COMPUTER SYSTEM FOR SELECTION OF QUENCHING CONDITION AND PREDICTION OF HARDNESS (QPP)

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ABSTRACT

Selected quenchant and quenching conditions, as well as shape and size of treated part and its hardenability, are the basic elements for determination of hardness distribution on the cross section of the part after quenching. There are many different quenchants as well as the combinations of quenching conditions - i.e. bath temperature, agitation rate or concentration of polymer solutions. The method described gives the possibilities of computer aided review of measured and stored data about quenching conditions and obtained hardness on specimens of 50 mm Dia. Using the data bases of quenching conditions, hardness values of quenched specimens as well as the hardenability data of steels, the QPP software enables:

a) selection of quenching conditions for particular steel, diameter and hardness required at critical point of the cross section,
b) prediction of hardness distribution on the cross section for specified quenching conditions, steel grade and diameter (Dia. from 20 to 90 mm) of quenched part.

In the databeses of the latest QPP version are stored 53 combinations of test specimen quenching conditions measured data, Jominy hardness data of 8 tempering steels types.
The quantity of data in databases may be further increased.

1. INTRODUCTION

Quenching is the most critical operation about which the hardness distribution on the cross-section of a hardened work piece depends.
Hardness distribution after quenching is directly related to the strength profiles, fatigue endurance limit, crack propagation rate, toughness and resistance to impact loading of the work piece. Therefore prediction of the hardness distribution is so important. When predicting the hardness distribution after quenching on round bars' cross-section of different diameters, besides the bar diameter itself, the following factors are decisive:

- Hardenability of the relevant steel grade or heat;
- Specific quenching conditions (quenchant's properties, bath temperature, agitation rate and direction, the mass and loading arrangement of the batch), and
- Surface condition of the work piece.

In the workshop practice various quenching facilities (oil baths, water baths, polymer solution baths, hot salt baths, fluid beds, high pressure gas quenching in vacuum furnaces) of different design are used. From the other side several different steel grades and heats are used in every production.
So, there are in practice too many and too complex influencing factors and lacking of specific data to predict the hardness distribution precisely enough, by any theoretical method.
Quenching Properties Prediction system - QPP enables you to create your own database for steel grades you are dealing with, and for actual quenching conditions that you use or you are interested to compare for your specific requirements.

QPP enables you to predict the hardness distribution after quenching for your specific quenching conditions on round bars' cross-section of 20 to 90 mm diameter for every steel grade or heat for which you can store (or calculate, based on chemical composition) the relevant Jominy hardenability data. The only thing you have to do, when using a new steel grade or applying new quenching conditions is to quench a standard specimen of 50 mm Dia x 200 mm made of the steel grade in question, cut it in the half length, measure the hardness along the radius and store the measured hardness values of 5 characteristic points.

The fact, that you can machine the specimen having the surface condition equal to your work pieces, and harden it together with other work pieces in the batch, contributes substantially to the exactness of the prediction.

This computerized system enables you also to instantly select (from all those stored in database), the optimum quenching conditions that will yield the required hardness at a specified point on the cross-section of a bar of the chosen diameter, made of selected steel grade. QPP is the adequate software developed in order to establish and gradually enlarge the individual database. The software supports: evaluation, storing and retrieval process, comparison and numeric or graphic presentation of measured, stored and predicted data.

As delivered the database of QPP contains data on 8 steel grades and about 53 different specified quenching conditions, but you should enlarge this database with your specific data to increase the ability for comparison and selection of optimum quenching conditions.

2. MODULES OF QUENCHING PROPERTIES PREDICTION SYSTEM (QPP)

The scheme of QPP system is shown in Fig. 1.

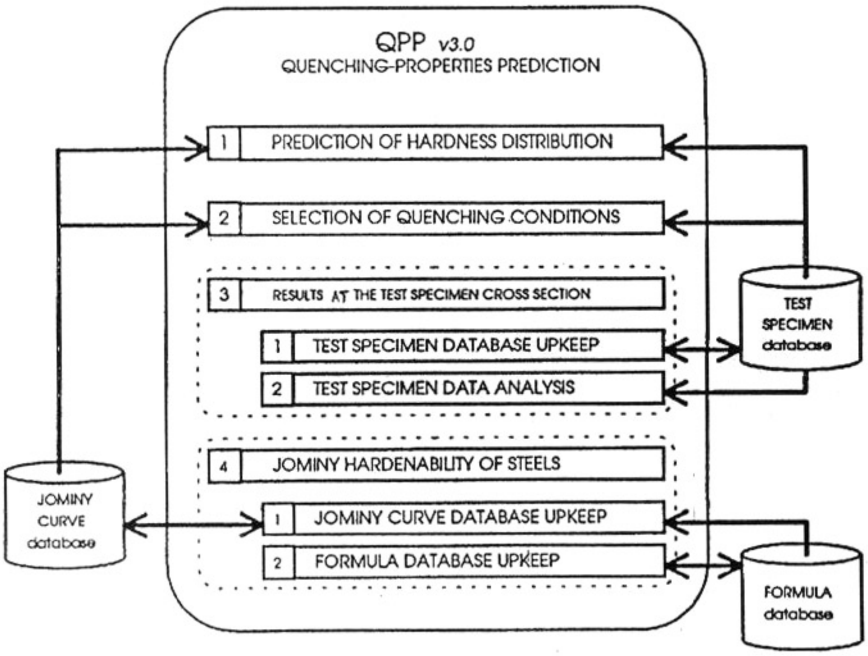

Fig. 1. Main modules of QPP system

2.1. OWN DATABASE

2.1.1. Data about quenchants and test specimens

The main data are hardness values measured in five characteristic points on the cross section of the test specimen made of the corresponding steel grade and quenched under specified

conditions. The specimen should have the dimensions of 50 mm Dia x 200 mm.
The specimen should be austenitized under conditions which prevail in the particular case in practise (temperature heating and holding time, heating environment, loading arrangement). These conditions should be specified and stored.
After quenching, the specimen should be carefully cut at mid length, the cross-section ground, and the hardness measured along the three radii at 120°. The average values for the five characteristic points on the cross section: surface, 3/4R, 1/2R, 1/4R and the centre, are then stored in the database.
Besides, the following data are stored:

- steel designation
- batch (heat) number of steel
- kind of quenchant and its characteristic (e.g. for oil - viscosity)
- provenance and commercial designation of quenchant
- quenching bath temperature, °C
- concentration (e.g. of a polymer solution) of the quenching medium
- agitation rate, m/s
- H-value according to Grossmann
- average hardness values (HRC) for the five characteristic points on the cross section of 50 mm Dia x 200 mm.
- date of measuring and other identification data.

2.1.2. The Jominy hardenability data

The following data about each steel grade are stored:

- steel designation
- batch (heat) number of steel
- provenance and commercial designation of steel
- chemical composition (13 elements and other)
- hardness at Jominy distance - the values in HRC for each distance from 0 to 40 mm and the value for 80 mm.

The additional new feature of QPP is going to be useful when you wouldn't know Jominy curve but the chemical composition of steel. Jominy curves are reconstructed according to regression formulae for hardness at specific Jominy distance /3, 4/. There are stored a few formulae for each hardening steel group - unalloyed steels, Cr, Cr-Mo, Ni-Cr...

The established database for steel grades of interest and quenching conditions available, completed with hardness values of test specimens, all enable a quick computer search for finding the optimum quenching conditions when a certain hardness value in a specified point of the bar cross section of different diameters is required.

2.2 THE BASIC OPERATING WITH THE DATABASES

The concept of the own database would be of greater value for the practical application if the data for a great number of different steel grades and quenching conditions are stored. If, for example, 10 steel grades and 5 different quenching conditions are of interest, then 50 test specimens must be hardened, hardness measurements taken, and the data stored.
This enables the user to obtain instantly the following:

a) For each stored steel grade, to compare the influence of specified quenching parameters on the depth of hardening (hardness distribution on the 50 mm Dia test specimen);
b) To compare the influence of the hardenability and of bar diameter of all stored steel grades on the hardness distribution, when quenching them under certain specified quenching conditions;
c) To predict the hardness distribution on round bars cross-section of different diameters, for each specified and stored quenching conditions and steel grades, by using the method described in /1/;
d) To select the optimum quenching conditions which would provide desired properties in a certain cross section spot of a defined steel grade, by using the procedure described in /2/.

The latest QPP version is delivered with 53 combinations of test specimen quenching conditions data, 8 Jominy hardness data of steels obtained and entered in Department of Materials at the Faculty of Mechanical Engineering and Naval Architecture, University of Zagreb. The quantity of data in databases may be further increased.

QPP is user friendly software: the input is made through very simple and, at the same time, powerful editor; data presentation through menus and windows with alphanumerical data and graphs. The program has a situation - sensitive integrated help.

The basic options of QPP are:

1. The option - JOMINY HARDENABILITY OF STEELS, a database program for Jominy database.
   Standard database operations are covered: viewing data, editing data/entering new data and deleting data from the database. It is also possible to see graphical presentation of data from Jominy curve.
2. The option - RESULTS ON THE TEST SPECIMEN CROSS SECTION - has two sub options:
   The A sub option enables operations on test specimen’s database: viewing, editing, entering and deleting test specimen data.
   The B sub option (ANALYSING RESULTS STORED IN DATABASE) enables comparison of up to 4 test specimens at the same time; a look into the influence of the quenching conditions on steels; comparison of hardness distributions (U-curves) for different steels with same quenching conditions etc.

2.2.1. Selection of quenching conditions

By using the described method /2/ makes it possible to find the optimum quenching conditions when a certain hardness distribution (or a hardness value) at a specified bar cross section of a known diameter and steel grade is required.
The option - SELECTION OF QUENCHING CONDITIONS of QPP system - expects the user's demand and according to it gives a list of all combinations: steel grade - quenching conditions, which have satisfied the demand. The user has a lot of freedom and possibilities in exposing it.

For example, there is a need for information about quenching conditions by which one could accomplish hardness of 42 HRC on 1/2 of radius of the cross section of a cylindrical part with 65 mm Dia. The steel grade desired is: AISI-6150.
First step is entering the demand and after evaluating it, QPP will list all acceptable combinations

steel-quenching conditions (Fig. 2).
The second step is entering the steel designation AISI-6150 in filter, after that there will be only two combinations which have satisfied both.

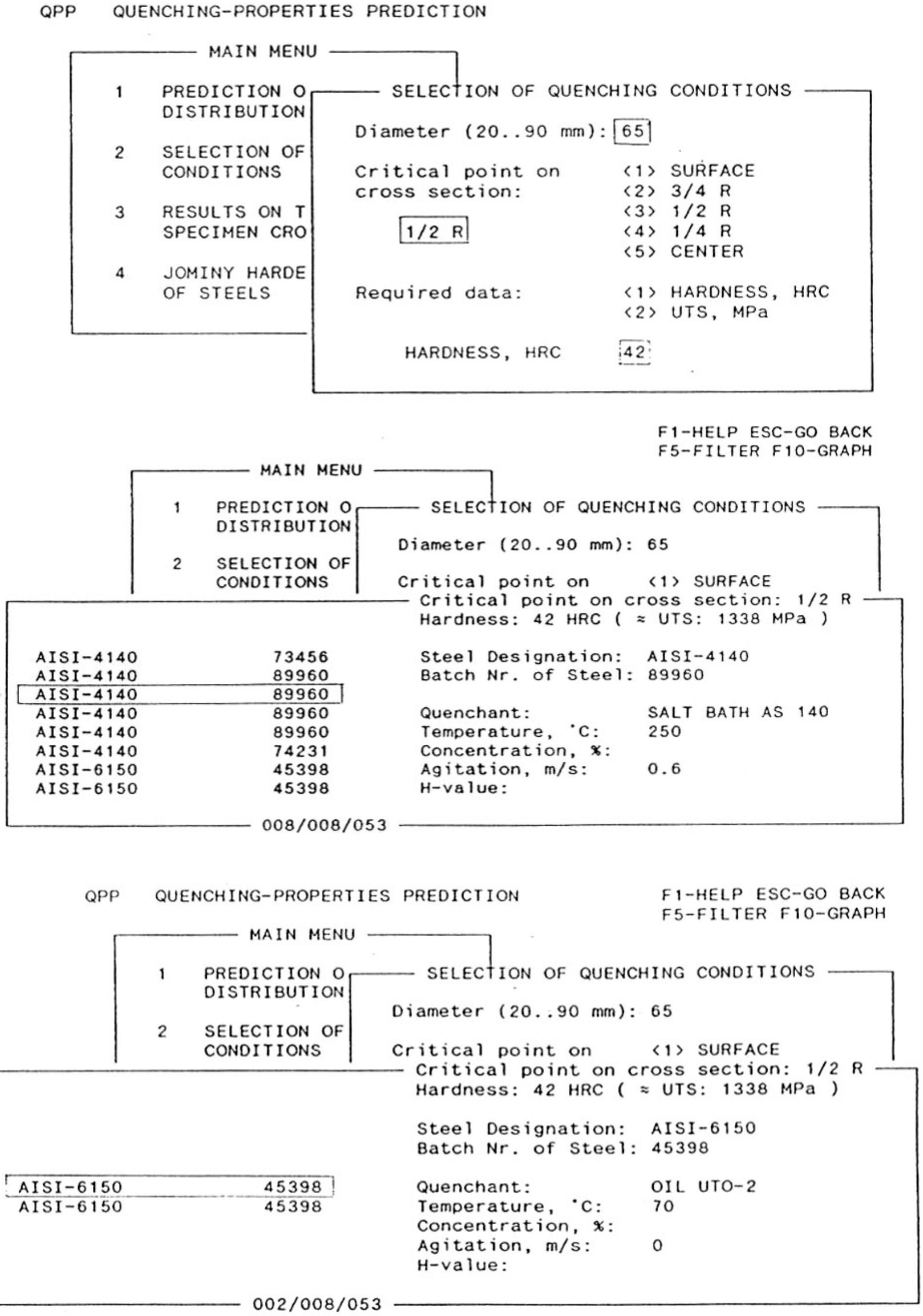

Fig. 2. The procedure for prediction of hardness distribution

2.2.2. Prediction of hardness distribution on round bars' cross-sections

The own method of computer aided prediction of hardness distribution /1/ after quenching is valid for bar diameters from 20 to 90 mm (because the used formulae for calculating equidistant locations on the Jominy curve have been established through regression analysis for this range of diameters).

The option - PREDICTION OF HARDNESS DISTRIBUTION - expects the user to choose a combination: steel grade - quenching conditions and enter the diameter of the part. QPP will for the chosen combination predict the hardness distribution.

The possibility of analysing up to 3 different U-curves at the same time gives the user a lot of freedom and an opportunity to make a great number of comparisons of all kinds.

The basic feature - prediction of hardness distribution after quenching with some quenching conditions can be obtained easily. The best start is using the filter for reducing the list of combinations steel grade - quenching conditions by entering known data.

With sufficient data significant reduction of the primary list is possible which will make further work much easier. Before graphical presentation of prediction it must enter diameter of the part and put it with the currently chosen combination steel grade - quenching conditions into graph-output window on desired graph position from A to C (Fig. 3).

A view-in on influence of diameter on hardness distribution can be accomplished by analysing U-curves for different diameters (with the same steel and the same quenching conditions). For example, after reducing list of combinations by filter to only one combination and putting it in graph-output window with different diameters the graph (U-curves) will clearly show the influence of the diameter on hardness distribution (Fig. 3).

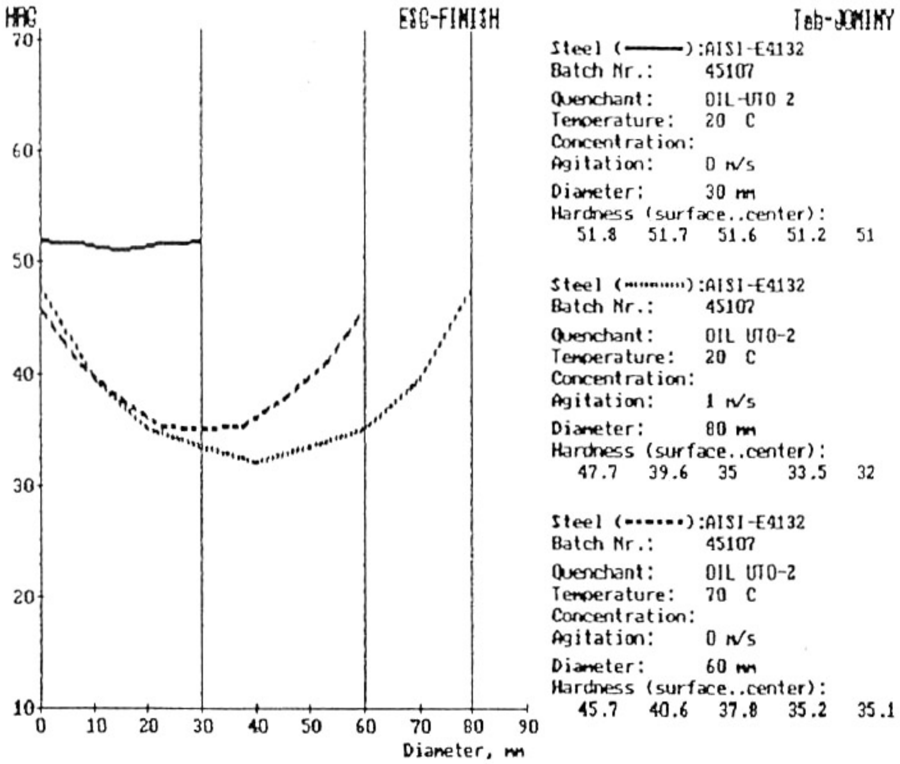

Fig. 3 Prediction of hardness distribution - the same steel grade quenched in the same quenchant, for different bar diameters

Of course, it is possible to choose combinations steel grade - quenching conditions completely freely. The useful example could be one with different steels, same quenching conditions and the same diameter (Fig. 4).

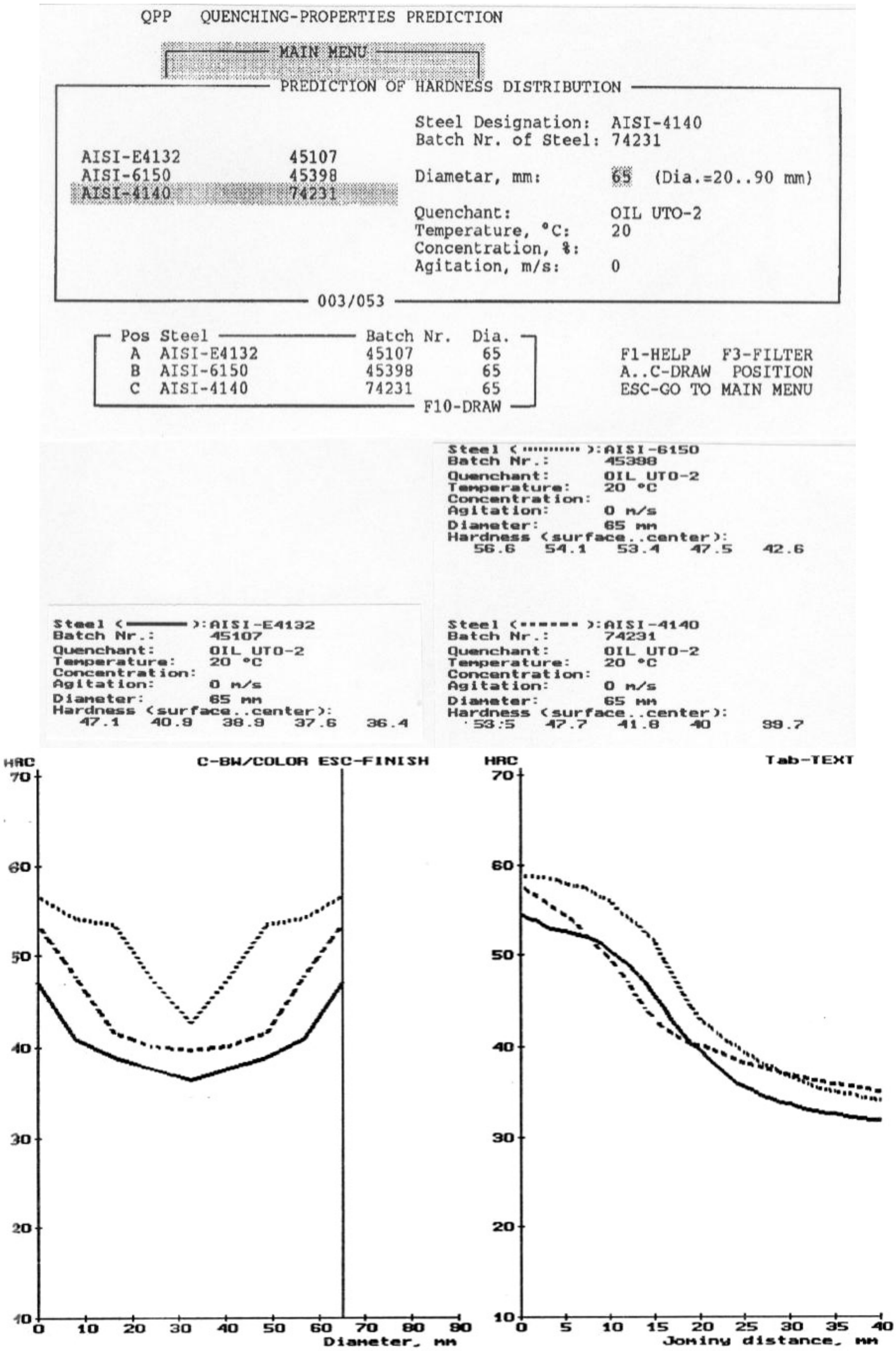

Fig. 4 Prediction of hardness distribution - different steel grades quenched in the same quenchant, for the same bar diameters (65 mm)

With QPP you can also analyse and compare every possible combination of data stored in specimens and Jominy databases. With presented examples we have covered only a small part of overall possibilities.

3. CONCLUSIONS:

The advantages of above described practical methods for prediction of hardness distribution and/or selection of quenching conditions, compared to pure theoretical methods are the following:

- The practical method is based on real heat transfer phenomena that prevail in a quenching facility when a certain batch of parts is being quenched, or specific quenching conditions are created for single quenching of special parts;
- It takes into account influences of: heat of transformation, stresses on the hardness distribution, surface condition of parts, austenitizing conditions (grain size);
- It can be applied not only for direct - quenching processes, but also for interrupted quenching processes and for isothermal - quenching processes (martempering and austempering);
- It is applicable not only to low alloy-steel grades, but for every steel grade for which a Jominy hardenability curve or chemical composition exist.

The new *Temperature Gradient System* (TGS) is designed /6/ to be used when quenching real axially-symmetrical workpieces of any complex shape, in different liquid quenchants and different conditions. The main purpose of this system is:

a) To calculate the real heat transfer coefficient as function of surface temperature and of time during the whole quenching process.
b) To analyze every quenching process by experimentally measuring and recording relevant cooling curves and evaluating the quenching intensity during whole quenching process, expressed by different thermodynamic functions. These functions enable to compare different quenching processes in regard of: quenching intensity, dynamic of heat extraction, thermal stresses, and cooling rates in all points within the probe, where the thermocouples are placed.
c) Prediction of hardness distribution, at once, on the whole axial section of the workpiece after quenching, as well as after tempering.

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