

# The flexible heat treatment of automotive components in a novel type of pusher furnace

B. Edenhofer, H.P. Lankes, H. Burgmaier, A. Kurz

*The typical heat treatment processes needed in the automotive industry are hardening and tempering, case-hardening, nitrocarburising and various types of annealing. Usually, different types of specialised furnaces are applied to the various processes with each furnace type possessing very little flexibility. An exception is the sealed quench furnaces, or also called multi-purpose furnaces, which can be used for various heat treatment processes. Their disadvantage is a certain limitation with respect to high productivity in large series component production. A continuous pusher furnace e.g. is better adapt for economical large series manufacturing, however, is designed only for single purpose usage. This all has changed with the novel concept of a pusher furnace, which allows large series production of automotive components and, at the same time, a switch-over from the hardening and tempering process to case-hardening, or isothermal annealing, or soft annealing, or spheroidizing. The features and technical data of this novel pusher furnace system are discussed together with various applications for automotive components.*

**Key words:** atmosphere pusher furnaces, sealed quench furnaces, heat treatment processes, investment costs

## INTRODUCTION

Despite its lack of visibility and recognition, heat treatment plays the dominant and decisive role in manufacturing of automotive components. No other manufacturing process determines the behaviour and properties of finished parts more than the heat treatment process. This is true for most engine components, all parts of gear boxes, axles, drive shafts and suspension parts as well as steering components and injection systems.

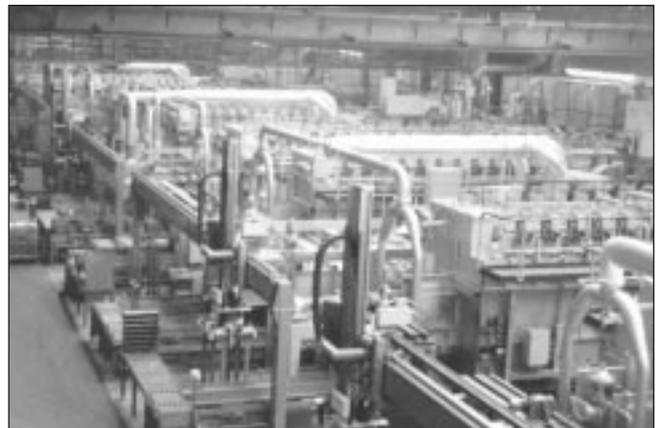
During the manufacturing process of automotive components, the most different types of heat treatment are in use today.

For semi-finished components after forging or cold-forming, annealing treatments like isothermal anneal, re-crystallization or soft anneal, are common in order to produce a uniform material structure or provide for better machining conditions.

Finished components are frequently hardened and tempered, or carburized, hardened and tempered, or nitrocarburised.

## FURNACE CONCEPTS FOR HARDENING; CASE-HARDENING AND ANNEALING

Typically, due to the large number of vehicles produced annually, heat treatment for automotive components requires special installations adapt for mass production. This can be best demonstrated looking at the example of a gear box manufacturing plant of a large German automotive manufacturer. The capacity of this factory is extremely high. It produces roughly 20,000 complete gear boxes every day. As al-



*Fig. 1 – View on a section of a heat treatment plant with 27 pusher furnaces in the gear box manufacturing of a large German automotive supplier.*

*Fig. 1 – Sezione di un impianto di trattamento termico con 27 forni a spinta nel reparto di produzione di trasmissioni di una grande azienda tedesca di forniture automobilistiche.*

most all parts of a gear box are case-hardened, the heat treatment plant of this factory consists of 27 identical pusher furnaces for gas carburising, hardening and tempering. A small section of this heat treatment plant is shown in figure 1.

Each pusher furnace line consists of the pusher furnace itself, which holds 20 loads, an oil quench tank, a washing machine and a tempering furnace plus roller tracks (Fig. 2) [1]. These furnaces are single-purpose systems especially engineered for case-hardening. They have a limited flexibility with respect to case-depth. In the gear box plant described here, they are used for a case-depth range of 0.3 mm to 1.3 mm with any switch from one type of case-depth to another requiring a change of step time, temperature and carbon potential, which results in a certain production loss. However, with 27 pusher lines available in this plant, the need to change the parameter settings for a different case-depth on any given pusher furnace line hardly ever arises. The throughput of such a single-track gas-carburising pu-

**B. Edenhofer, H.P. Lankes**

*Ipsen International GmbH, Kleve, Germany*

**H. Burgmaier, A. Kurz**

*Schwäbische Härtetechnik Ulm GmbH, Ulm, Germany*

Paper presented at the 2<sup>nd</sup> International Conference  
HEAT TREATMENT AND SURFACE ENGINEERING IN AUTOMOTIVE APPLICATIONS,  
Riva del Garda, 20-22 June 2005

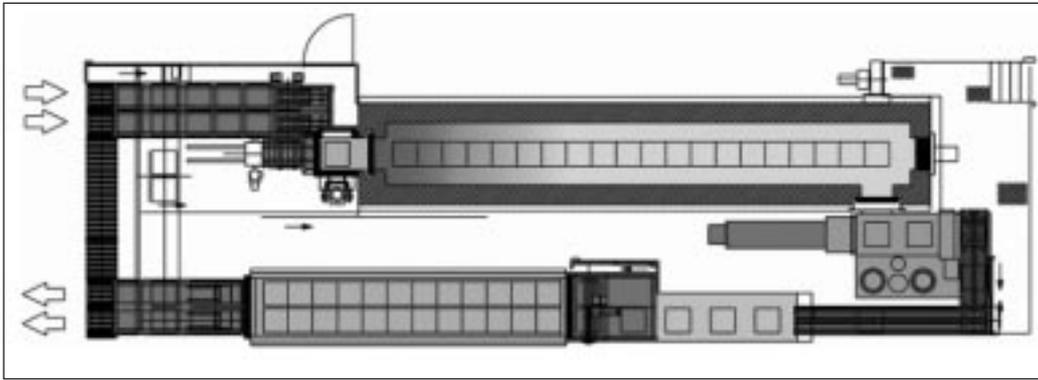


Fig. 2 – Scheme of a single-track pusher furnace for case-hardening of gear box components.

Fig. 2 – Schema di un forno a spinta a binario singolo per la tempra di componenti di trasmissioni.

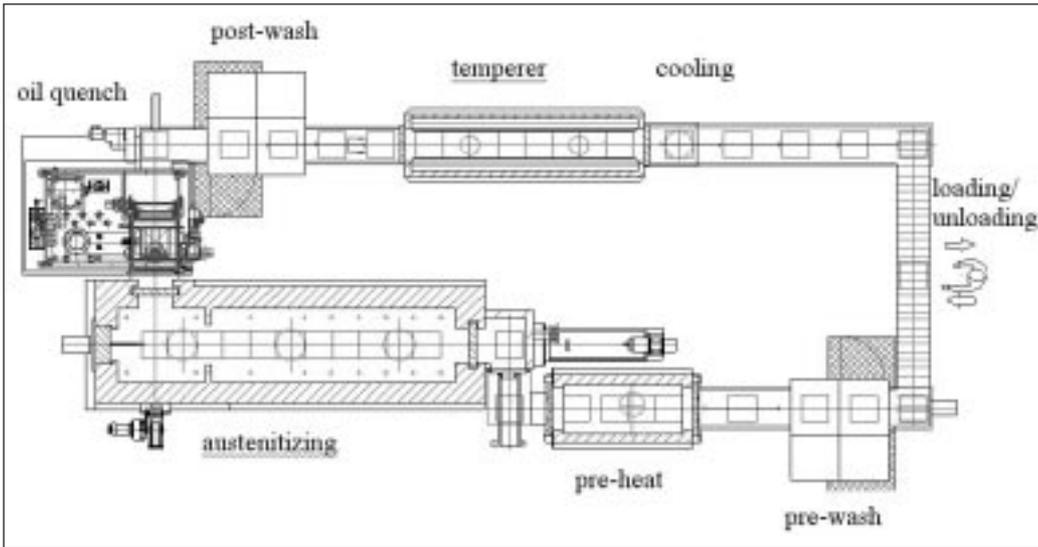


Fig. 3 – Scheme of a semi-continuous hardening furnace line with a throughput of approx. 650 kg/h.

Fig. 3 -- Schema di una linea di forno di bonifica semicontinuo con capacità produttiva di circa 650 kg/h.

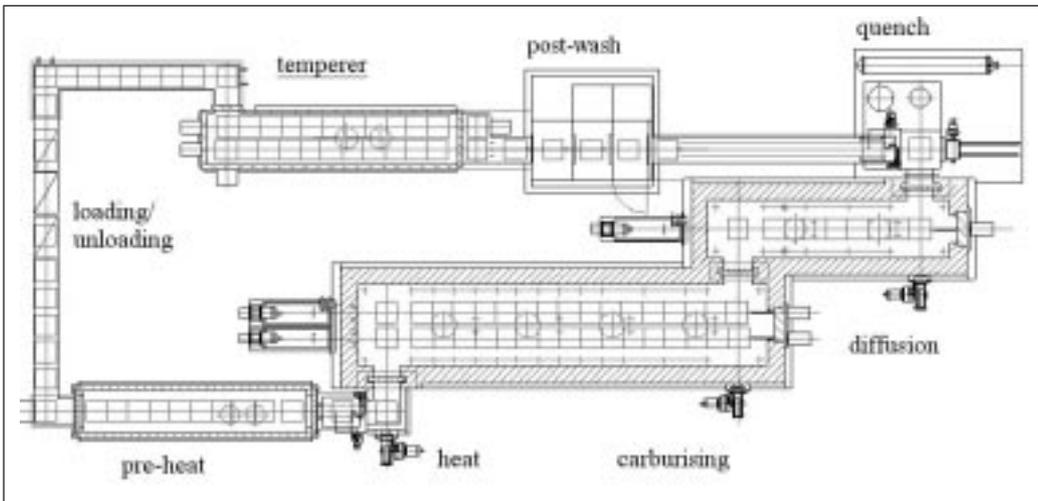


Fig. 4 – Scheme of a twin-track gas carburising pusher furnace.

Fig. 4 – Schema di un forno a spinta a due binari per la cementazione gassosa.

sher furnace for a case-depth of 0.6-0.8 mm lies in the range of 600 kg per hour.

Atmosphere pusher furnaces form a very economical solution for mass production heat treatment. Therefore, this type of furnace system is not only used for carburising but also for nitrocarburising, for pure hardening processes and for annealing treatments. Naturally, the design of the pusher furnace has to be adapted to its specific use. Therefore, an annealing pusher furnace line differs from a carburising line or a pure hardening and tempering line, and none of these furnaces can be used for any other purpose than their specific assigned use.

Thus, figure 3 shows the layout of a small pure hardening line with 8 loads in the austenitising furnace, a step time of 13.8 minutes and a throughput of 653 kg/h. Larger pure har-

dening pusher furnaces are longer and hold more loads in the austenitising furnace, resulting in capacities of 1,000 or 1,500 kg/h.

In case-hardening, the capacity of a single-track pusher can be increased by engineering it with two or three parallel tracks. Figure 4 shows an example of a twin-track gas-carburising pusher, which has a capacity of about 2,000 kg/h for a case-depth range of 0.5 mm to 0.7 mm, which is about twice that of a comparable single-track system. Investment costs for such a twin-track pusher furnace, however, increase only by about 60% with a similar percentage increase also for the energy and gas consumption.

The pusher furnace concept for annealing processes differs from a hardening or carburising furnace line mainly by a totally different cooling section. Figure 5 shows the layout of a

Fig. 5 – Layout of an atmosphere pusher furnace for isothermal annealing.

Fig. 5 – Schema di un forno a spinta ad atmosfera controllata per ricottura isotermica.

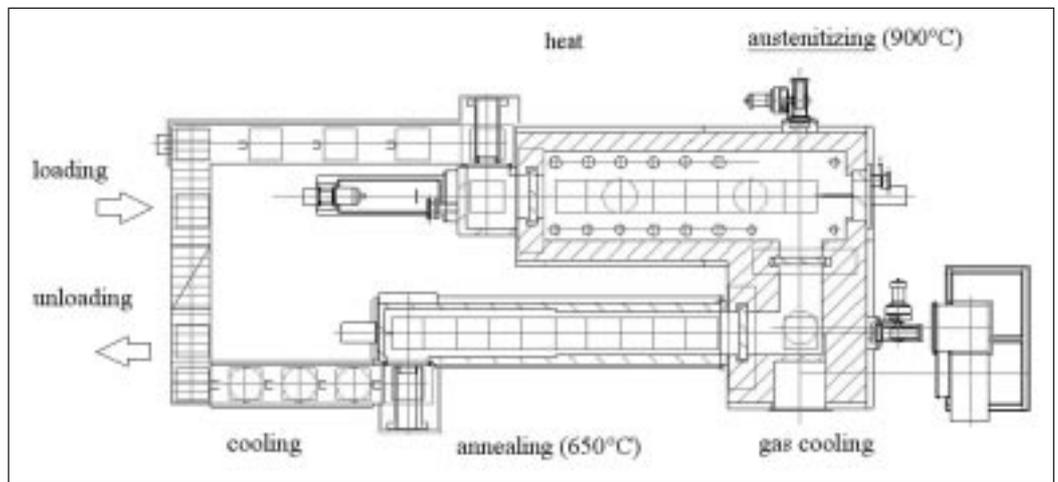


Fig. 6 – Layout of an atmosphere pusher furnace line for soft-annealing and re-crystallization.

Fig. 6 – Schema di una linea di forno a spinta ad atmosfera controllata per ricottura completa e ricristallizzazione.

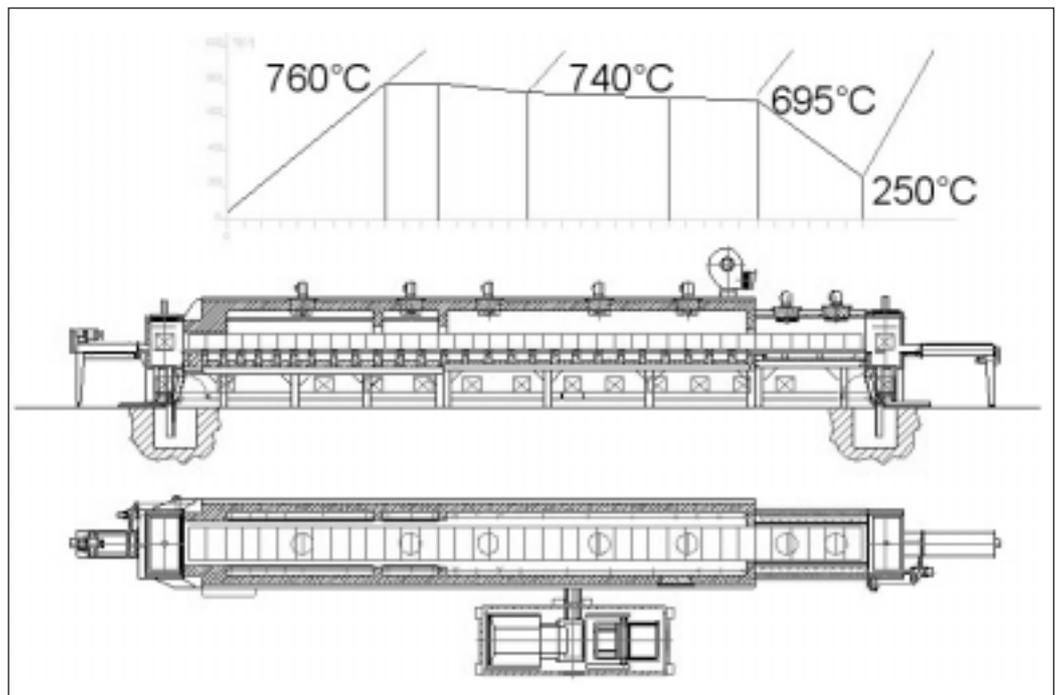


Fig. 7 – Typical automated batch furnace line with sealed quench furnaces, temperers, washers, loaders/unloaders and sequencers.

Fig. 7 – Tipica linea di forno a carica automatica con forni di tempra sigillati, di rinvenimento, caricatori/scaricatori e sequenziatori.



pusher furnace used for isothermal annealing. It consists of a high-temperature furnace running at 900°C, a rapid gas cool station bringing the loads down to 650°C, an isothermal annealing furnace (650°C) and a cooling zone. The total capacity of this pusher annealing furnace line is approx. 825 kg/h. In figure 6 an example of a soft annealing or re-crystallization pusher furnace line is shown with a heating section (to

760°C), a holding section (at 695°C) and a cooling section (to below 250°C). With load sizes of 900 x 500 x 450 mm, load weights of up to 310 kg can be realised, yielding together with a step time of 26 minutes a capacity of 1100 kg/h.

As can be seen from the design differences of all these various pusher systems, there was up to now no pusher design available, which can be used for all the different heat treatment processes described. Each type has its single purpose use.

Only the multi-purpose batch furnaces, also called sealed quench furnaces, allow a flexible use for almost all different heat treatment processes.

A typical, fully automatic atmosphere batch furnace line, as the one shown in figure 7, can do pure hardening processes, carburising, nitrocarburising and diverse annealing processes with a very high flexibility potential of being able to change heat treatment process from load to load [2]. This is the reason why the sealed quench batch furnace lines are the favourite work horses of the commercial heat treaters, allowing them to fulfil whatever heat treatments a customer requires.

Up to a certain limited amount of production, the sealed quench furnaces are also the most economical solution with respect to investment costs as well as energy and gas consumption.

With rising throughputs, however, the investment costs per

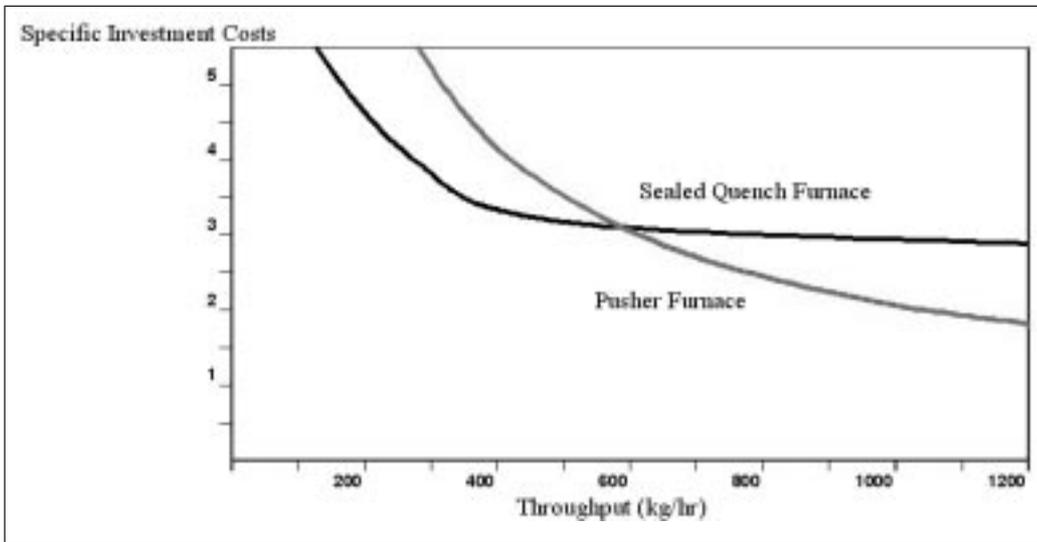


Fig. 8 – Development of investment costs for batch and pusher furnaces in relation to the throughput (case-hardening to a c.d. of 0.6 mm).

Fig. 8 – Diagramma del costo degli investimenti per forni a camera e a spinta in relazione alla produttività (profondità di cementazione di 0.6 mm).

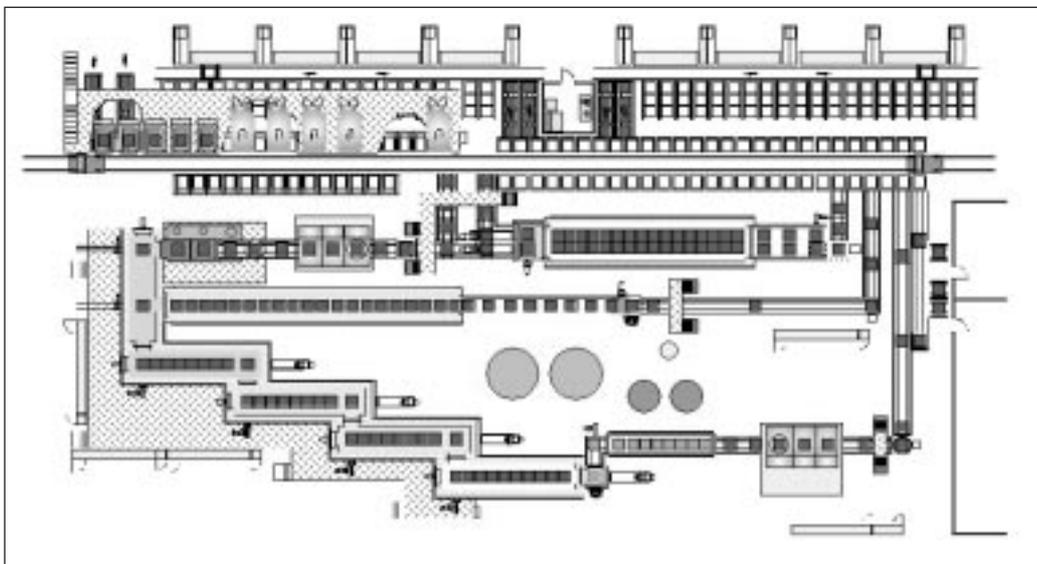


Fig. 9 – Layout of the novel, flexible pusher furnace system.

Fig. 9 – Schema di un sistema innovativo e flessibile di forno a spinta.

unit weight of heat treated goods decline stronger in case of the pusher furnaces, making them more economical (Fig. 8).

**NEW MULTI-PURPOSE PUSHER FURNACE LINE**

The growing business volume of the large German commercial heat treatment specialist SHU (Schwäbische Härtetechnik Ulm GmbH & Co. KG) led to the search for a new and different furnace concept, which would satisfy the specific demands with respect to:

- very high throughput
- flexibility for all heat treatment processes
- high economy and efficiency
- excellent consistent quality level
- low environmental impact.

On the basis of these requirements, a new flexible pusher furnace concept was developed between the two companies IPSEN and SHU [3].

Figure 9 shows the general layout of this new furnace line. As can be seen, it is actually more than one pusher furnace line, it is the combination of a pusher furnace line and batch furnaces.

The heart of the whole furnace line is naturally the pusher furnace itself, having four different zones, one heating zone with ten loads and three high-temperature zones with eight loads each.

In front of the pusher is a three-zone washer, followed by a

pre-heat furnace with eight loads.

Behind the four zones of the atmosphere pusher is a heated transfer tunnel, which serves for the transfer of the loads to the cooling/quenching sections of the heat treatment line.

The first position in the transfer tunnel leads the loads into an annealing and cooling section, which can hold 28 loads.

The second position in the transfer tunnel brings the loads into a double oil quench chamber followed by a three-zone post-washer and a twin-track tempering pusher furnace with a cooling section at the end and vacuum locks on both sides. After leaving the pusher tempering furnace, the batches can either be directed to the four QA stations (quality assurance), or can be transferred to one of the five cryogenic deep freeze and tempering stations, which are located behind the pusher furnace line, or can be temporarily stored in the high-bay racking sequencer.

The high-bay sequencer system is used to store green loads as well as hardened and washed loads, or hardened, washed and tempered loads. It is a huge racking system with in total 345 storage locations for complete loads plus an additional 114 slots for empty trays. The sequencer has six entry and exit points connecting to various points of the pusher furnace line and the loading/unloading area. It is served by two storage and retrieval robots.

The pusher furnace line has next to its entry and exit points a third connecting point to the sequencer and its robots just behind the oil quench tank and washer. Thus, loads can be taken out after hardening and washing, and are either tem-

porarily stored in the sequencer or diverted to five tempering furnaces type DAC-10-E, which are positioned on a raised platform within the high-bay racking area.

**THROUGHPUT REQUIREMENT**

The high throughput of this furnace line is for one thing generated by the large grid size of 710 x 710 x 800 mm, allowing loads of gross weight up to 800 kg to pass through the high-temperature portion of the pusher furnace, the oil quench and the subsequent washer and tempering furnace or the low-temperature annealing furnace, followed by the gas cooling zone.

The second factor, which contributes to the outstanding productivity of this furnace line is the pure size of the furnace.

In case of a hardening or case-hardening cycle, there are in total 88 loads in the total furnace line (8 in the pre-heat, 34 in the high-temperature zones, and 38 in the temperer).

During annealing cycles, the furnace holds at any time a total of 74 loads (8 in the preheating furnace, 34 in the high-temperature zones, and 29 in the annealing and cooling zones).

This large number of loads in the furnace leads to very short step times (defined as the time period between two subsequent steps of moving the loads one position further), which in the case of annealing cycles normally lie in the range of 6-8 minutes. For pure hardening cycles, the step times are of a similar length.

For case-hardening, a typical step time in order to reach an effective case-depth of 1 mm (case-depth at the hardness value of 550 HV1) is 13 minutes.

These short step times result in tremendous throughput values of up to 6,000 kg/hour for pure hardening or for pure annealing cycles, and up to 4,000 kg/hour for case-hardening to case-depths up to 0.6 mm.

**FLEXIBILITY REQUIREMENT**

The flexibility request for this high-capacity pusher furnace line is met by installing several different distinctive features, of which the most important ones are:

- separate pre-heat furnace
- multiple zone design of austenitising (high-temperature) furnace section
- transfer tunnel to different cooling/quenching sections
- large temperature range of atmosphere tempering furnaces
- integrated continuous and batch tempering furnaces
- integrated flexible cryogenic-tempering batch systems
- all high-temperature austenitising zones and annealing zones equipped with electric radiant tubes and separate cooling tubes
- tempering furnaces equipped with electric radiant tubes and quick gas cooling systems
- load management system.

The separate pre-heat furnace is an integral part of the continuous pusher furnace line and serves as a minor or major part of the total heating cycle, depending on the furnaces utilization to high-capacity annealing or hardening processes, or e.g. its use for deep-case carburising.

The multiple-zone design of the austenitizing furnace sections with in total five different zones (including the pre-heat furnace) allows the flexible extension of e.g. four zones for the pure heating part of the heat treatment cycle, or the use of at least three zones for the carburising and diffusion part of case-hardening cycles.

The parallel arrangement of an annealing zone and a rapid oil quench system, both connected to the high-temperature furnace by a transfer tunnel, allows the rapid change between hardening, carburising and annealing treatments.

The requirement for low-temperature tempering after case-hardening and high-temperature tempering under protective atmosphere for hardening applications is fulfilled by engineering the pusher tempering furnace as well as the batch tempering furnaces for a temperature range of 150-750°C. To prevent de-carburisation and oxidation during the high-temperature tempering cycles, the tempering furnaces are equipped with a protective gas system and vacuum locks at the front and back end.

The possibility to remove loads after the oil quenching and the washing, and automatically transfer them from the continuous furnace line into one of the several existing batch atmosphere furnaces makes a rapid change of tempering cycles even from one load to the other possible without any loss of productivity of the complete furnace system. This flexibility is further enhanced by linking the continuous batch furnace line to several multiple-purpose cryogenic and tempering batch systems.

The rapid change of carbon potential from one batch of loads to the other is also made possible by the multiple-zone design with separate doors between the zones, making the adjustment of different carbon potentials in each zone possible.

In addition, all four zones of the austenitising furnace section are equipped with electric radiant tubes and separate cooling tubes. As a consequence, the temperature of each zone can be changed within minutes, once a new batch of loads is programmed to be processed. The same measure is also used in the annealing zone with the capability of rapidly adapting the temperature in the annealing section of the pusher furnace to the different requirements of re-crystallization, normalizing or spheroidizing.

Also the tempering furnaces, continuous as well as batch furnaces, are equipped with electrical radiant tubes and a quick gas cool system with a separate water-cooled heat exchanger, making also a rapid temperature change from e.g. 600°C to 160°C possible.

Last, but not least, a complex load management system in connection with the high-bay storage racking allows the intelligent scheduling of load batches according to the vicinity of their treatment parameters. This way, even cycle parameter changes of temperature, carbon potential and furnace step time can be realised with hardly any loss of productivity. It is the Ipsen Conti-Control® and its inter-linkage with the Ipsen AutoMag® system (for the batch furnaces) which together with the management of the high-bay storage racking creates this flexibility.

**EXAMPLES OF APPLICATIONS**

The first example shows a load of piston pins. The parts are case-hardened to an effective case-depth of 1.0 to 1.5 mm.

There are 144 piston pins in each load, resulting in a gross load weight of 600 kg.

Together with a step time of 24 minutes, this yields a throughput of 1.500 kg/h (Fig. 10).

Figure 11 shows a load of long hollow shafts. They are case-hardened to an effective case-depth of 0.8 to 1.1 mm.

Each load contains 221 shafts, yielding a gross load weight of 550.kg.

The furnace step time in this application is 15 min., resulting in a furnace throughput of 2.200 kg/h.

Figure 12 shows components of a CVT transmission. These are heavy parts, each one weighing 4.4 kg. The total gross weight of the load, holding 32 pieces, is 260 kg.

The parts are case-hardened to an effective case-depth of 1.0 to 1.2 mm.

With a furnace step time of 15 minutes, 1.040 kg are case-hardened every hour.



Fig. 10 – Load of 144 piston pins case-hardened to 1.0 to 1.5 mm.  
Fig. 10 – Lotto di 144 teste di pistoni cementati e temprati da 1,0 a 1,5 mm.



Fig. 12 – Case-hardened parts of a cvt-transmission.  
Fig. 12 – Parti di una trasmissione cvt cementate e temprate.



Fig. 11 – Load of 221 shafts case-hardened to 0.8 to 1.1 mm.  
Fig. 11 – Lotti di 221 alberi cementati da 0,8 a 1,1 mm.



Fig. 13 – Loads of tripod forgings to be normalized.  
Fig. 13 – Carica di treppiedi forgiati da normalizzare.

A typical application for annealing treatments in the flexible pusher furnace line of high capacity is discussed in the last example.

Figure 13 shows tripods, which form part of a driveshaft system. The pieces are normalized in the pusher furnace after the hot forging forming process and before soft machining. 1.500 pieces are bulk loaded in triple-layer grid arrangements, yielding a gross load weight of 550 kg. With a step time through the furnace of 6 minutes, this yields a throughput of 5.500 kg/h.

These parts are heated and austenitised in the five heating zones with carbon potential control in a nitrogen-methanol atmosphere, then transferred via the transfer tunnel into the annealing and cooling zone, where they are slowly cooled according to the given cooling recipe.

#### CONCLUSIONS

On the basis of an existing, well proven furnace concept of an atmosphere pusher furnace suited for high productivity, the new type of flexible large heat treatment machine was developed and put into operation two years ago.

This furnace concept employs multiple heating and carburising zones linked together with two different and independent cooling and quenching sections, and at the same time integrated into a fully automatic batch furnace system to be

used for tempering and cryogenic treatments. This new furnace concept has completely met the requirements of high throughput at low costs, bundled with an up to now unknown flexibility for continuous heat treatment lines. After two years of continuous operation it can be stated, that this furnace line delivers constant and high heat treatment quality with excellent productivity values even with varying batches of loads. The typical children's diseases pertinent to any complicated and intrinsic manufacturing equipment during the start-up period have been overcome, and the furnace system now completely fulfils the expectations of its user and his customers.

#### REFERENCES

- [1] Wienstroth, T., Edler, K.-H., Güse, W., Fischer, M.: Konzept einer zukunftsweisenden Härtereier für die Großserienproduktion von Getriebeteilen. HTM 49 (1994) 5, p. 290-295.
- [2] "Lights-Out" Facility Illustrates a New Standard for Innovative Heat Treating Technology. Industrial Heating, November 1999, p. 60-64.
- [3] Burgmaier, H., Kurz, A.: Newly developed multi-purpose pusher furnace installation for hardening, case-hardening and annealing. Ipsen Customer Meeting, May 23-24, 2002, Düsseldorf, Germany.

**TRATTAMENTO TERMICO FLESSIBILE  
DI COMPONENTI AUTOMOBILISTICI  
IN UN NUOVO TIPO DI FORNO A SPINTA (PUSHER FURNACE)**

**Key words: trattamenti termici, tecnologie**

*I tipici processi di trattamento termico impiegati nell'industria automobilistica sono bonifica, cementazione, nitrocarburação e vari procedimenti di ricottura.*

*Solitamente, si utilizzano diversi tipi di forni specializzati per i vari processi e ogni tipo di forno possiede una flessibilità minima. I forni di tempratura sigillati, denominati anche forni multi-funzione costituiscono un'eccezione, e possono essere utilizzati per diversi processi di trattamento termico.*

*Il loro svantaggio è una limitazione nell'alta produttività necessaria per il trattamento dei componenti di grande serie. Un forno continuo a spinta, ad esempio, è più adatto alla grande produzione economica di serie, ma ha un progetto diverso per ogni singolo impiego.*

*Questo quadro è tuttavia cambiato con l'introduzione del nuovo tipo di forno a spinta, che permette la grande produzione in serie di componenti automobilistici e, nel contempo, permette di passare facilmente dal processo di bonifica alla cementazione, o alla ricottura isotermica, o alla ricottura di lavorabilità, o alla ricottura di globulizzazione.*

*In questa memoria vengono illustrate le caratteristiche ed i dati tecnici di questo tipo di forno insieme ai vari requisiti dei componenti automobilistici.*