FineCarb™ - the smart system for vacuum carburizing

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Abstract

FineCarb™, a new control system for low-pressure vacuum carburizing as well as general vacuum applications, is discussed in this paper. This new 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.

Keywords: Vacuum Carburizing, High Pressure Quench, Universal HPQ, FineCarb

Introduction

Low-pressure vacuum carburizing is a process that is characterized by irregular and changeable conditions. This process requires not only a new generation of control systems but also new solutions in the field of parameters selection to optimize both carburizing/diffusive and high pressure gas quenching stages. The new control / software system allows quick and precise parameters selection based on computer simulations. This system uses a special algorithm that uses the latest development in material science as well chemical irregular reaction during carburizing/diffusion stage. The complex computer aided system, FineCarb™, for vacuum carburizing assigned for Low-pressure vacuum carburizing furnaces is presented and characterized in this paper.

Field of application – Furnace Configurations

The vacuum carburizing process can be been performed in the single, double and multi-cell vacuum furnaces. Multi-cell furnaces have been developed, mainly, for large end users with repeatable, homogeneous, large scale production requirements. Companies with a high end product range, or Just in Time (JIT) production such as commercial heat-treating shops are best served with the Universal HPQ™ single or double chamber vacuum furnace with a carburizing system option. The two-chamber units and the Universal HPQ™ single chamber vacuum furnaces with carburizing option are very flexible with a relatively low cost of operation and fast payback. SECO/WARWICK offers all of these unit types for vacuum carburizing (fig. 1 and 2). These furnaces are technologically advanced and adapted for use with the FineCarb™ system.

a) b)

Fig. 1 The vacuum carburizing devices: special two-chamber furnace with cold chamber "ColdCam" (a) and the Universal HPQ™ vacuum furnace with carburizing option (b)

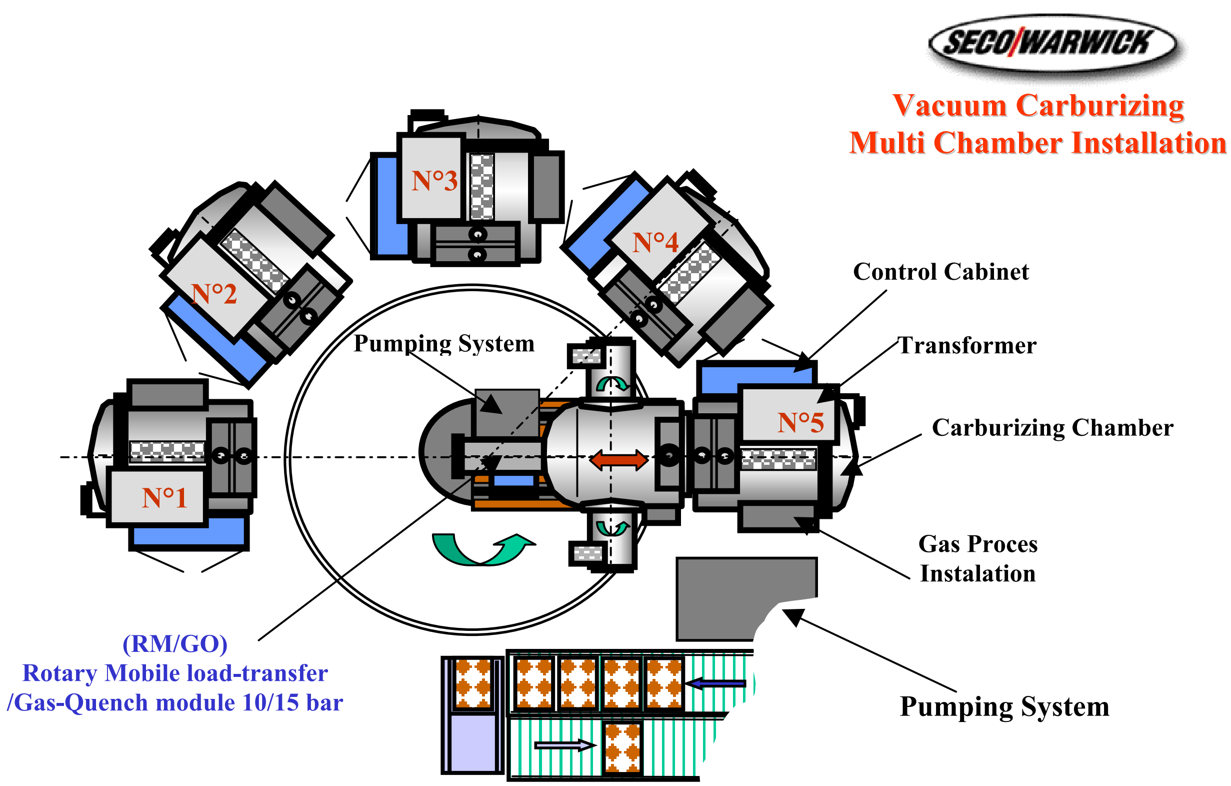

Fig. 2 The scheme for a multi chamber system for vacuum carburizing serviced by universal gas cooling chamber

Structure and system potential

The FineCarb™ system incorporates design features based on the newest original solutions in the field of vacuum carburizing parameters selection and optimization. This system takes into account the grade of steel, carbon concentration profile, carburized layer microstructure requirements, shape of treated elements, size, homogeneity of the load and grain growth propensities at elevated temperatures. The FineCarb™ control system:

- Creates the constitution of multi ingredient carburizing gases mixture, in compliance with the treated elements shape to obtain a homogenous carburized layer on every surface simultaneously (e.g. in the hollows and deep blind holes), clean charge surface and total elimination of the soot and tar – the by-products.
- Selects the pressure fluctuation characteristics in the carburizing phases [8] in accordance with chemical reactions rate in gases mixture of specified initial composition
- Controls the mass flow of carburizing atmosphere in function of charge volume and carburizing process phase
- Limits grain growth by specific gas mixture proportioning during the pre-heating stage
- Optimizes the carburizing stage, diffusion stage and pre-cooling before quenching to obtain demanded carbon concentration profile in diffusive layer according to specific steel grade and load geometry considering
- Records the executed processes parameters and actual treatment results

The proprietary FineCarb™ system is offered together with vacuum carburizing units free of charge on a lease basis. The databases and software upgrades are available to new and existing SECO/WARWICK High Pressure Quench customers.

Carburizing mixture Requirements

The optimized mixture of gases with changeable composition must be provided for each new process according to load characteristic. The carbon carrier in a form of preliminary mixed two undersaturated hydrocarbons in specified and patented ratio is the base of the carburizing atmosphere. The usage of ethene and acetylene gives advantageous effects and the improved final result of the treatment in comparison to atmospheres based on single carbon carriers[3-6]. Such prepared carbon carrier can be mixed with hydrogen or gas mixture.

The selected carburizing atmosphere composition comes from detail analysis of the mechanism and kinetics of chemical reactions. This composition guarantees avoiding disadvantageous reactions and prevent the undesirable outcomes such as:

- Creating the aromatic rings and their polymerization (soot and tar) – the reason for creating tar in the furnace chamber – especially dangerous phenomenon for atmospheres based on propane as a carbon carrier, in a lesser extent for solutions using ethylene [1,2],
- Internal oxidation in the carburized layer – observed at acetylene usage as a carbon carrier, coming from

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the method of storage and distribution of this gas.

- Absorption of hydrogen into the parts surface – a hydrogen is a product of chemical reactions – responsible for blocking the nucleation and carburized layer growth in hollows, holes, unfavorably stressed [2], and for uncontrolled and unpredictable deformations of treated charge.
- Homogenous thermal decomposition of the hydrocarbons – the reason for soot creation, especially intense in case of propane usage, but also observed (in a slight degree) for processes realized with use of acetylene as a carbon carrier.

The elimination of the above, undesirable outcomes is achieved, in FineCarb™ system, with preserving all characteristics merits for particular important for high quality aerospace requirements. The uniform, properly shaped carburized layers on the each surface of the carburized elements are guaranteed including carburizing deep holes, such as holes in fuel injectors. (fig. 3). The surfaces of carburized parts are clean - without any tar or soot footprints (fig. 4). There are no traces of tar creation on cold parts of the furnace and pumping system as well, and whole process is realized efficiently minimum gas consumption.

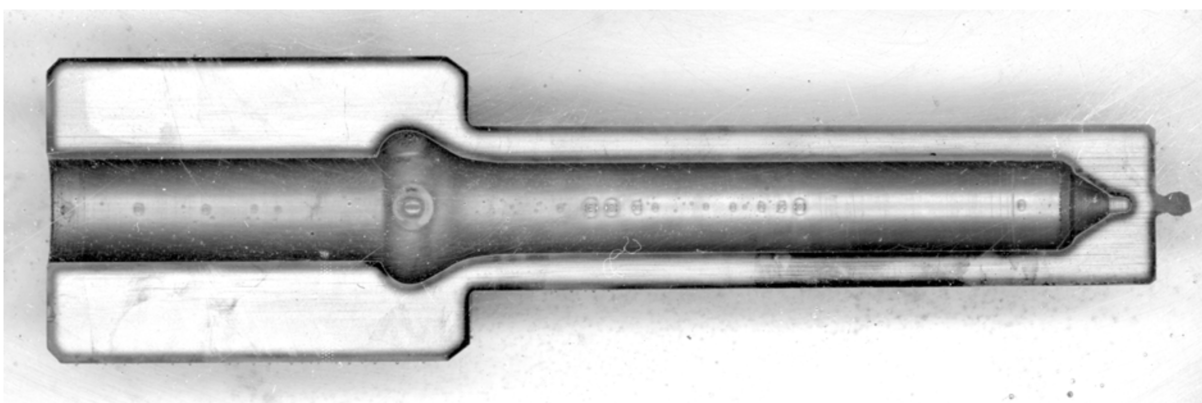

Fig. 3 Well formed and uniform carburized layer in the hole of the fuel injector

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Fig. 4 The charge after the vacuum carburizing process

Reactive gases dosage

Initial preparation of carburizing gas mixture is realized automatically by mass flow controllers system. The carburizing gas dosage into the hot furnace chamber takes place by numerous uniform located nozzles to ensure uniform carburizing atmosphere flow around a charge. The new FineCarb™ system of calculating, mixing and controlling carburizing reaction is applied and based on the special pressure fluctuation inside the furnace carburizing chamber. [8]. The system, speeds up the carbon absorption from the atmosphere to the surface layer of the charge and it is especially useful and effective in case of carburizing elements with thin and blind holes. In the past the carburizing atmosphere movement outside the part with blind hole was done under constant, unchanged level of the working pressure (e.g- figure 5 present the situation where the atmosphere is circulated at 800Pa. It is readily noticeable, that in this case the movement of the atmosphere is limited only to 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.

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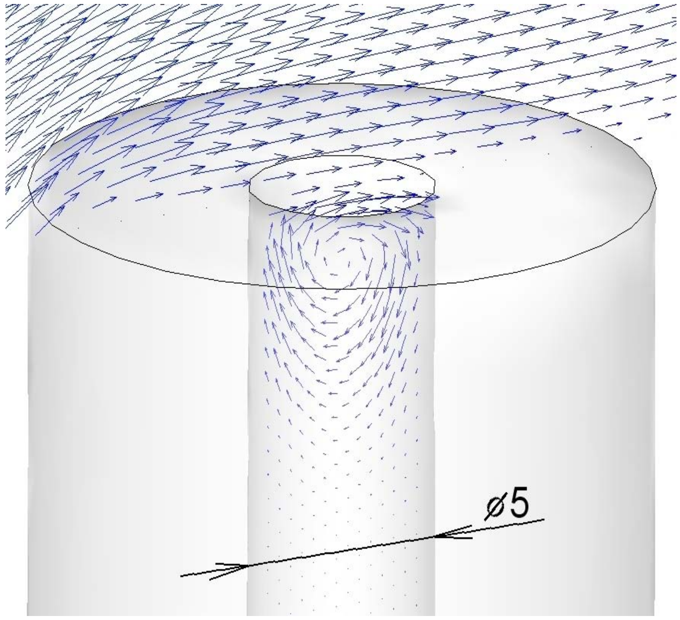

Fig. 5 The atmosphere movement in the deep blind hole during keeping the pressure at constant level 800Pa

To avoid this disadvantage the specific pressure fluctuation during the carburizing stage, is applied in by the FineCarb™ system. The pressure fluctuation is realized by variable pumping system output, and continuous carburizing atmosphere inflow. Single pressure fluctuation cycle (fig. 6) has the 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 the effective removing of the reaction products from the surface and variety hollows in the charge. The exchange efficiency of the reaction products and parent substances inside the blind hole, with use of described above method is illustrated by computer simulation result (fig.7)

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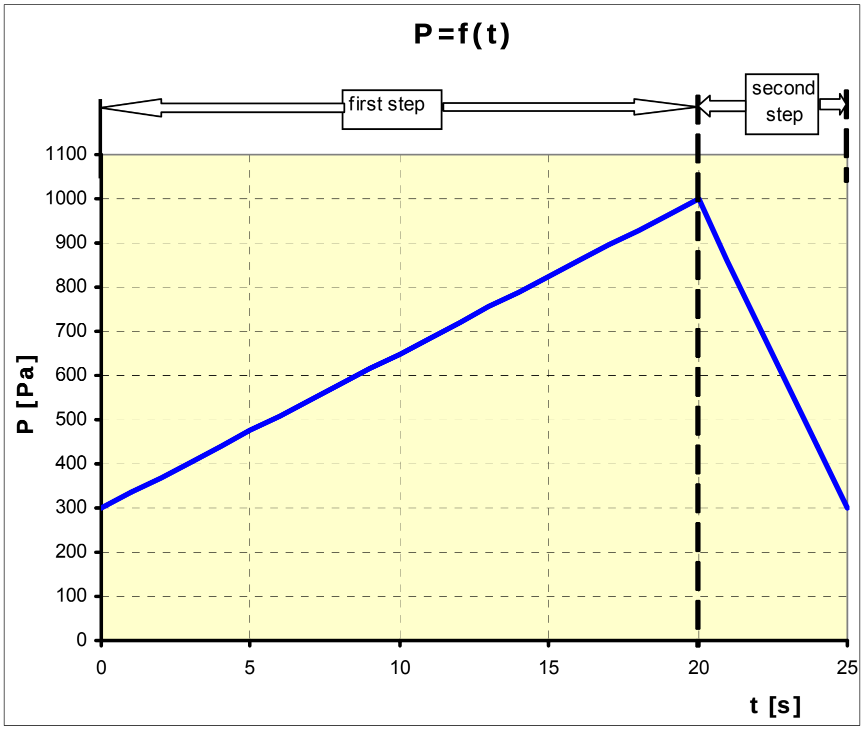
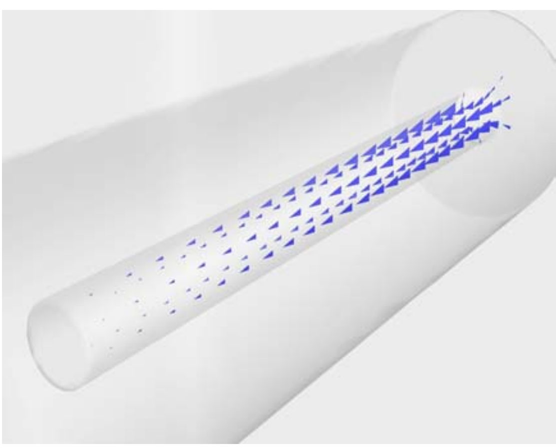
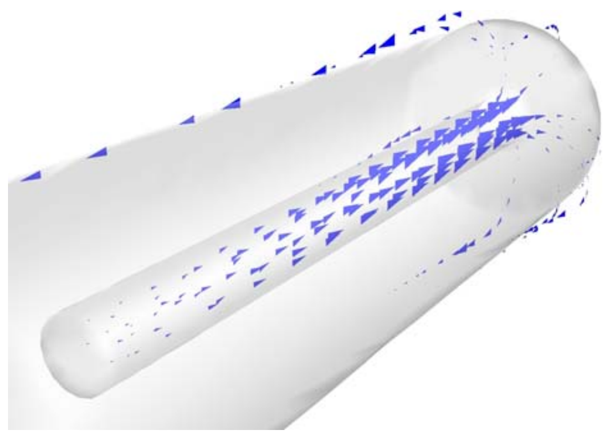


Fig. 6 The shape of a single pressure impulse in the carbon saturation stage applied in FineCarb™ system



First step



second

Fig. 7 The atmosphere movement in the deep blind hole during following pressure fluctuation stages control by FineCarb™ system

The FineCarb™ system minimizes the grain growth to minimum. This new, original procedure, consist in dosing the active nitrogen carrier (i.e. gas mixture) into the furnace chamber during the charge heating to the carburizing temperature stage, before starting the carburizing process [9]. This initial saturation of the surface layer of the steel with nitrogen effectively impedes the austenite grain growth, what makes possible application of the higher carburizing temperatures, and simultaneously shorting the total process time. The elevated concentration of the nitrogen in the surface layer of the steel improves its hardenability and widens range of the steel grades that can be carburized in vacuum furnaces.

Process structure- carbon concentration profile forming

The atmosphere based on the hydrocarbons as the carbon carriers is characterized by very high carbon potential. Disequilibrium character of the vacuum carburizing force the carburizing process into a series of carburizing and diffusion stages [1,2]. In order to prevent the carbides precipitations, time of each carburizing stages should be precisely control. [7]. The widely used method is the simulation that consists in virtual analysis and optimization of the process course on the base of systematically supplemented databases and calculation algorithms. The most efficient way planning the vacuum carburizing process is to calculate the diffusion layer thickness and carbon concentration profile. However, this method requires determination of the new relationships between carbon diffusion coefficient as of function of temperature, steel chemical composition and carbon concentration. Commonly used at gas carburizing Wunning equations, in the range of 0-0.9%concentrations fails in Vacuum carburizing with higher carbon concentrations that occurring temporarily during vacuum carburizing process.

FineCarb™ system offers the computer simulation program for 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 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 the pre-cooling before quenching procedure. The program is based on the dependence between diffusion coefficient and temperature and steel chemical composition (in the range of the concentrations 0-2,0%).

The example of the typical screens is shown in the figure 8. After parameters are programmed (carburizing temperature, quenching temperature, steel type, parts geometric characteristics) operator can choose between automatic and manual mode. In the manual option additionally, preprogram number and duration of carburizing and diffusion stages. In automatic option, number of segments and duration is optimized to obtain surface carbon concentration and thickness of the layer and not to exceed the instantaneous concentration during the whole process, and to avoid hardly soluble carbides precipitation. The structure and algorithms of the program guarantee the very quick calculations both manual and automatic options.

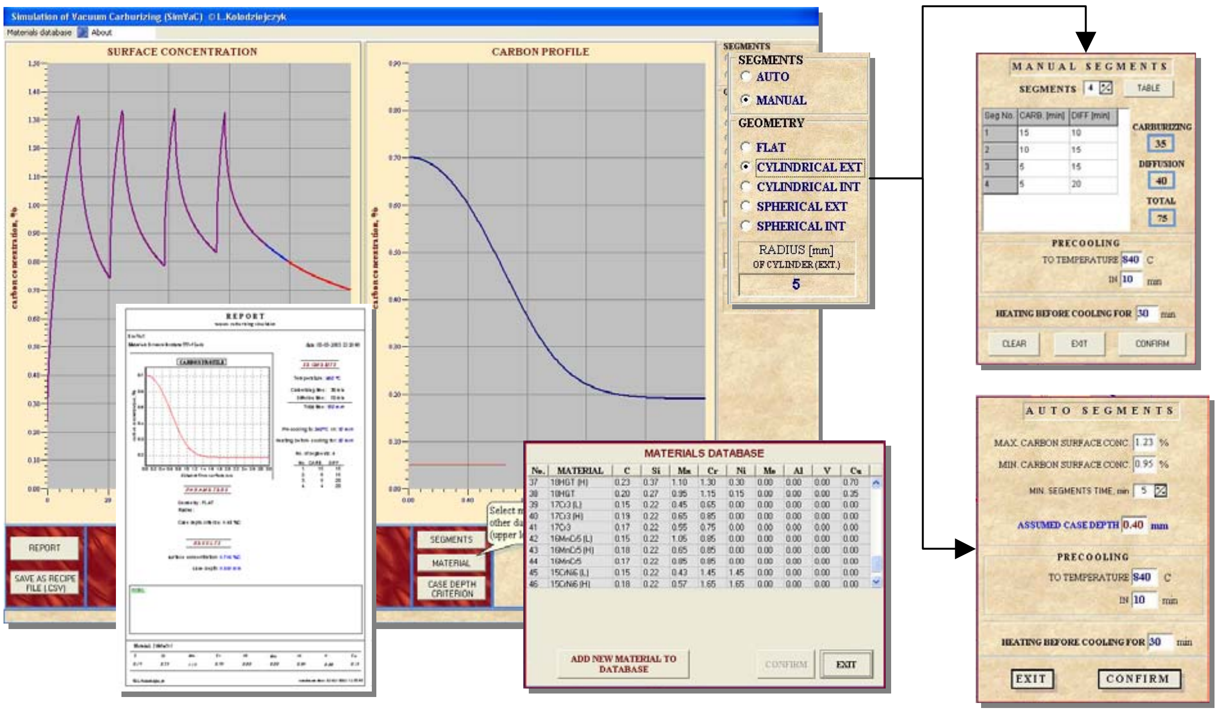


Fig. *8 The example of the dialog boxes and result ones of the computer program that services FineCarb® system*

Summary

The smart control system, FineCarb™, is a useful tool for every user of the vacuum carburizing technology. It allows quick parameter selection without time consuming research. This is extremely important for commercial heat treating shops, with variable and short-series orders. The technical support provided by SECO/WARWICK allows quick adaptation and system mastery, permitting immediate access to its upgrades and extensions.

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