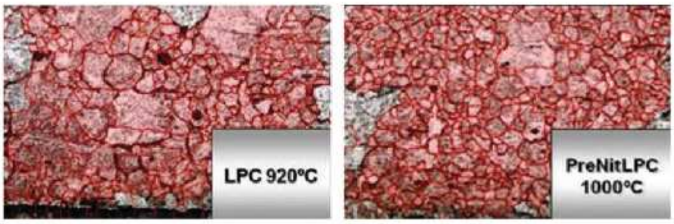

Fig. 10. Austenite grain size of 16MnCr5 steel after carburizing for 0.6 mm ECD by regular LPC at 920˚C (left) and PreNitLPC at 1000˚C (right)

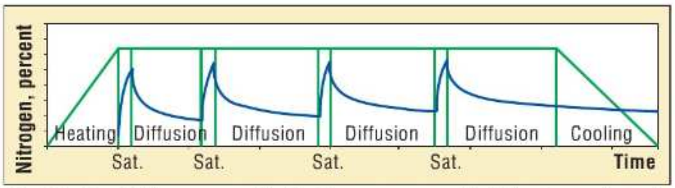

Fig. 11. FineLPN – new method of low-pressure nitriding for tool steels

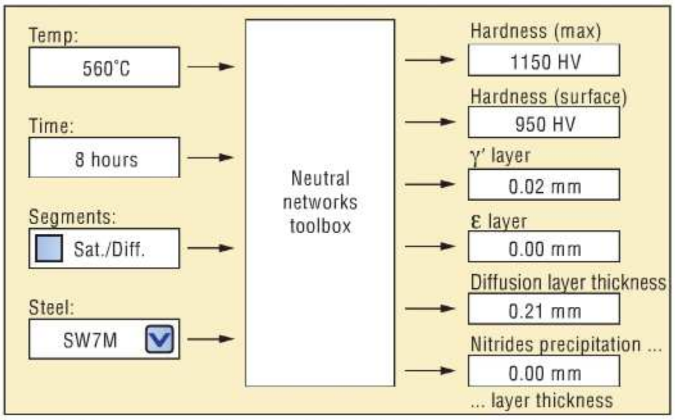

Fig. 12. An example of forecasting nitriding results using the SimLPN module

PreNit® Technology

The next stage in the FineCarb® vacuum-carburizing development is the carburizing technology supported by nitriding – PreNitLPC®. This technology involves feeding ammonia in the initial phase of the process – at the stage of heating for carburizing (Fig. 9). Nitrogen being introduced into the surface layer supports the carburizing process by accelerating carbon diffusion, reducing the tendency to create carbides and, most importantly, considerably limiting austenitic grain growth. These advantages make it possible to reduce the process time by increasing the carburizing temperature. At the same time, the achieved layer has the appropriate microstructure and mechanical properties, which are not inferior in comparison to those obtained in traditional processes at a lower temperature.

Using traditional carburizing at the temperature of 925°C as a reference, the process time can be reduced by half at 980°C. It is possible to further decrease the process time three, four and five times at temperatures of 1000°, 1020° and 1040°C, respectively. In order to obtain the effective case depth of 2 mm for 16MnCr5 steel, the process will last 22 hours at the temperature of 925°C, whereas it will take less than 5 hours at 1040°C.

Thanks to the use of the PreNitLPC® method, it is possible to carburize at the temperatures of 1000°C and higher without changing the austenitic grain size. Figure 10 illustrates a comparison of the microstructure of a 0.6-mm carburized layer obtained in a vacuum furnace at the temperatures of 920°C and with the use of the PreNitLPC® method at 1000°C. As can be observed, in spite of the high temperature, the grain size in the layer is smaller after the PreNitLPC® process and amounts to 13.6 µm in comparison to 16.7 µm in LPC process alone. As expected, the grain size outside the carburized layer in the core is larger for a higher temperature and amounts to 19.2 µm for PreNitLPC® at 1000˚C and 17.2 µm for vacuum carburizing at 920°C.

Further testing of mechanical properties obtained in PreNitLPC® high-temperature processes proved them to not be worse than those obtained in traditional temperature processes. Tests of comparative hardness, fatigue resistance, pitting and impact resistance were conducted for this purpose.

HPGQ with Vacuum Nitriding

Tool steels hardened and tempered in HPGQ vacuum furnaces can be nitrided utilizing the FineLPN technology. Nitriding takes place during the second and third tempering cycles. Nitriding, illus-

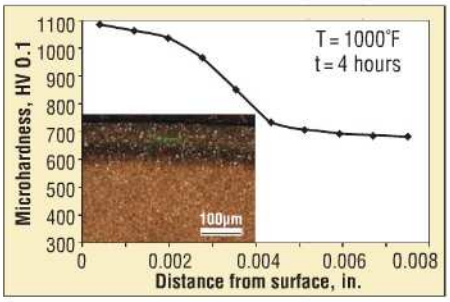

Fig. 13. FineLPN nitriding, HS6-5-2 steel (1.3343, M2)

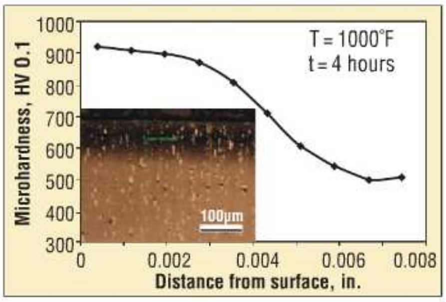

Fig. 14. FineLPN nitriding, X38CrMoV5-1 steel (1.2343, H11)

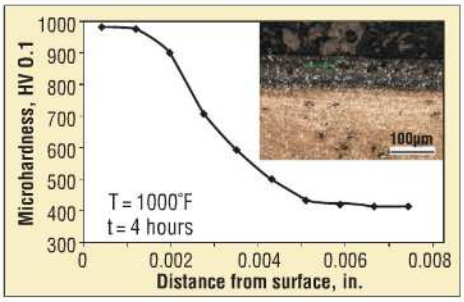

Fig. 15. FineLPN nitriding, X155CrVMo12 steel (1.2379, D2)

trated in Fig. 11, is similar to vacuum carburizing, where, with the appropriate process segmentation (NH_3 dosing, vacuum level and diffusion times), the structure and layer thickness for typical tool steels can be programmed (Fig. 12). The oxygen-free atmosphere of hardening and tempering processes preceding nitriding makes it possible to increase the nitriding uniformity in comparison to other methods of layer activation before nitriding.

Figures 13, 14 and 15 illustrate hardness distribution and typical structures achieved for the most commonly used tool steels (M2, H11 and D2).

Summary

A new generation of single-chamber vacuum furnaces is the result of ongoing vacuum-technology development at SECO/WARWICK S.A. The furnaces make use of a variety of technologies, and available process software makes it easy to operate them with precision. A single HPGQ vacuum furnace can be utilized for multiple technologies, making it very versatile. In the heat treatment of tools, it is possible to combine hardening and tempering with nitriding. These furnaces are prepared for quick assembly and start-up, and thanks to applied control solutions they result in significant energy savings. **IH**

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3. U.S. patent 7193188

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