Modular heat treatment using nitriding and low-pressure carburising (part 1)

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Vacuum heat treatment, and with it vacuum hardening, has become increasingly important in recent decades. In addition, low-pressure carburising has been an alternative to the conventional carburising processes for more than 30 years. Its use, which was slowed down for a long time by technical and economic problems, has been further established in series production over the last 15 to 20 years. New considerations and applications now also bring together the nitriding and nitrocarburising processes with modular vacuum hardening technology. The three-part article represents the basic considerations of process and plant engineering in connection with the economic and environmental factors. In part 1, the plant technology is represented.

Vacuum heat treatment such as low-pressure carburising or brazing, but also nitriding and nitrocarburising of metallic components is determined by the parameters time, temperature, pressure, atmosphere and quenching or cooling. These process parameters can be adapted and optimised to the requirements in terms of improved component quality, energy efficiency and economic viability. Here, the industrial furnace technology has the decisive task of supporting the target values of the heat treatment process, i.e. the economic production of a component treated in a certain way from the point of view of suitability and possible applications as well as maximum service life.

Today, modern vacuum furnaces are generally designed with a flexible structure and, due to the specific vessel and insulation design, can generally be classified as particularly energy-efficient. The demand for integration into production, which exists in many places, can be implemented in lean production due to the clean operation. Sectors such as tool and mould making, aerospace industry, automotive industry and medical industry rely primarily on the possibilities of this technology. In addition to the classic one- or two-chamber vacuum furnaces ("cold chamber"), modularly designed and fully automatically operated modular multi-chamber vacuum furnace systems are often used today for larger part throughputs in serial operation.

Special developments can be seen in the modular vacuum hardening plants with up to 10 treatment chambers and here in particular in low-pressure carburising with subsequent oil quenching, which is generally used for low-alloy structural steels, case-hardening steels, rolled steels or also for certain cold work steels. These steels require higher cooling rates than the steel grades which are normally cooled with overpressure gas quenching. The modular ICBP plant concept, which has been tried

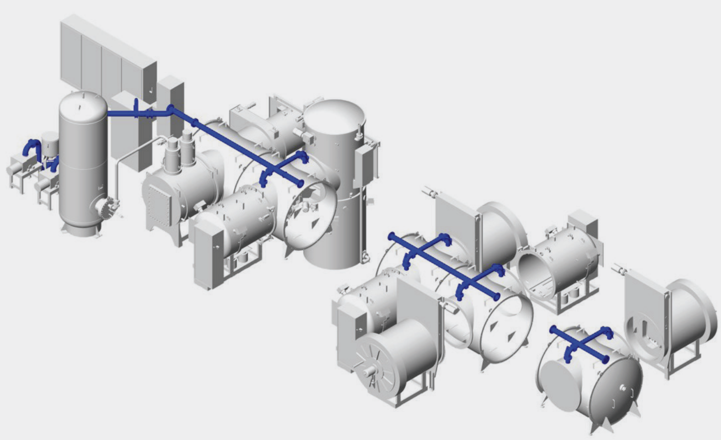

Fig. 1: Multi Flex system

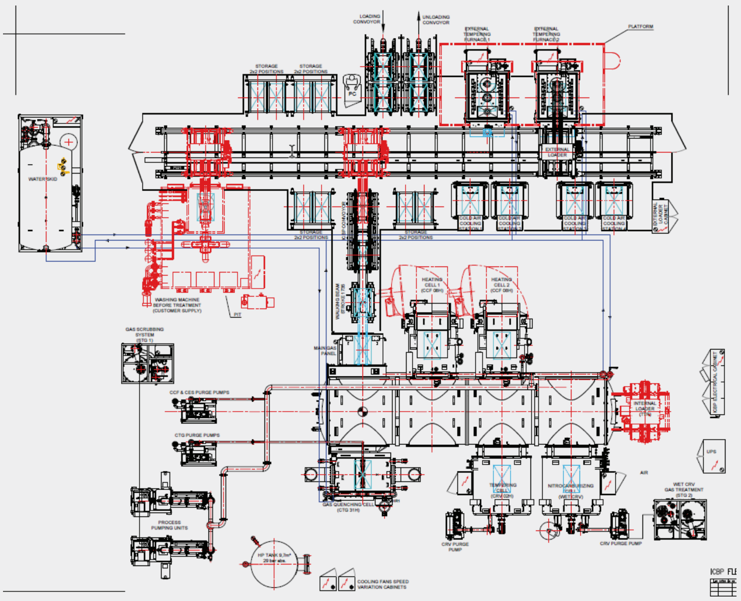

Fig. 2: ICBP Flex with automation

and tested for many years, is particularly noteworthy here. It combines heating and low-pressure carburising chambers, high-pressure gas quenching chambers and also oil quenching chambers in a flexible and modular way – a plant technology that allows almost all component specifications and requirements in the field of vacuum hardening and can offer an interesting universal solution, especially for contract hardening companies. The modular vacuum furnace technology is widely used, above all in the transmission industry for hardening, among other things, manual and automatic transmissions, continuously variable transmissions and double clutch transmissions. On the other hand, drive trains (axles, homokinetic joints), common rail injection systems (injectors, pumps), roller bearings and power steering are hardened in low-pressure processes and in larger series in the automotive and aerospace industries.

MODULAR VACUUM HEAT TREATMENT

Low-pressure carburising technology (NDA) was developed in the 1980s by several companies in parallel. The development focused on the use in single or double chamber systems. After the first experiences were gained, ECM focused on further developing the process for the mass production of transmission components. With PSA, the concept of modular plant technology has been developed to market maturity. In 1996, the first modular vacuum system for the NDA of mass production components was presented worldwide. The ICBP® Flex combines all the advantages of modern plant technology: high degree of automation, good process control and excellent metallurgical results. Since then, over 240 systems with 1,300 heating chambers have been delivered worldwide (**Fig. 1**).

The concept

The design principle of a modular vacuum system has been tried and tested since 1996 and is used especially in large-scale series production, for example in the automotive industry. The loading, heat treatment and cooling processes are divided into respective, specially designed chambers. All chambers are connected to a transport system operating under vacuum, which takes over the batch transport between the chambers. The entire system remains under vacuum, i.e. under exclusion of air and thus oxygen. Depending on the process

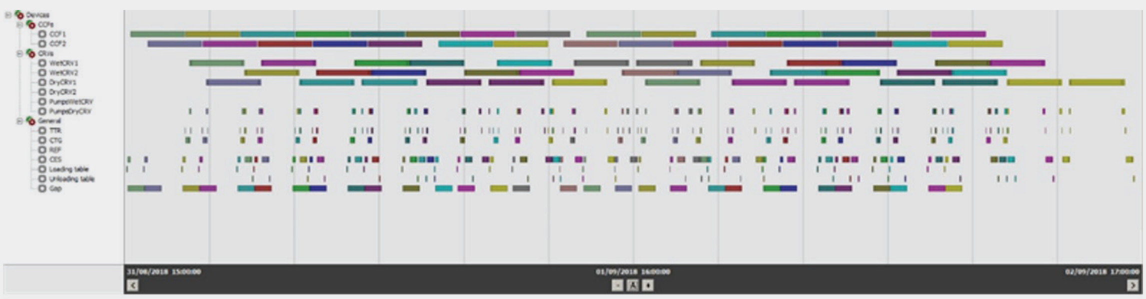

Fig. 3: Graphical representation of the furnace occupation

type, the ICBP Flex is equipped with either centralised or decentralised pump systems, i.e. each heating chamber is operated by its own vacuum pump. Here too, it is essential to comply with the safety regulations for ammonia processes. Depending on the user, it is also possible to equip a central vacuum pumping station, which is connected to the heating chambers via a pipe system. Depending on the process, vacuum flaps switch the heating chamber on and off from the central system. It should be emphasised that with this modular system type, even in oxygen-sensitive processes such as nickel soldering, no diffusion pumps are necessary.

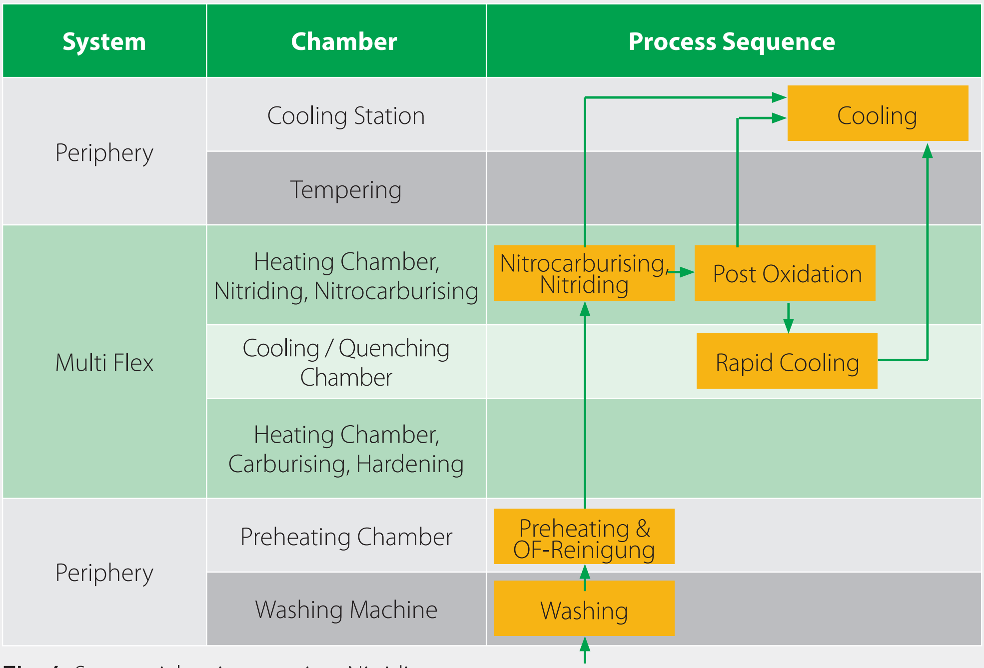

Fig. 4: Sequential recipe creation: Nitriding

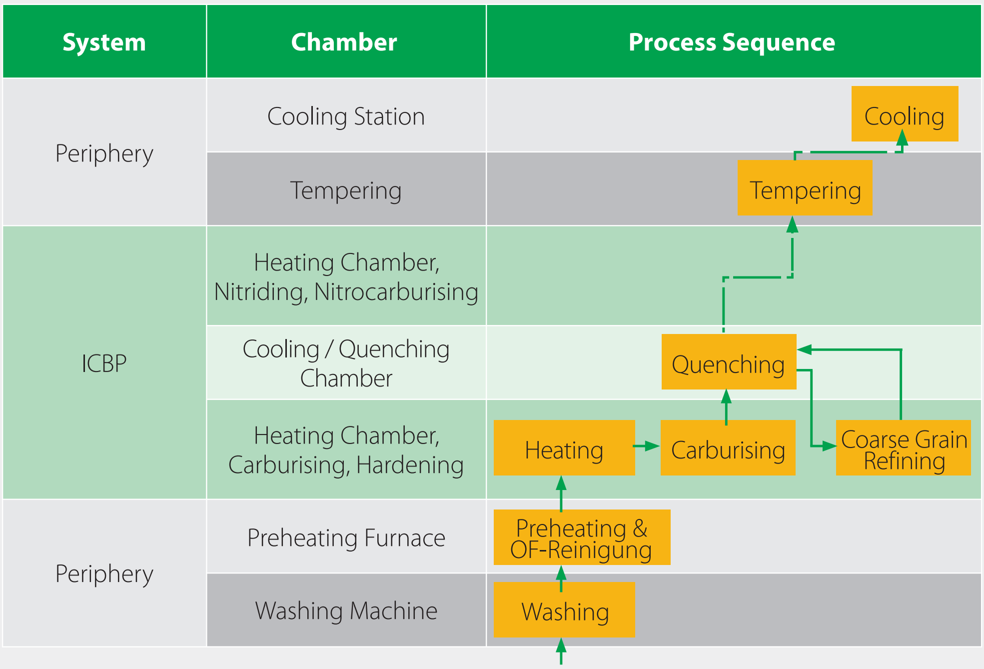

Fig. 5: Sequential recipe creation: Carburising

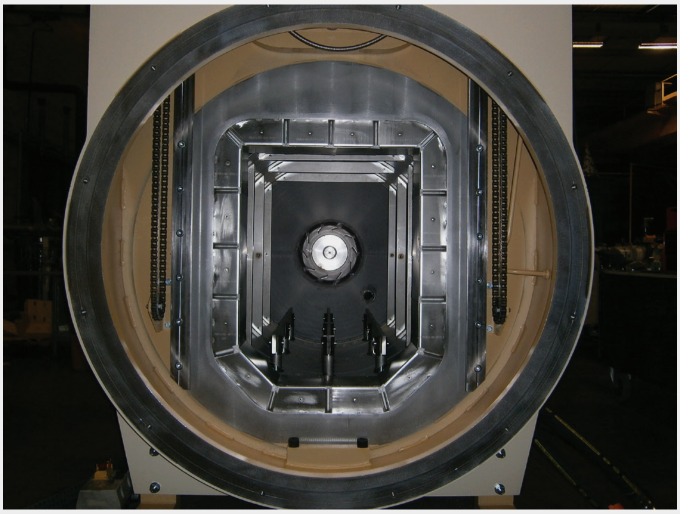

Fig. 6: Nitriding/carburising chamber

Fig. 7: Loading

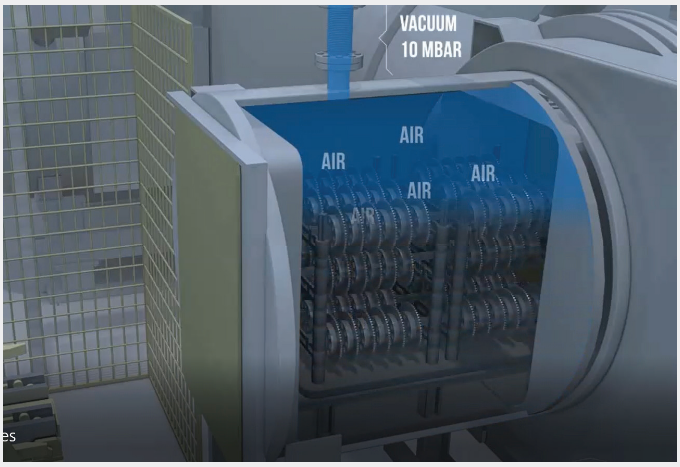

Fig. 8: Evacuation of the loading chamber

Automation in the periphery

Depending on the production capacity and customer requirements, automation can be implemented for loading and unloading, pre-washing, intermediate buffering, pre-oxidising and also downstream processes such as tempering (**Fig. 2**). The advantage for the user is obvious: Once the batch has been built up, all necessary upstream and downstream processes are carried out automatically. Another important factor is the documentation of the processes, which is massively simplified and carried out batch-related. Inspection/quality reports can be included. Industry 4.0 offers even more possibilities here: Robotic loading, component recognition, Visio system for bin-picking, etc.

ECM-OTPT – Production Planning Software

The utilisation of a heat treatment system, such as the ICBP Flex, is essential for every user. It seems to be contradictory to combine maximum flexibility and productivity. Especially in a multi-process system, which has to combine many different process types and times, productivity will suffer. To solve this conflict, the use of state-of-the-art production planning software is essential. The ECM-OTPT software analyses all recipe times in the batch storage of the transport system and splits the recipes into three sections: infeed – heat treatment – cooling. The chambers for infeed and cooling are central chambers and serve several heating chambers. The task of the OTPT is to calculate the optimal utilisation and thus avoid overlapping of the central chambers. **Fig. 3** shows the furnace occupation of each heating chamber (long bars) and the short occupation of the central chambers. Due to the virtual arrangement by the OTPT software, all existing batches are optimally arranged in the batch buffer to achieve the highest possible productivity of the system. Nevertheless, the user always retains the possibility to bring forward important orders. The OTPT recalculates the optimal process sequence after each manual intervention.

Creation of recipe sequences

In order to show its full flexibility, the recipe creation must be just as flexible and transparent for the user. The recipe creation of the ICBP Flex system is divided into individual sequences that can be strung together. **Fig. 4** shows the graphical representation (derived from the recipe manager). In the left column, the system is divided into peripherals (transport system, washing machine, tempering oven, etc.) and the ICBP Flex with its different heating chambers for the processes (see structure of heating chamber) and the rapid cooling chamber. The user creates a recipe by stringing together the individual sequences as shown in Fig. 4. In each recipe step, details such as temperatures, times and ramps are programmed.

Fig. 4 and **Fig. 5** highlight the flexibility of the ICBP Flex. Even after a high-temperature carburising process, the charge can be returned to a heating chamber for coarse grain refining after quenching. The quenching chamber should also be emphasised here. Due to the programmable quenching pressure, this is used for cooling with low pressures (1 bar) and up to 20 bar for hardening. The frequency converters supplied for both turbines can be programmed in the recipe with flow speeds (0-100 %) so that the component deformation can be optimally influenced.

Structure of ICBP Flex heating chamber

Due to the different process requirements, heating chambers (**Fig. 6**) are constructed differently. While heating chambers for higher (> 800 °C) temperatures are equipped with graphite hard felt plates and graphite resistance heating, stainless steel retorts are provided in the furnace for the lower temperatures. The NiCr heating elements used here are mounted outside the heating chamber to avoid contact with the process gases. Each heating chamber has its own process gas supply by means of mass flow controllers and temperature control systems.

SEQUENCE ICBP FLEX BATCH TRANSPORT

Loading

Loading and unloading takes place through the infeed chamber (EK) (**Fig. 7**), which is equipped with a separate vacuum pumping station. Two automatic, vacuum-tight doors hermetically seal the EK. The material to be charged is placed in the EK and evacuated; there is no interruption of the running processes in the heating chambers. Once the vacuum between the EK and the transport system has been equalised, the internal door opens automatically.

Transport and loading of the heating chamber

After the internal door has been opened, the charging trolley (**Fig. 8**) with its lift/telescopic fork takes over the batch for transport (**Fig. 9**) in a heating chamber. Each heating chamber can be equipped with a vacuum-tight door so that all heating chambers can carry out individual processes (NDA, hardening, nitrocarburising, etc.) with different pressures, temperatures and gases. **Fig. 10** shows the unloading in the heating chamber.

Process start

As soon as the batch is placed in the heating chamber and the door is closed, the process starts fully automatically. Process gases are monitored by the standard mass flow controllers and document the addition of media. At the end of the process, the same transport procedure is carried out as for loading in the reverse direction. Under vacuum conditions the batch is transported into the quenching chamber and quenched or cooled down depending on the programmed pressure.

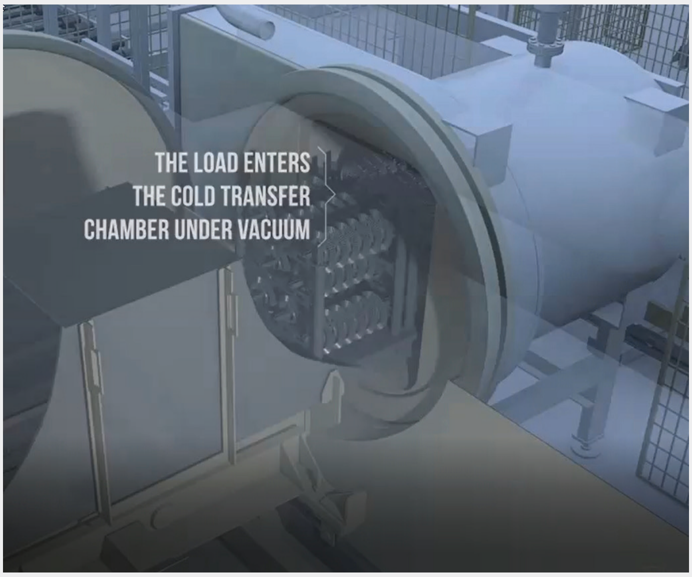

Fig. 9: Transfer to the internal transport system

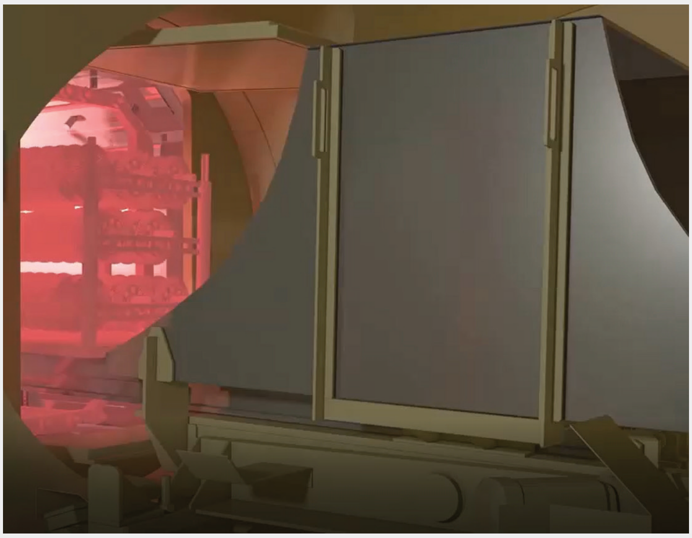

Fig. 10: Loading the quenching chamber

Industry 4.0 connection

Industry 4.0 has already found its way into many areas. The heat treatment industry, whether as a user or plant manufacturer, will have to adapt to increased customer requirements. The ICBP Flex already provides the necessary prerequisites for optimal connection and operation.

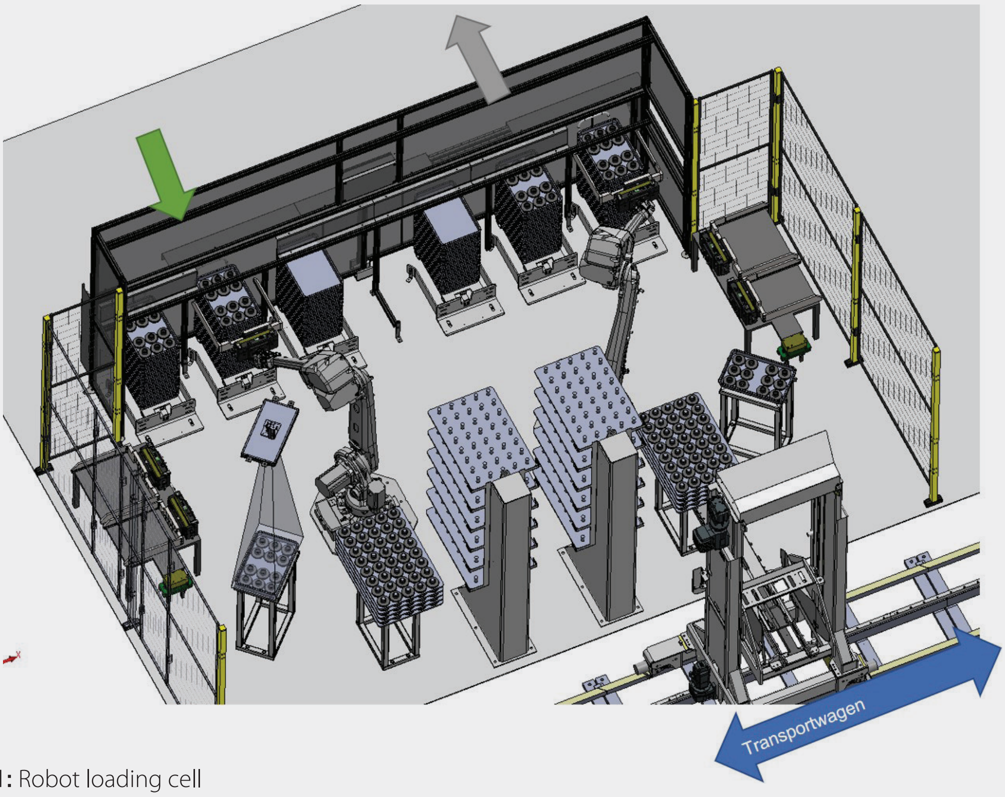

Fig. 11: Robot loading cell

Fig. 11 shows a robot loading cell equipped with the latest image recognition technology. With the aid of modern cameras, today's systems can identify components on the basis of characteristics, e. g. number of teeth, notches, etc., and load them onto batch carriers sorted by type. The so-called teaching of a new component takes approx. 2 h, so all parameters are stored. The Visio system automatically recognises the component if it is repeated. The operating personnel loads the cell with green material and unloads with heat-treated components.

The finished batches can then be taken over from the transport trolley and transported to the ICBP Flex.

In the following part 2 the basics of the considered heat treatment processes are discussed.

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