Smart Control System Optimizes Vacuum Carburizing Process

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Smart control-system technology offers a new opportunity for vacuum heat-treatment applications with the option of selecting a low-pressure vacuum carburizing process cycle within a single Universal HPQ™ furnace system. It allows quick parameter selection without time-consuming experimenting, which is especially important for commercial heat-treating shops with variable, short-series orders.

Low-pressure vacuum carburizing is a process characterized by irregular, changeable conditions. The process requires a new generation control system and new solutions in the area of parameters selection to optimize the carburizing/diffusion and high-pressure gas quenching stages. Seco/Warwick's FineCarb© smart control/software system allows quick, precise parameter selection based on computer simulation. The system uses a special algorithm based on the latest developments in material science and on the irregular chemical reactions that occur during the carburizing/diffusion stage.

Vacuum carburizing is carried out in single- and double-chamber and multicell vacuum furnaces. Multicell furnaces mainly are used for high volume production, while single- and double-chamber vacuum furnace with a carburizing system option, such as the Universal HPQ™ furnace, are well suited for companies with a high-end product range, or just-in-time (JIT) production, such as commercial heat treaters. The single- and double-chamber units are flexible with a relatively low cost of operation and fast payback, and are adapted for use with the smart control system (Fig. 1 and 2).

System design

The FineCarb smart control system is designed around the latest solutions in the area of vacuum carburizing-parameter selection and optimization. It takes into account the grade of steel, carbon concentration profile, carburized layer microstructure requirements, shape of treated parts, size, homogeneity of the load and grain growth propensities at elevated temperatures. The control system:

- Creates the composition of the carburizing gas mixture required to simultaneously obtain a homogenous carburized layer on every surface of a particular part shape (e.g., in hollows and deep blind holes) to produce a clean part surface and totally eliminate soot and tar by-products [1]
- Selects the pressure-fluctuation characteristics in the carburizing phases [2] in accordance with chemical reaction rates of gas mixtures for an initially specified gas composition
- Controls the mass flow of carburizing atmosphere as a function of charge volume and carburizing process phase
- Limits grain growth by specific gas mixture proportioning during the preheating stage
- Optimizes the carburizing stage, diffusion stage and precooling before quenching to obtain the required car-

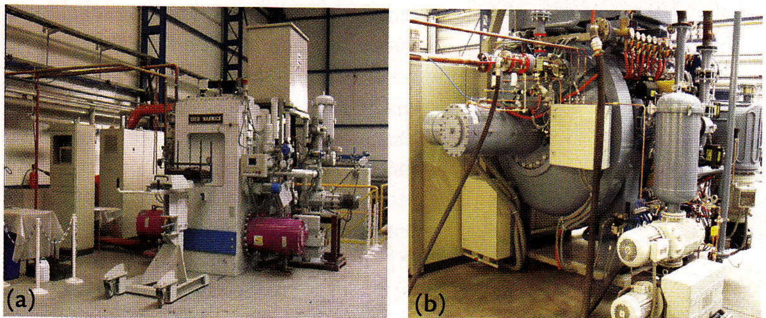

Fig 1 Special two-chamber furnace with cold chamber "ColdCam" (a) and Universal HPQ™ vacuum furnace with carburizing option (b)

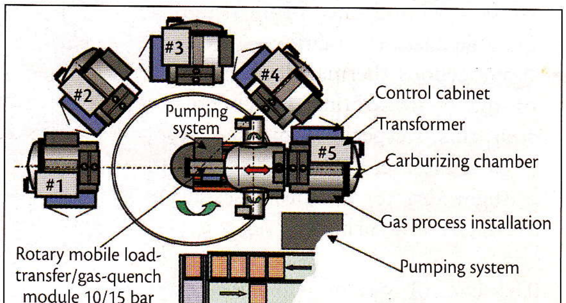

Fig 2 Multichamber system for vacuum carburizing serviced by universal gas cooling chamber

bon concentration profile in the diffusion layer for the specific steel grade and load geometry
- Records the process parameters used and final heat-treatment results

Carburizing mixture requirements

An optimized gas mixture with changeable composition must be provided for each new process based on load characteristics. The carburizing atmosphere is base on a carbon carrier consisting of two undersaturated hydrocarbons (ethane and acetylene) premixed in a specified, patented ratio [1]. Carburizing results are improved over those using atmospheres based on single carbon carriers [3,4]. The prepared carbon carrier can be mixed with the gas mixture.

The selected carburizing atmosphere composition is based on a detailed analysis of the mechanism and kinetics of chemical reactions, avoiding disadvantageous reactions and preventing undesirable results such as:

- Creation of aromatic rings and their polymerization (soot and tar); tar can result from propane-base atmospheres, and to in a lesser extent, from ethylene-base atmospheres [5-7]
- Internal oxidation in the carburized layer, which has been observed with acetylene-base atmospheres, and is related to the method of storage and distribution of this gas [1],
- Absorption of hydrogen (a product of chemical reactions) into the part surface, which blocks nucleation and carburized-layer growth in hollows and holes, and creates unfavorable stresses [6] and uncontrolled, unpredictable part deformation
- Homogenous thermal decomposition of the hydrocarbons, which creates soot; this is especially intense in case of propane use, but also observed (to a slight degree) for processes using acetylene as a carbon carrier

The control system eliminates these undesirable conditions while preserving desired characteristics particularly important for high-quality aerospace requirements including uniform, properly shaped carburized layers on all surfaces of carburized parts including deep holes, such as holes in fuel injectors (Fig. 3). Surfaces of carburized parts are clean (no tar or soot footprints as shown in Fig. 4), and there are no traces of tar creation on cold parts of the furnace and pumping system. In addition, high process efficiency minimizes gas consumption.

Reactive gas dosage

A mass flow controller system automatically prepares the carburizing gas mixture. Numerous nozzles introduce the carburizing gas dose into the furnace chamber to ensure uniform carburizing-atmosphere flow around the charge. The FineCarb system calculates, mixes and controls the carburizing reaction based on pressure fluctuation inside the furnace carburizing chamber [1,2]. The system speeds up carbon absorption from the atmosphere to the surface of the charge, which is especially useful and effective when carburizing thin parts and those having blind holes. In the past, the carburizing atmosphere movement around a part with a blind hole was done under constant working pressure. Figure 5, for example, shows a situation where the atmosphere is circulated at 800 Pa (116 psi). It is noticeable that atmosphere movement is limited only to a shallow zone of the stationary vortex just at the entry to the hole, which practically blocks the atmosphere exchange in the rest of the opening.

To avoid this, the smart control system applies the specific pressure fluctuation during the carburizing stage. Variable pumping system output and continuous carburizing atmosphere inflow cause pressure fluctuation. A single pressure-fluctuation cycle (Fig. 6) has a triangular shape, and consists of boost and decrease stages. However, the boost stage is repeatedly longer and depends on the rate of the chemical reaction proceeding. The decrease stage depends only on the maximum delivery of a pumping system and serves to effectively remove the reaction products from the surface and various hollows in the charge. Computer simulation illustrates the exchange efficiency of the reaction products and parent substances inside the blind hole using the method described above (Fig.7).

The new procedure consists of dosing the active nitrogen carrier (ammonia) into the furnace chamber during charge heat up to the carburizing temperature stage before starting the carburizing process [8]. The initial saturation of the surface layer of the steel with nitrogen effectively impedes austenite grain growth, which could allow the use of higher carburizing

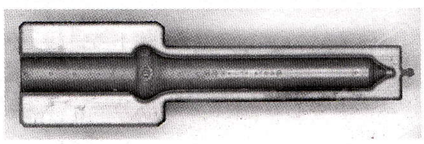

Fig 3 Well-formed, uniform carburized layer in the hole of a fuel injector

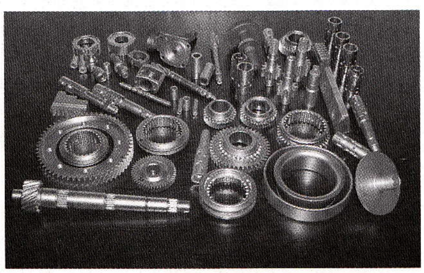

Fig 4 Furnace charge after a vacuum carburizing treatment

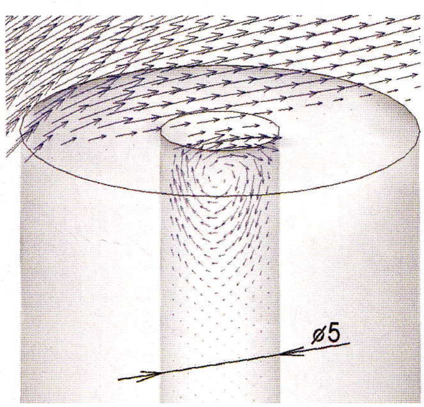

Fig 5 Atmosphere movement in a deep blind hole at a constant pressure of 800 Pa

temperatures, thereby shortening total process time. The higher concentration of nitrogen in the surface layer of the steel improves its hardenability and widens the range of the steel grades that can be carburized in vacuum furnaces.

Carbon concentration profile

The carburizing atmosphere is characterized by very high carbon potential. The nonequilibrium character of vacuum carburizing forces the carburizing process into a series of carburizing and diffusion stages [5-7]. The time of each carburizing stage should be precisely controlled to prevent carbide precipitation [9].

A widely used method is simulation consisting of virtual analysis and optimization of the process path based on systematically supplemented databases and calculation algorithms. The most efficient way to plan the vacuum carburizing process is to calculate the diffusion layer thickness and carbon concentration profile. However, this method requires determination of new relationships between carbon diffusion coefficient as of function of temperature, steel chemical composition and carbon concentration. Commonly used gas-carburizing Wünning equations in the range of 0 to 0.9% concentration do not work for the higher carbon concentrations that occur temporarily during the vacuum carburizing process.

The smart control system offers a computer simulation program for the low-pressure vacuum carburizing process. The program takes into account a series of factors that influence the final carbon concentration profile and the carburized layer microstructure. It allows the user to program for the optimum structure of the carburizing layer according to process temperature, chemical composition of the steel, shape (curvature) of the carburized parts and precooling before quenching. The program is based on the relationships among diffusion coefficient, temperature and steel chemical composition (in a 0 to 2.0% concentration range).

Figure 8 shows a typical screen display. After programming the parameters (car-

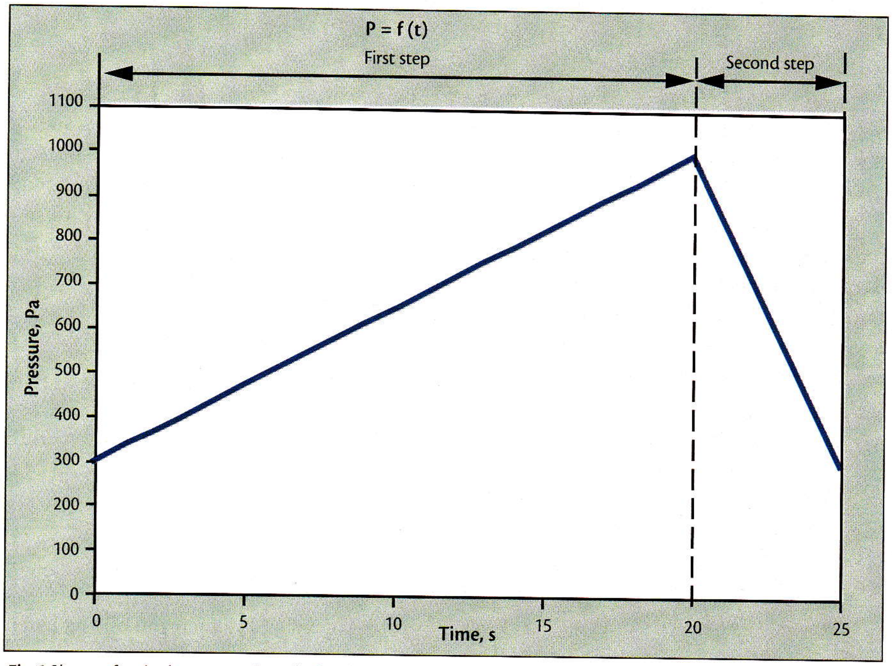

Fig 6 Shape of a single pressure impulse in the carbon saturation stage applied in the FineCarb® system

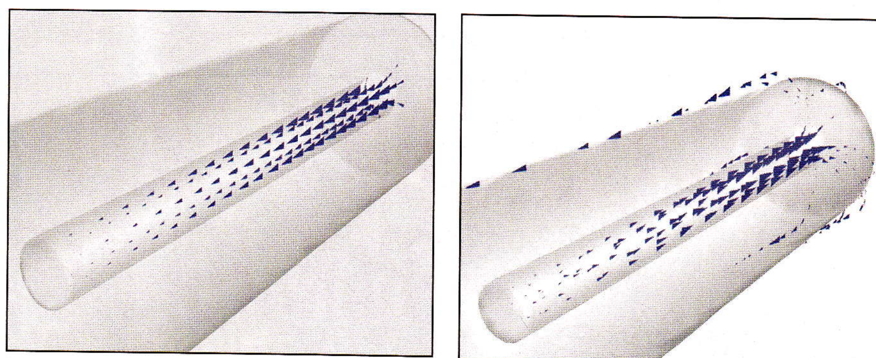

Fig 7 Atmosphere movement in a deep blind hole following FineCarb® control of pressure-fluctuation stages; first step (left), second step (right)

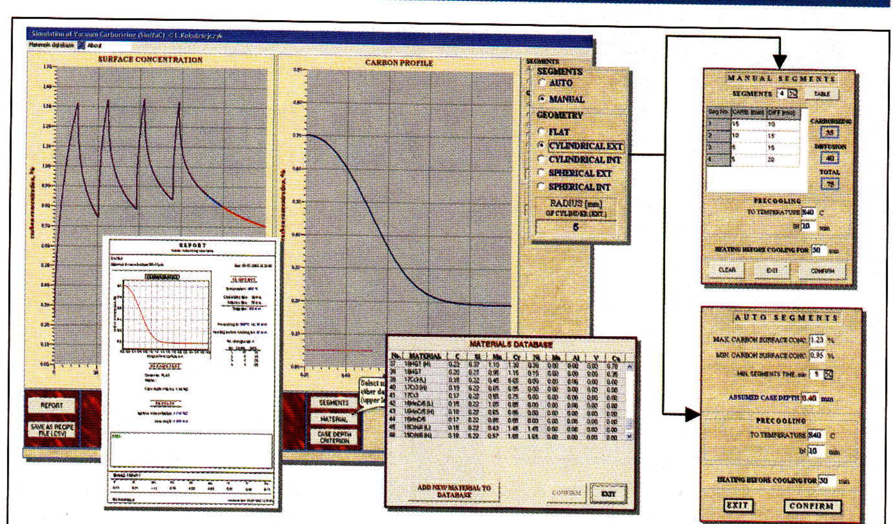

Fig 8 Dialog box containing results of computer program that services FineCarb® system

burizing temperature, quenching temperature, steel type and part dimensions), the operator can choose either automatic or manual mode. Manual mode also requires a preprogram number, carburizing duration and diffusion stages. In automatic mode, the number of segments and duration are optimized to obtain surface carbon concentration and case thickness, to not exceed the instantaneous concentration during the entire process and to avoid low-solubility carbide precipitation. The structure and algorithms of the program provide very fast calculations for both manual and automatic options.

Summary

FineCarb smart control system allows quick parameter selection without the need for time-consuming research. This is extremely important for commercial heat-treating shops with variable and short-series orders. Seco/Warwick's technical support allows quick adaptation and system mastery, permitting immediate access to upgrades and extensions.

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