EMTEC CT-76-II

Industrial-Scale Intensive Quenching Process for Tool Products Commercialization

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This Technical Report has been reviewed and is approved for publication.

Percy J. Gros, Jr.
Director Core Technology Programs
EMTEC
SUMMARY

Intensive quenching (IQ) technology developed by Dr. Nikolai Kobasko was successfully validated and demonstrated for a variety of tool products by performing numerous experiments in full-scale IQ equipment and by conducting computer simulations. The following work has been done in Phase 2 of this project:

⇒ We developed guidelines for designing production IQ equipment for batch and continuous operations.
⇒ AFC-Holcroft, Inc., of Wixom, Michigan, a major heat treating equipment manufacturer in the USA and a licensee of IQ Technologies, Inc. used these guidelines for: a) designing the first production integral quench furnace equipped with an IQ water tank and installed at the Euclid Heat Treating Co. (EHT) of Cleveland, Ohio, and b) designing an IQ water tank for a continuous shaker hearth furnace installed at the Center for Intensive Quenching in Akron, Ohio.
⇒ We provided engineering services to EHT in commissioning of the new furnace and in determining cooling recipes for a variety of steel parts quenched in the new furnace.
⇒ We designed and built a fully automated new IQ system installed at the Center for Intensive Quenching. This system includes the following major components: a stand-alone 1,900-gallon IQ water, a ∅24”x24” atmosphere pit furnace, and an automated load transfer mechanism.
⇒ We established a “Center for Intensive Quenching” at the Akron Steel Treating Co. (AST) of Akron, Ohio facilities. The 4,000 square feet Center includes the following equipment:
  o High-velocity single part quenching IQ unit developed and built previously under EMTEC CT-65 project. The unit is equipped with a neutral salt bath furnace and a high-temperature, electric-fired, atmosphere, box furnace.
  o The new 1,900 gallon IQ system with ∅24”x24” atmosphere pit furnace.
  o The above shaker hearth furnace equipped with an IQ water tank and with a chiller to maintain the required water temperature.
⇒ We conducted a number of demonstration IQ trials for tool products. We applied the IQ process to a variety of parts (punches, chisels, dies, wear plates, etc.) made of different tool steels as well as of alloy and plain carbon steels. We conducted IQ demonstrations in the production IQ systems installed at Akron Steel Treating Co. and Euclid Heat Treating Co.
⇒ Our customers tested intensively quenched parts in actual field conditions to evaluate the product service life and performance improvement. The data obtained from the field showed the following:
  o Service life (number of holes punched) of cold-work punches (provided by American Punch, Inc. and made of S5 shock-resisting steel) was improved by two to eight times.
  o Aluminum extrusion dies provided by General Aluminum Co. and made of hot work, H-13 steel outperformed the standard dies by at least 50%.
  o Dies provided by Midway Machining Co., made of plain carbon 1045 steel and used for pellet manufacturing outperformed the standard dies by more than 100%.
  o Concrete crusher liner wear plates (provided by an EHT customer and made of 1045 steel), had the same surface hardness as the plates made of more expensive, pre-hardened high alloy HARDOX®-500 material supplied by a Swedish
company and used currently by EHT’s customer. The 1045 material intensively quenched wear plates are currently in the field).

- Concrete block molding machine wear plates (provided by Bergen Machine Co. and made of 8620 steel) were processed at AST using a 40% reduced carburization cycle. An effective case depth in the intensively quenched wear plates was the same as in the standard, oil quenched parts.

- Base keys (provided by an EHT customer and made of 8620 steel) were processed using a 40% reduced carburization cycle. The intensively quenched parts showed the same performance as standard parts.

- Other intensively quenched tool products are still being evaluated in ongoing field trials.

⇒ We introduced the IQ process in three commercial heat treating shops: Akron Steel Treating Co., Summit Heat Treating Co., a division of AST, and in Euclid Heat Treating Co.

⇒ We continue working on commercialization of the IQ technology throughout the USA heat-treating industry.

We expect to realize savings from our new IQ system (when fully utilized) in the range of $100,000 to $165,000 per annum per system due to a significant reduction of the heat treatment process cost. The end-users of intensively quenched tool products will realize additional savings due to a significant improvement of the part performance.
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Introduction

1.1 Background

Phase II of EMTEC CT-76 project started in November 2001. In April 2003, EMTEC has received a grant from the Department of Energy (DOE) for a project entitled “Intensive Quenching Technology for Heat Treating and Forging Industries”. As a condition of the DOE grant, EMTEC contributed the remaining money from CT-76 project as matching funds to the DOE project. The goals and deliverables of the original CT-76 project Phase II were reconsidered with respect to the objectives of the above DOE project. This report summarizes the work on the application and the commercialization of the intensive quenching (IQ) process for tool products that has been done under both the EMTEC and DOE projects from November 2001 till August 2005.

The IQ technology was developed by Dr. N. Kobasko in the Ukraine and is being introduced into the USA by EMTEC and IQ Technologies, Inc. (IQT). In accordance with this technology, steel parts are quenched in violently agitated water with a cooling rate that is significantly faster than quenching in oil, quenching with high-pressure gas in vacuum furnaces, or quenching in the air. This is accomplished by using water or a low concentration water/mineral salt solution as the quenching medium together with a high velocity of the quenchant contacting the surface of the work. The austenite/martensite phase transformation in the steel being quenched is caused to occur simultaneously over the whole part surface resulting in the development of a strong martensite case (“shell”) and residual, surface compressive stresses. The strong case and compressive stresses prevent cracking of the steel part and minimize distortion. The IQ process is interrupted when the surface compressive stresses reach their maximum level (as determined by the IQT computer model) and subsequent cooling of the core through the cold shell is controlled to maintain the compressive, residual surface stresses. Reference 1 describes the IQ process in details (see also a technical paper on our web site www.intensivequenching.com).

In Phase 1 of EMTEC CT-76 project, we validated and demonstrated the IQ technology by performing numerous experiments with a variety of tool products and by comparing the actual results to our computer simulations. We used two IQ units for the IQ process demonstration: a 500-gallon experimental IQ system installed at Akron Steel Treating Co. (AST) of Akron, Ohio, and in a full-scale 6000-gallon IQ system installed at Summit Heat Treating Co. (SHT), a division of AST, also of Akron, Ohio. We proved experimentally that the IQ process considerably improves strength and wear resistance properties of the steel parts while using a lower cost, less hazardous, environmentally friendly quenchant -- water (or a low concentration water/mineral salt solution) instead of oil. For example, the service life of S5 steel, 11/16” square punch was improved by at least two times. The service life of a 0.5” round punch also made of S5 steel was improved by more than 50%.

1.2 Project Objectives

The major objectives of this project were the following:
⇒ To further validate the IQ process for tool products.
⇒ To develop and to build production heat-treating equipment for implementing the IQ process on production-size loads.
⇒ To establish the Center for Intensive Quenching at AST.
To develop an industrial-scale intensive quenching process for single part and batch quenching of tool products that is a significant improvement over the current methods of steel hardening relative to quality of the finished product, the overall cost of heat treatment, and elimination of oil quench hazards and pollution.

To commercialize the IQ process at three commercial heat-treating plants: AST, SHT and Euclid Heat Treating Co. (EHT) of Cleveland, Ohio

1.3 Approach

Initially, two directions of work were planned under this project. The first direction was to develop an intensive quenching technology for specified tool products that require a heating temperature below 2,000°F and that could be treated in a controlled atmosphere, heat treating furnace. These tool products are made of materials such as the following: chromium hot-work steels air and oil hardening cold-work steels, shock-resisting steels, and water-hardening tool steels. In the beginning of the project, EHT was going to modify its Surface Combustion integral quench atmosphere furnace to accommodate a water-base quenching system. A part of this modification was a replacement of the existing oil quench tank in the cooling chamber with a water-base quenching system with high agitation. Also, in contrast to the current designs of integral quench furnaces, EHT was going to equip the new unit with a gas-tight door between the heating and cooling chambers to minimize an effect of water vapors on the endothermic gas, furnace atmosphere. Later in the project, EHT made a decision to order a brand new integral quench furnace equipped with an IQ water tank from AFC-Holcroft Company of Wixom, Michigan (see Section 2 below). IQT has provided AFC-Holcroft with guidelines for designing IQ water tank as well as with a technical support in installation and tuning of the above furnace with IQ capabilities. IQT also provided engineering services to EHT in commissioning of the new furnace.

The second direction of the project was to develop an industrial-scale IQ process for specified tool products that require a high temperature heating cycle (above 2,000°F -- usually performed in a vacuum furnace). These tool products include the following: molybdenum high-speed steels, tungsten high-speed and hot-work steels, and some chromium hot-work steels. Mercer Technologies Inc. of Terre Haute, Indiana was going to redesign and to reconstruct a two-chamber vacuum furnace with an oil quench tank. Similar to the above atmosphere furnace, Mercer Technologies was going to substitute the oil quench tank in the cooling chamber of this furnace with a water-base quenching system with high agitation. In contrast to the current designs of two-chamber vacuum furnaces, Mercer Technologies was planning to equip the new unit with a gas-sealed door between the heating and cooling chambers. The reason for this was to eliminate vacuum conditions above the water tank during the heating cycle (water, in contrast to oil, will fully evaporate under the vacuum). AST was planning to install this furnace at its facilities. However, during the course of the project, Mercer Technologies Inc. could not allocate proper technical resources and funding for modifying the vacuum furnace, and this portion of the project was dropped.

The third direction of work was specified under the DOE project, which was to develop a Center for Intensive Quenching that utilizes different heating equipment with intensive quenching systems for processing a variety of steel parts including tool products, in batches, continuously or as a single part.

IQT introduces the IQ process into the heat-treating practice in two steps. In step one (that is completed), IQT assisted three commercial heat-treating companies (AST, SHT and EHT,
participants of this project) in the introduction of the IQ process. IQT developed general
recommendations for designing optimal intensive quenching systems for these facilities. IQT
assisted the shops in mastering the new quenching technology. On as needed basis, IQT provided
the participating plants with IQ process cooling recipes for a variety of steel parts. In the next
step of the IQ process commercialization, IQT introduces the quenching method in other heat-
treating plants using the experience learned from the above three commercial heat-treating shops
in the development, installation and running of new IQ equipment.
2. Designing of Intensive Quenching Equipment

There are three types of IQ equipment. The first one is designed for implementing “single-part” intensive quenching process. The second type of IQ equipment is designed for “batch” operations. IQ units of the third type are designed for “continuous” operations.

In single part intensive quenching systems, the parts are quenched one-by-one after being heated throughout to the austenitizing temperature. Any type of heating method can be used for heating the parts prior to quenching: an atmosphere furnace, a salt-bath furnace, an induction (through-heating) unit, etc. We have developed and built a single part quenching high-velocity IQ system under the EMTEC project CT-76 (Reference 2). This system is installed at the AST Center for Intensive Quenching and equipped with both a neutral salt-bath furnace and an atmosphere electric furnace.

In batch type IQ systems, parts are grouped in baskets and through-heated to the austenitizing temperature in the furnace. For intensive quenching, the baskets of parts are moved from the furnace hot zone and into the IQ quench tank. Any type of batch furnace equipment (atmosphere, fluidize bed or salt bath) can be used when implementing the batch IQ process. The IQ tank can be separated from the furnace (as was done in our first production IQ system installed at Summit Heat Treating Co. of Akron, Ohio, Reference 2), or the IQ tank can be a part of an integral quench furnace (as is done in the second production IQ system described below).

In continuous IQ systems, the steel parts are quenched in an IQ water tank out of a continuous furnace. Any types of continuous furnace can be used (mesh belt or cast belt furnace, shaker hearth furnace, pusher furnace, walking beam furnace, etc.). In the sections below, we described the three production IQ systems we have developed, built and tested under this project.

2.1 Integral Quench Atmosphere Furnace

As we mentioned in Section 1.3, the second production IQ system was installed at the EHT facility. It is a three-chamber, integral quench, batch-type furnace with working dimensions of 91cm×91cm×183cm (36”×36”×72”) for implementing the batch IQ process. Note, that when using an in integral quench type furnace with the water quench tanks, one of the major issues is a possibility of contamination of the furnace protective atmosphere by minute amounts of water or water vapor coming from the quench tank into the furnace heating chamber. This may happen while inner furnace door is open and the load is moved from the furnace to the quench tank or even when the door is closed by migration around the door. To solve this problem, the AFC-Holcroft Co. proposed a three-chamber design approach similar to their integral, atmosphere to salt austquenching system (Figures 1 and 2).

As seen from the Figures 1 and 2, the AFC/IQ unit has three chambers; a heating chamber, an intermediate chamber, and the quench tank chamber. The intermediate chamber and the quench chamber are constantly ventilated (purged) to the outside air. The furnace chamber and the vestibule over the quench tank both have “leaking” doors; therefore the furnace protective atmosphere gases are continuously flowing from the heating chamber, then entering the intermediate chamber and then flowing out over the water quench tank, creating a buffer between the quench tank and the furnace. When the load starts moving from the heating chamber of the furnace into the intermediary chamber, the quench chamber door is closed. After the load leaves the furnace, the furnace door is closed and the intermediate chamber door to the
Figure 1  Elevation Drawing of Production IQ System Installed at Euclid Heat Treating Co.

Figure 2  Picture of Integral Quench Furnaces With IQ Water Tank Installed at Euclid Heat Treating Co.
quench chamber is opened. Thus, the water vapors have no chance to enter the furnace hot zone and destroy the integrity of the protective atmosphere of the heating chamber.

IQT provided AFC-Holcroft with technical guidelines for designing the IQ water tank (the size of the tank, number of props and their characteristics, prop location, baffles design, etc.). The 39.7 m³ (11,000-gallon) quench tank is equipped with four 61 cm (24") propellers that are rotated by four motors providing a total recirculation of 5.67 m³/sec (90,000 gpm). The approximate velocity of the quenchant in the tank will be about 1.6-1.8 m/sec (5-6 ft/sec) passed the parts. Internal direction vanes and baffles provide a uniform quenchant flow velocity through the workload.

The quenching chamber is equipped with a unique lifting mechanism that provides accelerated vertical motion (about 2 seconds) into and out of the quench tank. Minimizing this motion time is very important for accurately implementing IQ cooling recipes.

The new integral quench furnace is equipped with a chiller to maintain the water temperature in the tank 65-70°F. We also added a sodium nitrite salt to the water to minimize the film-boiling mode of heat transfer during quenching (minimizing the duration of any film boiling in-turn reduces part distortion). The salt concentration in water is about 8 to 10% that is optimum for the parts processed in this furnace and helps prevent corrosion of the quench tank system.

We conducted a cooling uniformity survey in the 11,000-gallon IQ water tank a number of test samples placed in the load. It was proven that the full-scale intensive quenching system provides a uniform and intensive quenching of up to 2,500 pound batches of steel parts.

2.2 Stand-Alone Intensive Quenching Water Tank

IQT developed a design of a stand-alone intensive quenching water tank for batch quenching of steel parts out of a batch furnace (atmosphere, neutral salt bath or fluidized bed). The IQ water tank presented in Figures 3 and 4 is designed for intensive quenching of steel parts out of an atmosphere furnace of ∅24x36".

The IQ tank dimensions are 8’x8’x4’. The tank contains 1,900 gallons of water. The major IQ tank components are the following::

⇒ U-shaped tube of ∅24” attached to the tank walls and to the tank bottom.
⇒ ∅22” marine prop rotated by a 10 hp motor and installed within one leg of the U-tube. The prop pushes the water from the tank down into one leg of the U-tube and up the other leg and back into the tank.
⇒ A star-shaped baffle is installed right beneath the prop to straighten the water flow after the prop.
⇒ The quench section is located in the other leg of the U-tube where the load to be quenched is placed.
⇒ A set of turning baffles at the entrance into the quench section provides a uniform water flow distribution throughout the U-tube cross-section.
Figure 3  Stand-Alone 1,900-gallon IQ Water Tank (Top View)

Figure 4  Stand-Alone 1,900-gallon IQ Water Tank (Side View)
Four guards around the quench on the top of the IQ tank prevent the water from splashing when loading the quench section (one guard is retractable to clear the way for the load to and from the quench section).

The IQ tank has an inlet and outlet pipes for providing a water circulation between the tank and a chiller. The Bison Welding & Fabrication Co. of Cleveland, Ohio, built the above IQ water tank. Prior to commissioning of the unit, we tested the tank for the water flow velocity uniformity. The water flow velocity distribution was very uniform (1.7±0.15 m/sec or 5.6±0.5 ft/sec) throughout the quench area. This tank became a part of the IQ system built for the Center for Intensive Quenching (see Section 3 below).

2.3 Shaker Hearth Furnace With IQ Water Tank

When implementing IQ processes in a continuous furnace, it is very important to eliminate film boiling from the onset of part cooling (when parts are still in the furnace chute). It also important to have an ability to interrupt the quench at a certain time (when the part core is still hot so that the self-tempering process can take place). We developed a guideline for designing IQ water tanks for continuous furnaces that provide the units with both these required features. According to this guideline, the furnace chute should be equipped with a set of nozzles and a pump. These nozzles provide high turbulence of water in the chute that in turn helps to eliminate any film boiling at the initial stages of cooling. In addition, the quench tank conveyer should be equipped with a variable speed motor that will allow controlling the part cooling time (or “dwell-time” in the tank. The chute cooling requirements and the dwell time after the initial cooling in the chute depends on the part dimensions and is calculated using the IQT’s software program.

The Euclid Heat Treating Co. donated to the IQT Center a used 4”x1” shaker hearth furnace equipped with an oil quench tank. To provide the furnace with ability to quench parts intensively, we replaced the oil quench tank with a customer fabricated IQ water tank. Also, together with AFC-Holcroft Co., we redesigned the existing furnace chute and provided the IQ tank conveyer with a variable speed motor.

We placed twenty Ø0.25” mixing nozzles (10 on each side of the chute). A 150-gpm pump provides a water circulation through the nozzles. We connected the quench tank to a chiller to maintain the water temperature within the specified range. We also plumbed the furnace with a protective atmosphere (endo gas or nitrogen) and wired all new controls and instrumentation. The furnace is capable of quenching of a variety of steel products (fasteners of different kinds, hand tool sockets and socket adapters, small ranches, etc.). Figure 5 presents a picture of the furnace.
Figure 5  Shaker Hearth Furnace
3. Demonstration of Intensive Quenching Process for Tool Products

Over the course of the project, we conducted a number of demonstration IQ trials for actual tool products. We applied the IQ process to a variety of parts (punches, chisels, dies, wear plates, etc.) made of different tool steels as well as of alloy, plain carbon steels and carburized grades of steel that are traditionally quenched in oil, air or inert gas. Table 1 summarizes the IQ demonstrations we have performed. Figures 6-12 show the pictures of some of the processed parts. To evaluate the metallurgy of the intensively quenched parts we measured the following parameters: a surface and core hardness, micro hardness and effective case depth for carburized grades of steels.

A majority of tool products presented in Table 1 have favorably responded to the IQ process. For example:

⇒ Punches provided by American Punch, Inc. and made of shock-resistance S5 steel demonstrated a service life improvement from 100% to 800%.
⇒ Aluminum extrusion dies provided by General Aluminum and Manufacturing Co. and made of hot work H-13 steel out performed the standard, air quenched dies by at least 50%.
⇒ Dies provided by Midway Machining Co., made of plain carbon 1045 steel and used for pellet manufacturing out performed the standard, oil quenched dies by more than 100%.
⇒ Concrete crusher liner wear plates provided by an EHT customer and made of plain carbon 1045 steel had the same surface hardness as the more expensive, Swedish-sourced, pre-hardened high alloy HARDOX®-500 material used currently by the customer.
⇒ Concrete molding machine wear plates provided by Bergen Machine Co. and made of 8620 steel were processed using a 40% shorter carburization cycle. The intensively quenched parts showed the same effective case depth as parts carburized in a 40% longer cycle and then quenched in oil.
⇒ Base keys provided by an EHT customer and made of 8620 steel were processed using a 40% shorter carburization cycle. The intensively quenched base keys showed the same performance as the same parts carburized in a 40% longer cycle and quenched in oil.

Some of the tool products we quenched intensively are still in the field under the customer evaluations (the chisels, wear plates, hammers). Some of the tested parts did not respond well to the IQ method due to different reasons (for example, both the extrusion tips provided by Chamberlain Manufacturing Co. and the digging teeth provided by a EHT customer developed cracks on the surface due to complex part geometries that did not allow the parts to be batch, intensively quenched. Also, we could not provide required surface conditions for the sockets provided by Danaher Tool Co. and made of 40B25 steel (the surface had an excessive oxidation due to an absence of the right combination of atmosphere heating equipment and IQ equipment at the time of IQ trials).

The major findings from the IQ demonstrations we have conducted are the following:

⇒ American Punch Co. is planning to send all punches for heat treatment to the Center for Intensive Quenching as soon as the new IQ equipment is ready for production runs. The company will also continue a further evaluation of the IQ process for S7 steel shear blades.
General Aluminum Manufacturing Co. agreed to heat treat H-13 steel aluminum extrusion dies using the IQ process. We will heat treat the H-13 steel parts in the new IQ system installed at the Center for Intensive Quenching (see Section 4.2).

After initial favorable metallurgical findings and field-testing, both of the wear plates manufacturers will be sending more parts to EHT for intensive quenching.

Table 1  List of Tested Parts

<table>
<thead>
<tr>
<th>Part Name</th>
<th>Type of Steel</th>
<th>Customer</th>
<th>IQ Equipment and Facility Used</th>
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<tr>
<td>Dies</td>
<td>Hot work H-13</td>
<td>General Aluminum</td>
<td>IQ tank, EHT</td>
</tr>
<tr>
<td>Dies (extrusion tips)</td>
<td>Hot work H-13</td>
<td>IQT customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Dies</td>
<td>Plain carbon1045</td>
<td>AST customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Cold roll dies</td>
<td>Cold work DC-53</td>
<td>AST customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Punches</td>
<td>Shock-resisting S5</td>
<td>American Punch</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Punches</td>
<td>Shock-resisting S5</td>
<td>IQT customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Punch holder</td>
<td>9310 carburized</td>
<td>AST customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Share blade</td>
<td>Air-hardening cold work A8</td>
<td>IQT customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Share blade</td>
<td>Shock-resisting S7</td>
<td>American Punch</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Chisels</td>
<td>Plain carbon 1070 and 1080</td>
<td>EHT customer</td>
<td>IQ tank, EHT</td>
</tr>
<tr>
<td>Hammers</td>
<td>Alloy 4150</td>
<td>AST customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Tubes</td>
<td>Plain carbon1010 carburized</td>
<td>EHT customer</td>
<td>IQ tank, EHT</td>
</tr>
<tr>
<td>Digging teeth</td>
<td>Low carbon low alloy steel</td>
<td>EHT customer</td>
<td>IQ tank, EHT</td>
</tr>
<tr>
<td>Wear plates</td>
<td>Alloy 4140</td>
<td>EHT customer</td>
<td>IQ tank, EHT</td>
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<tr>
<td>Concrete crusher liner wear plates</td>
<td>Plain carbon 1045 (instead of pre-hardened HARDOX-500 material)</td>
<td>EHT customer</td>
<td>IQ tank, EHT</td>
</tr>
<tr>
<td>Concrete molding machine wear plates</td>
<td>High alloy 8620 carburized</td>
<td>IQT customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Hand tool sockets</td>
<td>Boron 40B25</td>
<td>IQT customer</td>
<td>IQ tank, AST</td>
</tr>
<tr>
<td>Base keys</td>
<td>Plain carbon 1018 carburized</td>
<td>EHT customer</td>
<td>IQ tank, EHT</td>
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Figure 6  S5 Steel Punches

Figure 7  H-13 Aluminum Extrusion Die

Figure 8  – 1070 and 1080 Steel Chisels

Figure 9  – 9310 Steel Punch Holder
Figure 10  1018 Steel Base Keys

Figure 11  – Load With 1018 Steel Base Keys
4. Center for Intensive Quenching

The Center for Intensive Quenching is designed to implement the IQ processes for a variety of steel parts including tool steel products. The Center’s mission is two fold: a) to demonstrate and to validate the IQ processes on an industrial scale basis, and b) to generate revenues for IQT by processing production loads. The Center for Intensive Quenching includes the following IQ equipment:

- Single-part quenching high-velocity IQ system
- Batch quenching IQ system
- Continuous IQ system

Figures 12 and 13 present pictures of the above IQ equipment installed in the Center for Intensive Quenching. The sections below describe designs of the IQ systems and their operation.

4.1 Single-Part Quenching IQ System

The single-part quenching high-velocity IQ system includes the following major components (Figure 12):

- 800-gallon water tank equipped with high-pressure 600-gpm pump, loading/unloading lift table, three-way valve, piping, controls, etc. (see details in Reference 3)
- \( \varnothing 12'' \times 18'' \) neutral salt bath furnace with a maximum heating temperature of 1,700°F
- 8”x8”x12” electric box atmosphere furnace capable of heating parts up to 2,300°F

The part to be quenched is through-heated in either of the above two furnaces depending on the part size and required heating (austenitizing) temperature. The part is manually transferred from the furnace to the IQ tank. A sample sequence of operations of the high-velocity IQ unit is presented in details in Reference 3.

Note, the above electric box atmosphere furnace allows processing tool products made of high alloy steels that require a high temperature heating cycle (above 2,000°F) and that are usually processed in vacuum furnaces. These high alloy steels are usually “air” or “gas pressure” quenched and include the following: molybdenum high-speed steels, tungsten high-speed and hot-work steels, and some chromium hot-work steels.

4.2 Batch IQ System

The batch IQ system includes the following major components:

- 1,900-gallon water tank described in Section 2.2 above.
- Atmosphere pit type furnace with a working space of \( \varnothing 24'' \times 24'' \) high. The furnace is equipped with electrically heated elements, a fan attached to lid (door), an automated, pneumatically operated lid, a thermocouple for controlling the furnace temperature, and an oxygen probe for controlling the furnace’s protective atmosphere. Parts are heated in the furnace in typical fixtures equipped with a center pole. The fixture center pole has a ring at the top of the pole for picking and carrying the load. The fixture with parts is placed on the furnace supports.
Figure 12  High-Velocity Single-Part Quenching IQ System and Shaker Hearth Furnace With IQ Water Tank and Chiller
Figure 13  Batch Type IQ system
⇒ Loading/unloading table that is designed to place the load prior to loading the parts into the furnace and to place already quenched parts before transferring them to a tempering furnace. The loading/unloading table is also used when transferring the hot part from the furnace to the 800-gallon high-velocity system (see Section 5 below). The loading/unloading table can move along the rails towards the aisle so the load can be placed on or taken from the loading/unloading table by a forklift.

⇒ Load transfer system that is designed to transfer the load from the loading/unloading table into the furnace, or from the furnace into the 1,900-gallon quench tank, and from the quench tank back to the loading/unloading table. The load transfer system also transfers parts from the furnace to the 800-gallon high-velocity IQ system. The load transfer system includes the following major components:

- Steel frame consisting of four vertical columns and two horizontal I-beams.
- Two load transfer mechanisms: one that transfers the load in horizontal direction and another one that transfers the load in vertical direction.
- Carriage providing a horizontal movement of the load.
- Electrical motor located on the carriage, a rack pinion drive and a linear bearing placed on two horizontal beams providing fast and controllable movement of the carriage.
- Two air cylinders with two linear bearings attached to the carriage that provide a vertical movement of the load.
- Pneumatic lock attached to the air cylinders.

The system’s mode of operation is the following. Initially, the fixture with the batch of parts to be heat treated is on the loading/unloading table, the carriage is above the loading/unloading table, the air cylinders are completely retracted, the pneumatic gripper is in a top position and is unlocked, pneumatic gripper aligns with the fixture center pole. The load transfer mechanism operates in four steps:

⇒ Step 1: This step starts after the operator opens the furnace door. The air cylinders move the pneumatic gripper down towards the fixture with parts. The pneumatic gripper grips the ring attached to the fixture center pole and locks in place. The air cylinders move the load up from the loading/unloading table to the upper position.

⇒ Step 2: The carriage moves the load towards the furnace. The carriage stops above the furnace working space so that the fixture center pole aligns with the furnace axis. The air cylinders lower the load into the furnace. After the load is placed on the furnace load supports, the pneumatic gripper releases the fixture center pole ring, and the air cylinders move the pneumatic gripper to the upper position (the air cylinders are fully retracted). At the end of Step 2, the operator closes the furnace door. The carriage remains above the furnace till the heating cycle is over.

⇒ Step 3: When the heating cycle is completed, the operator opens the furnace door. The IQ tank prop is ON (the prop should be turned on a one minute or so prior to the completion of the heating cycle). The retractable guard on the top of the IQ tank moves to clear the way for the load being transferred from the furnace to the IQ tank quench section. The air cylinders push the pneumatic gripper towards the fixture center pole ring; the pneumatic gripper grips the ring and locks. The air cylinders move the load to the upper position (the air cylinders are fully retracted). The carriage moves the load to over the IQ tank. The carriage stops above the IQ tank quench so that the fixture center pole aligns with the quench section axis. The retractable guard moves back and seals the
area around the quench section. The air cylinders lower the load into the quench (the air cylinders are fully extended). The load is kept in the quench for the specified time after which the gripper cylinders pull the load out from the intensive water quench and into the air.

⇒ Step 4: The load transfer mechanism operation in Step 4 depends on what type of the IQ process is applied (IQ-3 or IQ-2):

- Step 4a: If a one-step quenching (IQ-3) process is used, the retractable guard opens and the carriage moves the load back to the loading/unloading table. The retractable guard moves back and seals the area around the quench section. The IQ tank prop is turned off. The air cylinders lower the load onto the loading/unloading table. The pneumatic gripper releases the fixture ring. The air cylinders move the pneumatic gripper up and out of the way. The load is ready to be transferred to a tempering furnace; OR

- Step 4b: If a three-step (IQ-2) process is used, the load is kept in the air for a specified period of time to allow self-tempering of the intensively quenched shell by the hot core of the part. Then the air cylinders push the load back into the quench. The load is kept in the quench for a specified time after which the gripper pulls the load out from the quench. The retractable guard opens and the carriage moves the load back to the loading/unloading table. The retractable guard moves back and seals the area around the quench section. The IQ tank prop is turned off. The air cylinders push the load down and place it on the loading/unloading table. The pneumatic gripper releases the fixture ring. The air cylinders move the pneumatic gripper up and out of the way. The load is ready to be transferred to a tempering furnace.

Operator closes the furnace door after Step 4 is completed.

The IQ unit control system includes the following controls and safety sensors.switches:

⇒ Sensor controlling the furnace door position, so that Step 1 can be initiated only if the furnace door is open.
⇒ Sensor controlling the condition of the pneumatic lock, so that the air cylinders start pulling the load up from the loading/unloading table only if the pneumatic lock is locked.
⇒ Sensor controlling the position of the air cylinders, so that the carriage starts moving only when the air cylinders are fully pulled in (the load is in the upper position).
⇒ Sensor controlling the position of the retractable guard so that the carriage starts moving to and from the IQ tank only when the guard is open.
⇒ Sensor controlling the mode of the prop so that the carriage starts moving to the IQ tank only when the prop is ON.
⇒ Proximity switches controlling the position of the load on the loading table
⇒ Proximity switches controlling the position of the carriage, so that the air cylinders start pushing the pneumatic lock down towards the load only if it is aligned with the fixture center pole ring; and the air cylinders start pushing the load down into the furnace or into the quench only when the fixture center pole is aligned with the furnace axis or with the quench section axis respectively.
⇒ Sensor controlling the carriage acceleration and deceleration.
⇒ Sensor controlling water temperature.
⇒ Sensor measuring the sodium nitrite content in the water.
⇒ Sensor monitoring the prop rpm and amps.

Note that the total transfer time of the load from the furnace to the 1,900-gallon quench tank is less than 12 seconds. This time includes the time to pull the load from the furnace, the time to transfer the hot load from the furnace to the IQ tank quench section, and the time to fully immerse the load into the quench.

4.3 Continuous Intensive Quenching System

The continuous IQ system includes a shaker hearth furnace equipped with an IQ water tank described in Section 2.3 above (see also Figure 5). The key elements of the unit design are the following:

⇒ The furnace chute that is equipped with a set of water nozzles that provides a very intensive agitation within the chute resulting in high convective heat transfer. A high heat extraction rate from the part within the chute results in a complete elimination of a non-uniform quenching from the sporadic film boiling stage of heat transfer. By the time the part being quenched falls through the intensive quench chute and onto the furnace conveyor, the thermal energy contained in the part surface is not enough to support film boiling.

⇒ The furnace conveyor has a variable speed that allows a dwell time in the water quench that is specified by the computer model. For the parts of a complex shape, it is very important to maintain thermal energy in the part core by the end of cooling in the intensive quench chute to provide self-tempering of the part hardened case and to fully eliminate a possibility of part cracking.

⇒ The IQ tank is equipped with a chiller that maintains the water temperature within a specified range (usually from 65°F to 70°F).

The current status of the IQ equipment installed at the Center for Intensive Quenching is as follows:

⇒ Single part quenching high-velocity IQ system is fully operational.
⇒ Electric atmosphere box furnace used for heating parts prior to quenching in the above IQ unit is fully operational.
⇒ Neutral salt bath furnace designed for heating parts prior to quenching in the high-velocity IQ unit to be equipped with a salt pot and controls.
⇒ New batch type IQ system to be wired with proper controls and to be tuned.
⇒ Shaker hearth furnace with an IQ water tank is fully operational.
5. Commercialization of Intensive Quenching Process for Tool Products

5.1 Introduction of IQ Process in Heat Treat Practices

Currently, the IQ process for tool products is introduced in heat treat practices of three commercial heat-treating shops: Akron Steel Treating Akron Steel Treating Co., Summit Heat Treating Co., a division of AST, and in Euclid Heat Treating Co. These shops have fully automated production IQ equipment that is capable of intensive quenching of a variety of steel parts including tool products. The companies trained their personnel to run the IQ units and developed a standard procedure for controlling a concentration of the sodium nitrite in the IQ water tank, a water temperature and a rate of the quenchant agitation.

The above companies run several jobs from different customers on continuous basis. For example, AST runs the following jobs:
⇒ Gear blanks made of alloy 4140 and 4340 steels for manufacturing rack and pinion gears
⇒ Shafts made of 1010 carburized steel for lawnmower tractors
⇒ Wear pads made of 1010 carburized steel

Since the size of the IQ equipment in the above shops is relatively big, the companies process tool products only occasionally. Table 1 of Section 3 presents some examples of processed tool products.

We are currently working on further commercialization of the IQ method throughout the heat-treating industry. Due to the EMTEC support of this project, we were able to design and built the Center for Intensive Quenching. This was a great leap towards the acceleration of the IQ commercialization process. The Center for Intensive Quenching will be the major tool for IQ process demonstrations. The Center includes basically all types of IQ equipment and allows us to validate the IQ processes on an industrial scale for a variety of steel products including high-temperature tool steels. However, the wide commercialization of the IQ process is still facing the following barriers:
⇒ No industrial (captive) installations of IQ systems in the USA
⇒ Absence of industry standards recognizing the IQ method – in fact some part specifications specifically prohibit “water” quenching due to traditional water quenching’s high probability of causing part distortion or cracking.
⇒ Lack of steel properties database on many steel types – database is needed for conducting computer simulations that will optimize the compressive stresses while minimizing distortion.
⇒ Limited capabilities in education/promotion of the IQ technology – IQT is not currently taught in any metallurgical curriculum in the USA (Dr. Kobasko and Dr. George Totten are currently “writing the book” on intensive quenching methods and practices. The American Society of Materials International (ASM) is planning to publish the book in 2006)

We need also to develop new standards for heat treatment of steel parts that include the use of the IQ methods. Commercial heat treaters usually process materials according to specifications established by the part designer -- their customers, or in some cases, their customers’ customers. In many instances these specifications are taken from generally recognized standards published by organizations such as SAE, SME, ASTM, AISI, the Department of Defense, etc. that do not included the intensive water quenching processes. Developing standards for IQ will require that these organizations be provided with a
comprehensive body of data from simulations and actual production part testing that clearly demonstrates the benefits of the technology to increase part performance, to lower part costs, and to eliminate the hazards and pollution from traditional oil quenching methods.

IQT also needs to generate mechanical and thermal property database for a wider variety of steels by conducting extensive material characterization studies. Note that this database can be used for performing computer simulations of material characterizations, as well as, for calculations of part cooling recipes. Some of this data will be presented in the DOE project final report.

To successfully proceed with the commercialization of intensive quenching technology, we will continue seeking additional financial support from various governmental agencies (TAF, DOE, DOD, etc.) in the following areas:

- In designing and building pre-production IQ systems for our customers’ parts for which we have already proven the IQ technology benefits.

- In helping our customers to install production IQ systems in their facilities. Planting such “seeds” in big U.S. companies (such as Dana Corp., ArvinMeritor, Inc., Delphi Co., Timken Co., etc.) is extremely important; the large manufacturers have hundreds of plants where this technology can be effectively used.

- By conducting more IQ workshops at our facilities and at customers’ facilities, IQT can educate the wider metallurgical community on the many proven benefits of intensive water quenching, as well as, reduce the time lag between the first “demonstration” phase and the actual adoption of intensive quenching practices into production.

5.2 Value of Project Results

In the proposal, we evaluated the value of the project results assuming that three benefits from the IQ technology would be realized, namely increase of the performance of the parts, the minimization of distortion, and reduction of the part heat treatment cost. As yet, we do not have enough data from our customers to evaluate the first two benefits. This is because the AST and EHT companies, as mentioned above, process tool products relatively seldom in their large IQ systems. Additionally, data from tool users on a particular tool’s performance is difficult to track once the tools are placed in the field. Our data from material characterization does show that metallurgical improvements should correlate directly to part performance. We can, however, evaluate the third benefit (a reduction of the heat treatment cost due to the use of the IQ method) assuming that the new IQ system installed at the Center for Intensive Quenching will be processing mainly tool products. Note that this IQ system was specifically designed to quench intensively tool steels.

In the new IQ system, we will process tool products that are currently heat treated either in vacuum furnaces (for example, S5 steel punches, S7 steel share blades, H-13 steel dies, tools made from air hardening grades), or in atmosphere furnaces and quenched in oil (both the carburized grades and non-carburized grades of steel). Per AFC-Holcroft, Inc., a major heat-treating equipment manufacturer in U.S., a typical annual production rate of a ∅24”x24” pit furnace (a furnace that our new IQ system is equipped with) is about 500,000 lb. This is based on the assumption that a typical load mass for such furnace is about 500 lb and a typical heat-treating
cycle duration is about 4 hrs. It was also assumed that the carburization cycle is reduced by 40% when using the IQ method. Table 2 presents the major assumptions we made when evaluating the IQ process and the results of the economical evaluation.

Table 2  Effectiveness of Heat Treatment of Tool Products in New IQ System

<table>
<thead>
<tr>
<th>Type of Steel</th>
<th>Total Material Processed, %</th>
<th>Annual Production, lb</th>
<th>Heat Treatment Cost, $/lb</th>
<th>Annual Savings, $</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tool steels processed in vacuum furnaces</td>
<td>40</td>
<td>200,000</td>
<td>1.00 – 1.50</td>
<td>0.60 – 0.80</td>
</tr>
<tr>
<td>Carburized grades</td>
<td>20</td>
<td>100,000</td>
<td>0.60 – 0.70</td>
<td>0.42 – 0.49</td>
</tr>
<tr>
<td>Non carburized grades</td>
<td>40</td>
<td>200,000</td>
<td>0.25 – 0.35</td>
<td>0.24 – 0.33</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>100</strong></td>
<td><strong>500,000</strong></td>
<td></td>
<td><strong>100,000 – 165,000</strong></td>
</tr>
</tbody>
</table>

As seen from the table, we expect to realize savings from our new IQ system (when fully utilized) in the range of $100,000 to $165,000 per annum per system. The savings does not include the pollution prevention from the elimination of oil quenching.

References