# A NEW PRINCIPLE OF EQUIPMENT FOR THE HARDENING OF TOOLS AND DIES

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## Abstract
A technological analysis of the vacuum furnace application for hardening of tools and dies with respect to heating and quenching requirements has been performed. It was noted that in modern vacuum furnaces the hardening process is performed mainly under gas atmosphere but under vacuum conditions only at the beginning during air evacuation. Analyses show that the hypereutectoid carbide precipitation cannot be avoided due to the insufficiently fast cooling in the high pressure gas quenching. A design of an integral quench furnace with a closed system of introducing the noble gas, i.e. argon or helium, and of quenching in a hot oil bath has been developed. The new design reduces the possibility of carbide precipitation and also reduces thermal stresses applying thermal hardening.

## Keywords
Hardening, Tool steels, Oxidation, Decarburization, Nitrogen absorption, Noble gas, Carbide precipitation, Thermal hardening

# INTRODUCTION

The quality of a tool is affected not only by the class and quality of the selected tool steel, but also by the quality of the applied heat treatment. Manufacturers of tool steels present the user basic parameters of heat treatment processes which can be divided in three groups: annealing, hardening and tempering[1]. All heat treatment processes are important, but hardening can be set apart from the other two as this process consists of several critical stages, which crucially affect the tool quality. In industrial practice, vacuum furnaces are predominantly used for tool hardening, while furnaces with the protective gas atmosphere and those with salt bath are much less often used, the latter even more rarely. Each type of equipment has its own advantages and drawbacks, which can be related to two basic stages in the process of hardening, i.e. austenizing and quenching. Modern vacuum furnaces for hardening of tools and dies are designed in the way that the heating and quenching processes are carried out under inert gas atmosphere, the latter by high pressure. These vacuum furnaces thus operate in the vacuum condition only at the beginning of the hardening cycle, i.e. at the stage of air evacuation, which actually classifies them as inert gas furnaces. Heating is carried out in inert gas in order to improve the heat transfer by convection, as the heat transfer by radiation is very slow at low temperatures in the vacuum and different in the charge. Inert gas has an important function in tool steel hardening as it prevents the selective vaporization of alloying elements from the steel surface at temperatures exceeding 1000°C.

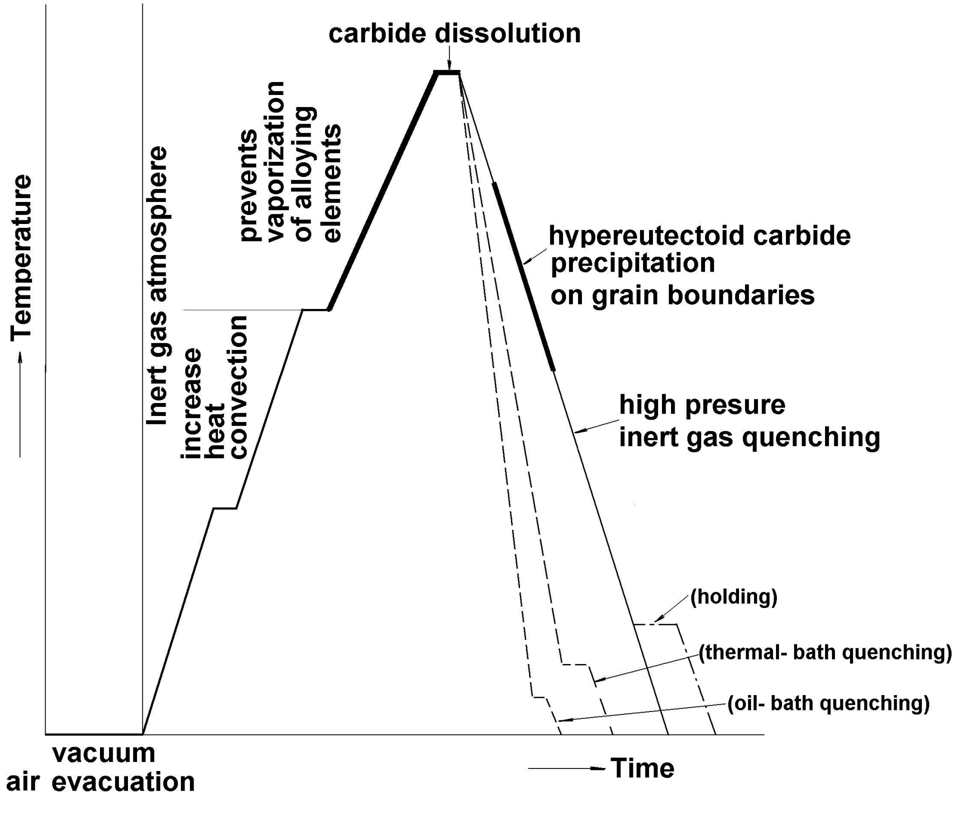


**Figure 1 :** Hardening sequence in vacuum furnace

As cooling in a gas is less intensive than cooling in other quenching media, manufacturers of furnaces have achieved a breakthrough in the increase of cooling intensity by[2-5]:

- Using an inert gases with a higher heat transfer: nitrogen, argon, helium and hydrogen,
- Increasing the inert gas pressure from the starting several bars to 20 bars,
- Introducing powerful turbines and heat exchangers,
- Introducing a second chamber only for cooling purposes.

In spite of all that, the achieved cooling intensity is not sufficient for some tool steel types, especially not for tools with large dimensions and bigger charges that are being hardened. Even if the required hardness on the surface of a tool has been achieved, the hardness of the tool core is often questionable. Along with achieving the required hardness, the achieved microstructure of tool steels is also very important. It is not always controlled, but its effects are always noticed. The phenomenon of hypereutectoid carbide precipitation on grain boundaries and forming of primary martensite near grain boundaries can be seen from CCT diagrams. An optical microscope cannot see the carbide precipitation on grain boundaries easily, but the use of a scanning microscope enables the identification of small carbides[6,7]. Carbides on grain boundaries decrease in toughness, dynamic properties as well as in heat fatigue resistance. The phenomenon of carbide precipitation occurs in most tool steels, i.e. in high-speed steels, ledeburitic cold-work tool steels, and hot-work tool steels. Steel manufacturers keep warning the involved parties of this phenomenon, but the manufacturers of vacuum furnaces as a rule suppress this harmful phenomenon, which limits the application of furnaces for hardening of tools and dies smaller dimensions.

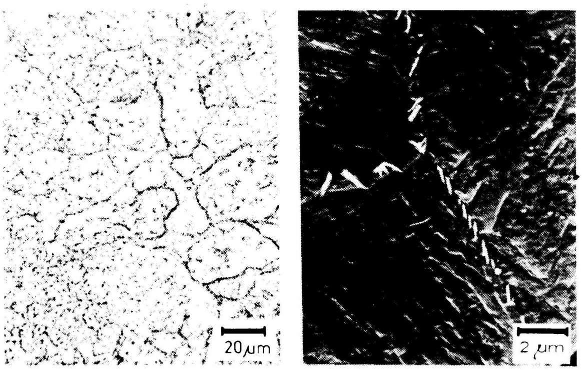


**Figure 2 :** Hypereutectoid carbide precipitation on grain boundaries (optical and scanning image)[6]

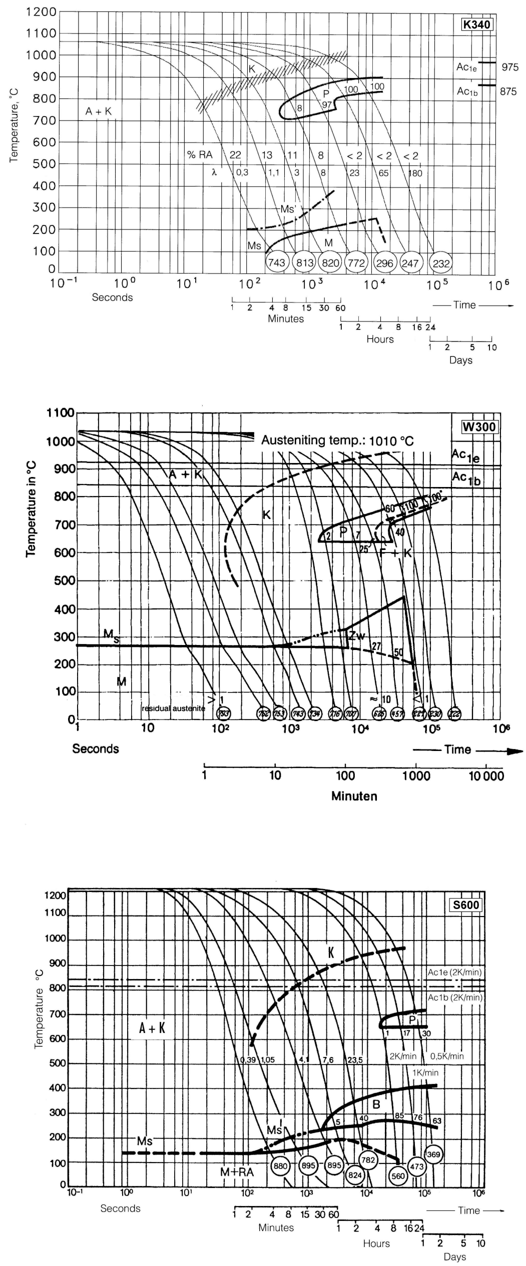


**Figure 3 :** Conditions of hypereutectoid carbide precipitation in CTT diagrams of characteristic types of tool steels: K340- cold-work, W300- hot-work and S600- high-speed steel[8]

A significant increase of cooling intensity can be achieved by bath quenching outside of the heating furnace. In addition, quenching in a liquid medium enables the application of thermal quenching (martempering process), which in turn results in reduced transformation stresses and in fewer possibilities of the occurrence of defects caused by inner stresses developed during hardening.

# EXPERIMENTAL

Due to high costs of vacuum equipment and process of hardening, the hardening of tools is rather expensive. This fact has given incentive to research focused on finding a possible cheaper solution while at the same time retaining the equivalent quality of hardened tools and dies. The basic starting points were that the heating process should be carried out under gas atmosphere without damaging effects on the tool surface (oxidation, decarburizing, carburizing, and nitrogen absorption) and that quenching should be more intensive than the quenching that can be achieved under gas atmospheres. These requirements related to gas atmosphere can be met only by noble gases because they are completely inert. Standard furnaces with protective gas atmosphere used for tool hardening contain nitrogen and dissociated methanol as a reducing component. Nitrogen is not completely inert because it is absorbed into the steel surface and affects the stabilization of austenite[9]. Nitrogen also forms a higher portion of soft rest austenite in hardened steel. Therefore, apart from the absorption of nitrogen, which takes place on the steel surface, the exchange of carbon depending on the carbon potential of such gas atmosphere and the carbon content in the heated steel also takes place[10,11]. The dissociation of methanol has as a result the formation of gas atmosphere containing carbon monoxide CO and hydrogen $H_2$, which act as reducing components and prevent the oxidation of the steel surface, but they can also have adverse effects on the exchange of carbon. The process of carburizing ($CO + H_2 > /C/ + H_2O$) or decarburizing (reaction in the opposite direction) may take place, depending on the carbon potential in the gas atmosphere and the chemical composition of the steel. Among noble gases, only argon and helium can meet the specific requirements of these applications. Since these gases are relatively very expensive, an economic system of introducing the gas into the furnace that would require a minimal consumption of costly gas had to be developed. Thus, a closed system for gravitate gassing which is made possible due to a big difference between the density of argon or helium and the air to be flushed out of the furnace. A non-flammable mixture of noble gas lower purity with the addition of 4% of hydrogen can be used instead of pure noble gases, i.e. argon and helium, which neutralizes the effect of oxygen and water vapour in noble gases lower purity. By introducing a minimal amount of noble gas and by maintaining low overpressure during the heating process, the consumption of gas is very small, which is not the case when nitrogen is used as it has identical density as air. In that case diluting carries out the exchange of air by nitrogen. This process requires large amounts of nitrogen because the tenfold volume of nitrogen is required to reduce the harmful influence of oxygen on steel surface. This is the reason why hydrogen and methanol, which prevent oxidation, are added, but harmful reactions of carbon exchange on the surface of steel, i.e. decarburizing and carburizing, or the absorption of nitrogen cannot be prevented.

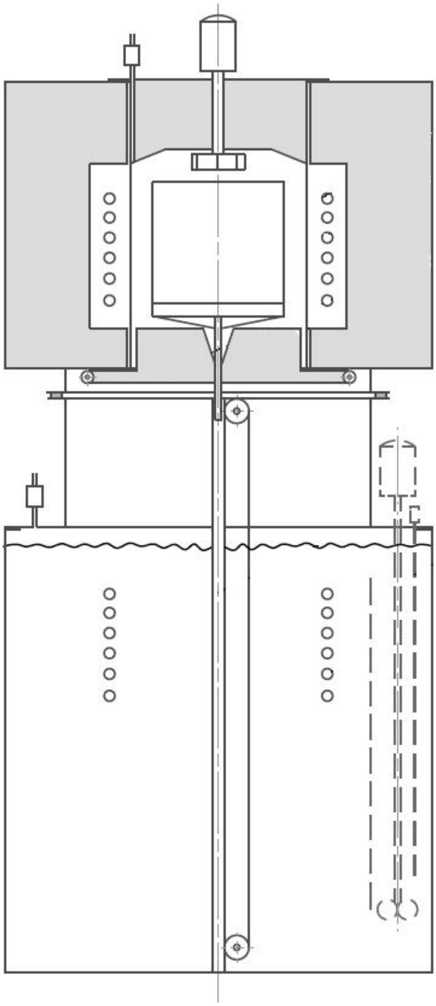

**Figure 4 :** Construction of the developed integral quench furnace

Regarding the ecological aspect of innovation one can say that the use of the noble gas argon or helium has no adverse effects on the environment since there are a completely inert gases. Argon and helium are produced by extraction from air and it is released from the furnace into the atmosphere without any changes. On the other hand, the most commonly used gas atmospheres in furnaces for the heat treatment of steel are produced from hydrocarbons which produce the gas atmosphere that is released into the environment in the form of carbon dioxide $CO_2$, water vapour $H_2O$ and nitrogen oxides $NO_x$. Because of their polluting effect, emissions of $CO_2$ and $NO_x$ are restricted by legislation. Quenching in oil bath is carried out in a closed noble gas system of integral quench furnace without any contact with air. Tool steel manufacturers recommend that tempering should be carried out immediately after cooling to the temperature of 80°C has been completed. This recommendation is applied in the integral quench furnace where the temperature of the oil bath is kept exactly at that temperature. A special advantage of the developed design is that the use of special oils for hardening at temperatures of approx. 350°C enables thermal hardening, which reduces the hardening stresses. This is of particular importance with high carbon and high-alloyed steels. The integral quench furnace consists of three vertically interconnected parts: a retort, a vestibule and a bath. Two variants of the furnace have been developed. The difference between the two variants lies in different versions of the vestibule and in the art of sealing. The hardening process in the integral quench furnace is carried out as follows: charging on the charge holder in the upper lift position, lowering of the furnace on the seal, introducing noble gas, closing the retort door, heating to the hardening temperature, opening the retort door, sinking the charge through the vestibule into the oil bath, lifting the hardened charge to the upper position and decharging. After hardening, tools are degreased in a warm detergent solution and immediately charged for tempering in a bell furnace. Tempering is carried out under the noble gas atmosphere or under a mixture with the addition of 4% of hydrogen, as well as cooling to the temperatures at which steel cannot oxidize in the air. Consequently, the surface of hardened and tempered tools remains metal bright without any damaging effects. The entire process of hardening and tempering is fully automatic due to the use of a program controller and a PLC, and is demonstrated by computer visualization.

# CONCLUSIONS

On the basis of a critical analysis of technical and economic aspects of the use of modern vacuum furnaces for the hardening of tools and dies, an integral quench furnace has been developed and patented. This furnace achieves a high quality of hardening at lower investment costs and significantly lower costs of treatment. Heating is carried out under noble gas atmosphere without the damaging effects on the tool surface. A closed system of gassing is applied so that the noble gas consumption is minimal. Quenching is carried out in an oil bath with the result of much faster cooling than that achieved under gas atmospheres in vacuum furnaces. This in turn reduces the possibility of hypereutectoid carbide precipitation on grain boundaries, which has a favourable effect on the exploitation properties of the tool. Examples of industrial application of the integral quench furnace in tool hardening prove a high quality of hardening achieved at much lower costs of treatment.

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