SYSTEMS FOR CONTROLLING THE TIME OF SUBMERSION OF PARTS IN A QUENCHING LIQUID IN PERIODIC AND CONTINUOUS PROCESSES

S. W. Han,1 A. V. Sverdlin,1 G. E. Totten,1 and G. M. Webster1

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The susceptibility to crack resistance and warping and the uniformity of hardness distribution over the cross section of a part can be improved by controlling the direction and the degree of stirring of the cooling liquid in quenching. In the initial stage of quenching the cooling rate of the part should be high in order to obtain the requisite hardenability. When the core of the steel part is cooled to the temperature of the start of martensitic transformation ($M_s$), the cooling rate should be decreased. Stirring seems to be a principal method of affecting the cooling rate in quenching and can be an ideal means if it is possible to change the stirring rate in correspondence with the requisite conditions. At present, this can be achieved comparatively easily with the help of a computer-aided system for control of the time of submersion of parts in the quenching liquid (SCST). SCST are currently used by some plants in Korea. The article concerns the principles and use of SCST with the purpose of replacing oils by water-soluble polymer cooling liquids for quenching.

We should distinguish four important factors exerting a substantial effect on the characteristics of polymer quenching media, namely, the composition and temperature of the quenching medium and the rate and method of stirring it [1 – 4]. It should be noted that only can the rate of stirring be changed during the process of quenching. The effect of these parameters on the quenching process can be illustrated by analyzing the cooling stages of parts [1].

Cooling of a steel preform submerged in a volatile liquid medium usually occurs in three stages (Fig. 1).

**Stage A** or cooling in a steam jacket begins immediately after submersion of the steel preform in the quenching medium. In this stage the heat is transferred very slowly due to the presence of a steam barrier enveloping the part. In the general case the capacity of the quenching medium to cool the steel part is inversely proportional to the stability of the steam jacket. The stability, homogeneity, and thickness of the polymer enveloping the part in this stage depends on its composition and concentration. The cooling rate of the part decreases with increase in the thickness of the film (at higher polymer concentrations). Stirring of the cooling liquid causes mechanical rupture of the steam jacket and increases the cooling rate in this stage.

**Stage B** is bubble boiling. In this stage the rate of cooling the part is maximum. The cooling rate can be increased further by intense stirring, which will break the film and create conditions for accelerated bubble boiling and bulk heat transfer due to the motion of the hot liquid over the surface of the part.

**Stage C** begins at the moment when the temperature of the quenching liquid at the surface of the cooled part becomes lower than the boiling temperature of the liquid. Heat transfer occurs by both convection and heat conduction, which in turn depend on the viscosity (concentration) of the quenching liquid and its stirring rate. With increase in the stirring rate the rate of heat transfer increases.

Stirring not only makes it possible to control the cooling rate in quenching, but also ensures the formation of a uniform
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Fig. 2. Cooling curves of a part quenched with stirring (1-3) and the C-curve of the austenitic transformation (#): 1) an ideal curve obtained with continuous changing of the stirring rate of the cooling liquid, 2) cooling in water, 3) cooling in mineral oil.

Fig. 3. Diagram of a system for controlling the time of submersion of a part in a quenching liquid for periodic processes.

Film of the cooling liquid over the metal [5]. If the velocity of the liquid flow around the part is low, the enveloping film has a nonuniform thickness (and can even disappear). This causes nonuniform bulk conduction of heat through the surface and from the surface to the center of the steel part. If the temperature drop over the bulk of the part is considerable, the part becomes warped and cracked.

In what follows we consider the principles that constitute the basis of a system for controlling continuous stirring of a polymer quenching medium and give examples of its use.

At was noted above, in the initial stages of quenching the cooling should be conducted at a high rate, because this decreases the probability of the undesirable pearlitic transformation. This requirement is most fully satisfied in cooling in cold water stirred at a high rate (Fig. 2). However, intense stirring of cold water in the temperature range of the start of martensitic transformation $M_s$ increases both thermal and structural stresses in the part, which can lead to crack formation and warping. One way to decrease the cooling rate at temperatures close to $M_s$ is to use a mineral quenching oil.

However, cooling in still (unstirred) quenching media occurs very slowly in stages A and B. In order to obtain optimum hardness and decrease crack formation, the cooling in stages A and B should be accelerated and that in stage C should be decelerated (near $M_s$) using different stirring rates, namely, a maximum rate at the beginning of cooling and a minimum rate at the end. The ideal cooling curve is shown in Fig. 2.

It should be noted that the idea of controlled stirring in the quenching process is not new. SCST are distinguished from the classical methods in that the sequence and duration of the stirring stages have been chosen theoretically, proved experimentally, and then implemented in industrial practice with the use of computer control.

At present, SCST can operate in periodic and continuous regimes [6, 7]. Both variants ensure regulation of the stirring rate in quenching.

The process of stirring in batch feeding of parts into the quenching tank is shown in Fig. 3. Two impeller mixers are placed in orientable sucking tubes. Stirring can also be provided by a pump. The velocity of the linear flow of the quenching liquid has been computed using such a system under industrial conditions and calibrated for different motor frequencies with the help of a Mead frequency meter. A computer system controls the stirring rate of the liquid.

A continuous SCST is shown in Fig. 4. The system has the following characteristics:

- the upper conveyor is used for cooling in stages A and B;
- the cooling rates are regulated on the upper conveyor by both stirring the liquid and changing the velocity of the conveyor itself (the latter controls the quenching time).