NEWER DEVELOPMENTS IN IMPROVING THE INTENSITY, FLEXIBILITY AND CONTROLLABILITY OF OIL QUENCH SYSTEMS IN SEALED QUENCH FURNACES

Dr. Bernd Edenhofer
Ipsen International GmbH, Kleve, Germany

Abstract

Oil quench systems of batch furnaces in the past had very little flexibility with respect to varying the quench intensity. Today’s requests of adapting the quenching intensity of oil quench systems to the needs of different components with respect to hardenability and minimized distortion led to the development of a new oil quench system. The new system has a largely increased agitation system. It produces a uniform oil flow through the load section and allows an adjustable oil flow speed. This increases the utilization of oil quench systems and makes the hardening of less alloyed materials and thicker sections possible. The experience with this new quench system using adapted quenching cycles for different components, especially gear components, are demonstrated. A special quench sensor measuring the heat transfer coefficient in the convection phase of the quenching is helpful in setting-up complex quenching cycles. It is also useful for quench cycle documentation, quench tank mapping and quench tank bench marking.

Keywords
- oil quench
- oil flow velocity
- gear wheels
- quenched micro structure
- quench sensor

1. Flexible oil quench system of high intensity

Oil quench systems in the past had limited quenching capability. Their average oil flow velocities are in the range of 0.1 to 0.2 m/s in the empty load area section. Any efforts made in the past to increase the flow velocity were obstructed by the usually increased distortion experienced on the treated components.

The new SuperQuench® system by Ipsen uses agitators with larger and more efficient wheels and motors with doubled motor power. This increases the oil flow by a factor of 4 and results also in quadrupled oil flow velocities.
In addition, the oil flow through the load section is increased by baffles on all 4 sides of the load space and it is much more uniform by a segmentation of the oil flow in separately controllable channels [1].

Each agitator motor is equipped with a variable frequency converter allowing the speed adjustment of each motor separately in the range of 10 to 50 Hz. Depending on the oil viscosity, a running of the motors even up to 60 or 70 Hz is possible for a limited period of time.

In order to keep distortion limited, it is desirable to run the agitators not at high speed during the whole quench cycle.

The high flow velocities are beneficial in producing a rapid break-down of the vapour phase, which increases the quench speed and also produces a uniform heat extraction. The latter having a positive influence on reducing distortion.

In addition, a reduction of the oil flow velocity in the temperature range of the martensitic transformation, e.g. the convection phase of the quenching, helps to equalize temperature differences within the quenched components and reduces distortion produced by thermal and transformational stresses.

The realization of such complex quench cycles is easily done by using modern process computers such as the Carb-o-Prof. Fig. 1 shows an example of a 4 step quench cycle with a short first segment of very high intensity followed by 3 segments with reduced oil flow speeds.

![Example of a programmed four-step quench cycle](image)

The establishing of such quench cycles is usually done by experience taking the section size, the type of material, the load density and also the type of quench oil (and temperature) used into account.
2. Practical experience

The higher oil flow velocities of the SuperQuench allow a better hardening of components made of unalloyed or low alloyed steels. This is demonstrated by the following example [2].

Fig. 2 shows a full and dense load of components made of the unalloyed material C60.

Fig. 2: Full load (750 mm x 900 mm x 900 mm) with 6 baskets of components of the steel C60 [2]

Slugs of the same material having a diameter of 30 mm and a length of 90 mm are distributed within the load. The load is hardened in a sealed quench furnace with a Super Quench® system (50 Hz) and for comparison reasons also in one with a standard quench tank.

The results of these 2 hardening cycles are shown in fig. 3. The hardness profiles taken along the length of the 90 mm long slugs for the parts quenched in the standard quench tank are on the average about 5 HRC lower than the ones achieved with the SuperQuench®.

![Graph showing hardness profiles](image)

Fig. 3: Hardness profiles along the length of the 90 mm slugs of C60 material after normal quench (nq) and SuperQuench® (sq) [2]
Even though the hardness distribution along the length of the slugs is not yet optimal after the sq-quenching, it can be further improved by shortly using the overspeed capability of the agitator motors.

The second example is a planetary pinion used in tractor transmissions (fig. 4) [3].

![Planetary pinion for tractor transmission](image)

**Fig.4:** Planetary pinion for tractor transmission

It is made of the steel 20 MnCr5 and weighs roughly 3kg. The specification calls for a surface hardness of 58-62 HRC after tempering and an igo (intergranular oxidation) below 20 µm.

Trials run with different agitator speeds in full loads in furnaces of size 17 (load size of 910 mm x 1.220 mm x 910 mm) yielded the results shown in table I [3].

**Table I:** Heat treatment results of the planetary pinion using 3 different agitator speeds [3]

<table>
<thead>
<tr>
<th>Fan Rotation</th>
<th>Microstructure of the gear tooth</th>
<th>Surface hardness (HRC)</th>
<th>Case-Hardening-Depth (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>as quenched</td>
<td>after tempering</td>
</tr>
<tr>
<td>800 min -1</td>
<td>troostite up to surface</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1100 min -1</td>
<td>troostite up to surface 1/10 martensite</td>
<td>65 – 66</td>
<td>60 – 62</td>
</tr>
<tr>
<td>1500 min -1</td>
<td>3/10 martensite</td>
<td>65 – 66</td>
<td>60 – 62</td>
</tr>
</tbody>
</table>

The results show that surface hardness is excellent whatever agitator speed used.
However, microstructure and case depth are heavily influenced by the oil flow velocity improving with increasing oil speed.

A third example further supports this point. A gear wheel used in construction machines weighs roughly 6 kg, has a module of 5.8 and is made of the steel 20NiCrMo2. Carburising and quenching this piece in a sealed quench furnace with a standard oil quench tank produces sufficient surface hardness, a core hardness at the lower limit, a good case depth on the tooth flank but an unacceptable deep surface layer of non-martensitically transformed (nmt) structure (perlite).

Using a well adjusted 4 step quench process in a SuperQuench® oil tank similar to the one shown in fig. 2 increases the core strength and especially increases the case-depth in the tooth root contributing to a largely increased tooth root fatigue strength (table II) [4].

Table II: Heat treatment results of a gear (6 kg, m = 5.8) of steel 20NiCrMo2 after carburising and quenching in a standard oil quench and in a SuperQuench® system

<table>
<thead>
<tr>
<th>Type of oil quench</th>
<th>Surface hardness (HRC)</th>
<th>Core hardness (HRC)</th>
<th>Case depth tooth flank (mm)</th>
<th>Case depth tooth root (mm)</th>
<th>Nmt (perlite) tooth flank (µm)</th>
<th>Nmt (perlite) tooth root (µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal quench</td>
<td>62</td>
<td>26</td>
<td>1,28</td>
<td>0,67</td>
<td>max. 15</td>
<td>max. 39</td>
</tr>
<tr>
<td>SuperQuench</td>
<td>62</td>
<td>32</td>
<td>1,23</td>
<td>0,87</td>
<td>max. 10</td>
<td>max. 15</td>
</tr>
</tbody>
</table>

In addition, the thickness of the nmt layer at the tooth root is reduced from 39 to 15 µm.

The increase of the core strength and the case depth in the tooth root as well as the decrease of the thickness and intensity of the nmt layer prove that the fast velocity of the oil flow in the early part of the quench cycle results in a reduction and a more uniform break down of the vapour phase.

The improved microstructure, the deeper case depth and the improved core hardness have a direct influence on the performance of the gear raising its load carrying capability and its root strength.

In addition, the more uniform quenching reduces thermal and transformational stresses and results in less distortion.

3. Quench Sensor

The user of intricate quench cycles using several steps and having a complexity similar to a carburising cycle cannot rely only on the correct programming of the cycle in order to assure the correctness of their execution.
The quality of the heat treated gear depends vitally on the correct sequence of the quench steps. Running the agitators e.g. on 1.100 rpm in the first quench step instead of the programmed 1.800 rpm makes the difference between a gear holding up or a gear failing.

Thus, the surveillance and documentation of the oil flow velocity is unavoidable. Depending on the furnace size, there are 2, 4 or 6 agitators, and as it is possible that only some but not all run on the right speed, a surveillance of each agitator is needed. The simplest way of surveying the agitators is to measure and document the motor current. Increasing the speed of an agitator increases its motor current.

But the motor current is only an indirect measure of the oil flow. It depends not only on the speed of the agitator wheel, but also on the viscosity of the oil e.g. its temperature. Also, a partly blockage of the flow channel, which can happen in industrial practice, increases the motor current because of the increased flow resistance even though the oil flow is obstructed.

Therefore, a better solution is a direct measuring device like the Quench Sensor shown in fig. 5 [5].

![Fig.5: Design and theory of the Quench Sensor](image)

It is a heated device which measures the heat extracted from the oil flow in the convective phase of the oil quench. This heat extraction depends directly on the oil flow velocity. It is a temperature difference measurement which yields the convective heat transfer coefficient.

The installation of the sensor is directly in the flow channel of each agitator. Looking at the benefits received from this direct quench flow surveillance, the additional costs for such a system are negligible compared to the value of one load not correctly quenched.

In addition, there might be more perspectives for such a sensor system in the future. For a given oil quality and given temperature, there might be a possibility to deduct from the measured convective heat transfer coefficient, the characteristics of the supplied heat:

\[
Q_{\text{heat}} = U \times I = \text{const}
\]

- Supplied Heat: 
- Removed Heat: 
- Heat Balance: 
- \( \Rightarrow (T_1 - T_2) = \frac{C}{\alpha} \)
  - if \( \alpha = \text{const} \)
  - \( \Rightarrow (T_1 - T_2) \) characterizes the convective heat transfer.

\[
Q_{\text{convection}} = \alpha \times A \times (T_1 - T_2)
\]

\[
\text{Heat Balance:} 
Q_{\text{heat}} = Q_{\text{convection}}
\]

\[
\Rightarrow (T_1 - T_2) = \frac{C}{\alpha} = \text{const.}
\]

If \( \alpha = \text{const.} \) then \( (T_1 - T_2) \) characterizes the convective heat transfer.

1. Temperature sensor measuring increased temperature \( T_1 \)
2. Temperature sensor measuring fluid temperature \( T_2 \)
3. Fluid
4. Constant heating
5. Protection tube
6. Heat insulation
7. Device for measuring the temperature difference
vapour phase and the maximum heat transfer coefficient in the boiling phase. This could be especially important for setting up complex, multiple-step quench cycles.

4. Conclusions

A new oil quench system in sealed quench furnaces produces higher oil flows with improved speed and pressure. Due to a continuous variability, the oil flow can be adapted to the section size, material and the load density to be quenched. For optimal heat treatment results, the flow velocity is not kept constant during the whole quench cycle, but segmented in as many steps as necessary. Usually a high oil flow in the start of the quench produces a more uniform break down of the vapour phase and a more uniform heat extraction in the boiling phase yielding especially in low hardenable steels largely improved heat treated qualities. Optimum results with respect to distortion are achieved by reducing the oil flow during the martensitc transformation. The surveillance of the oil flow with intricate and multiple-step oil quench cycles using a new Quench Sensor is vital for the repeatability of the high heat treatment quality.

Literature


