IAEA

International Conference on Opportunities and Challenges for Water Cooled Reactors in the 21st Century

Development of Universal Methodology of Specimen Free Nondestructive Inspection (Control) of Mechanical Properties of NPP Equipment Metal in All Stages of Lifetime

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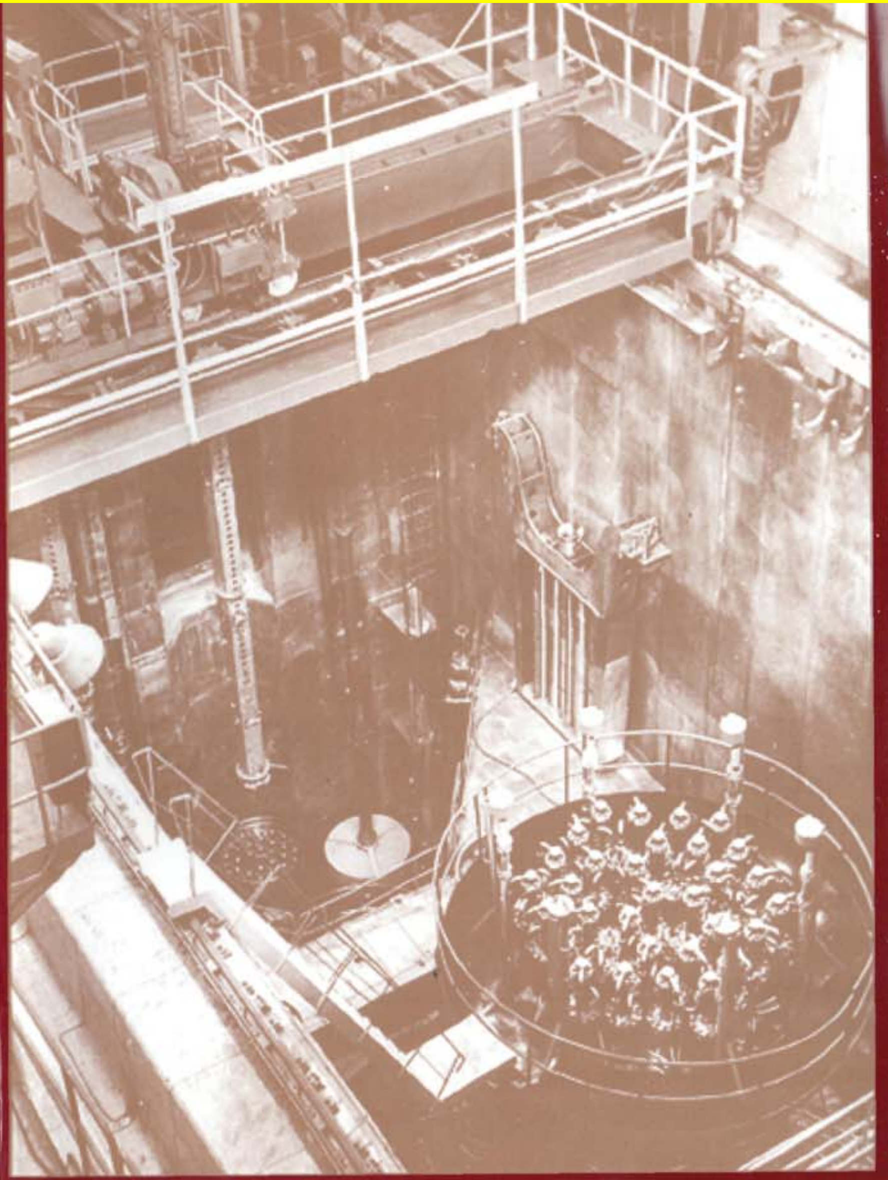
I. Frolov
I. Kiselev
J. Gastrock
M. Dripke

This year on September is 45 years from the day of getting on operation of the 1 unit of NVNPP (the first unit of WWER-type)



Reliability is provided by knowledge of the real mechanical properties at all stages of Plant Life – preoperation, operation, shutdown

Design of equipment

Requirement to the documents (specification, standards regulations)

Manufacture of equipment

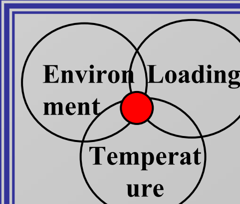
Production (sertificat)

Assembling of equipment

Registration sertificate (factual initial properties)

Design operation (explotation) –on average 30 years

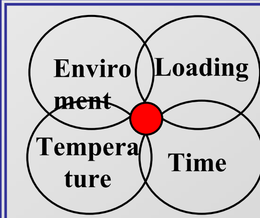
Results of periodical routin expert inspection (after each 100 000 hours of operation)



Analysis of ageing

Selection of «trigger» areas of the control (inspection)

Overdesigned period of exploitation (with resource + 30 years)

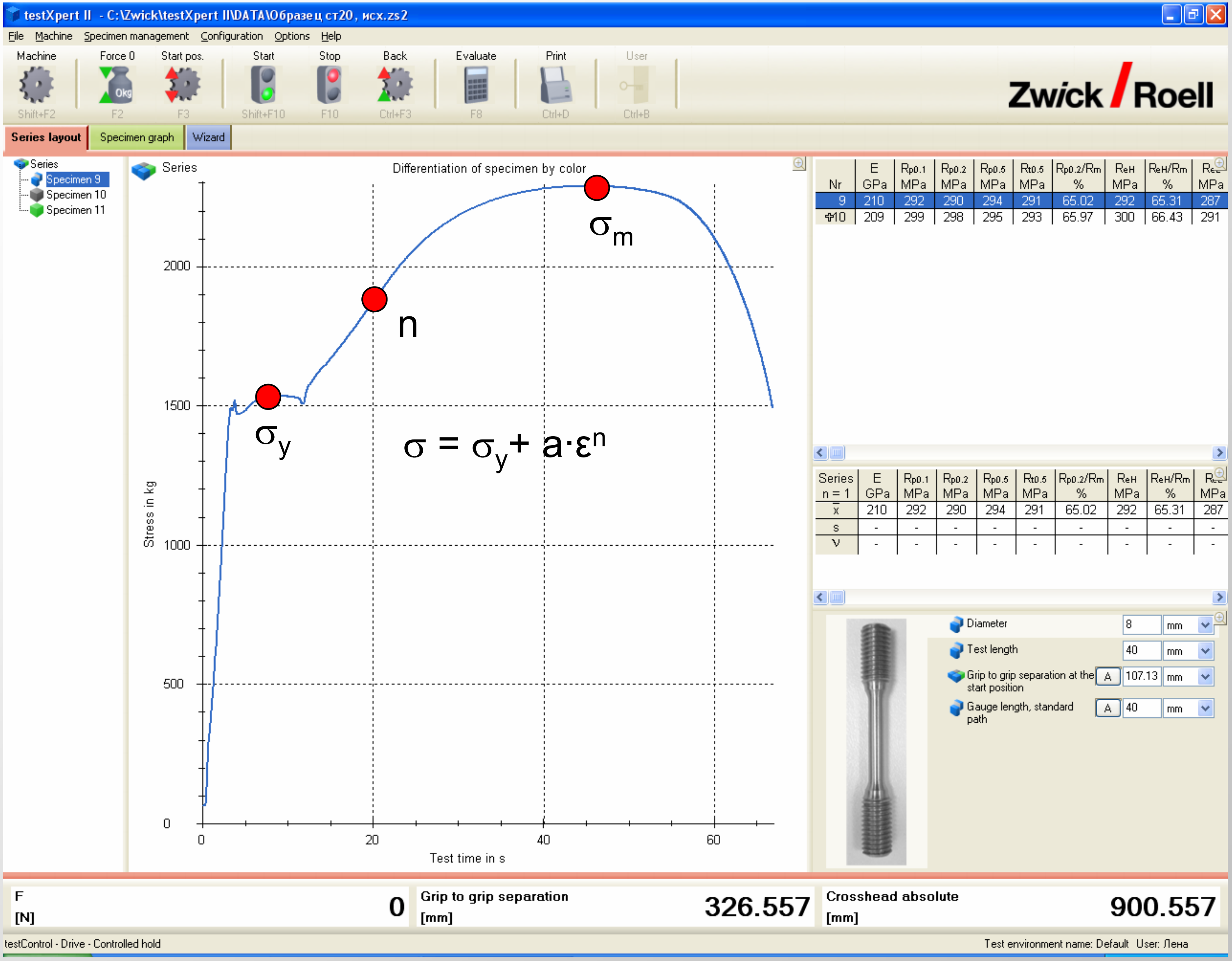


Expert control (inspection)

Shutdown

It is advisable to use for the inspection of mechanical properties one method, one methodic and united methodology

DEFINITION OF MECHANICAL PROPERTIES



New methodology of the control (inspection) at all stages of life cycle of the equipment should be created on use of non-destructive methods of the control (inspection)

At present there are more than 100 different specimen-free methods.

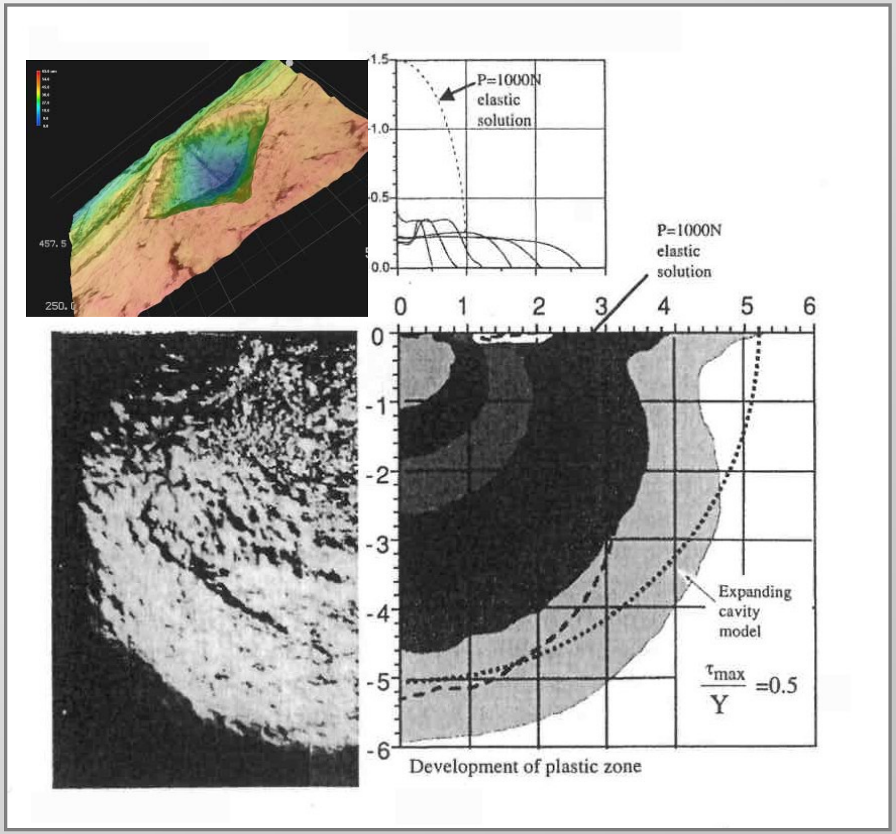
However, on this day moment, till now it is not selected one priority method of the control (inspection), which would be maximum informative from the point of view of materials mechanical properties inspection. This fact does not allow to use efficiently the results of exploitation control (inspection), which traditionally is conducted on Nuclear Power Plants and Thermoelectric Power Stations.

HARDNESS

The most perspective for the control (inspection) of the mechanical properties are the hardness methods, because only these methods give the information about the material condition by it's elastic-plastic deformation, such as by tensile tests of specimens.

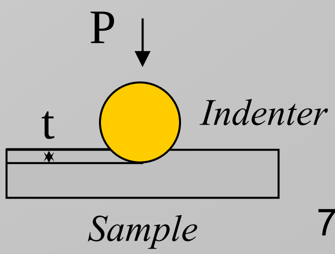
a) impression

c) distribution of contact stresses



b) distribution of deformations

$$H = \frac{P}{t}$$



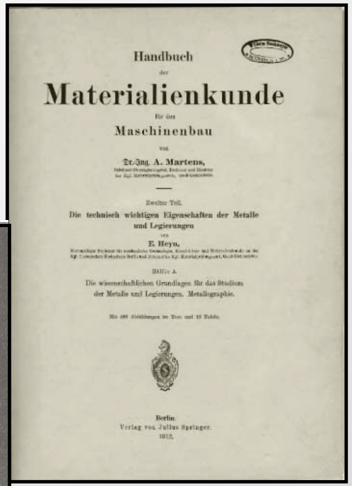
During the last 100 years there were obtained only statistical methods of definition of hardness by **Brinell**, **Rockwell** и **Vickers**. Only these methods are standardized in full measure. However, even for these methods the test conditions are different and it is not possible to compare results of the tests directly with each other. *In that way, imperfection of the methods of hardness measurement is absence of unification in conducting of tests (investigations)*

Johan August Brinell
1849-1925

HISTORY OF KINETIC INDENTATION TESTING

For the first time in 1898 distinguished German scientist Dr. Adolf Martens orderes to record the load-displacement curves for a spherical indenter

Adolf Martens
(1850 - 1914)



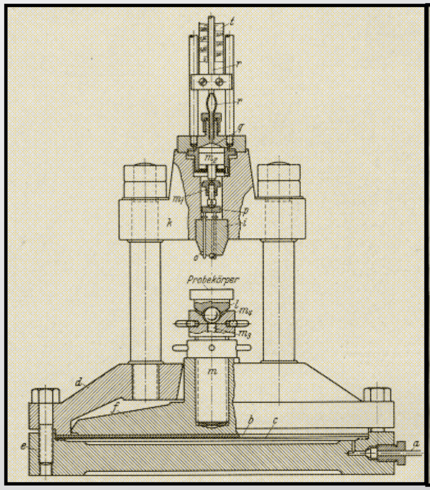
Handbuch
der
Materialienkunde
für den
Maschinenbau
von
Dr.-Ing. A. Martens,

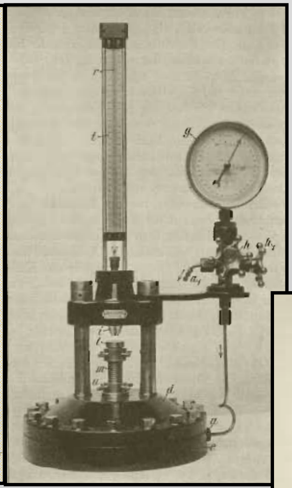
Zweiter Teil.
Die technisch wichtigen Eigenschaften der Metalle
und Legierungen
von
E. Heyn,

Hälfte A.
Die wissenschaftlichen Grundlagen für das Studium
der Metalle und Legierungen. Metallographie.

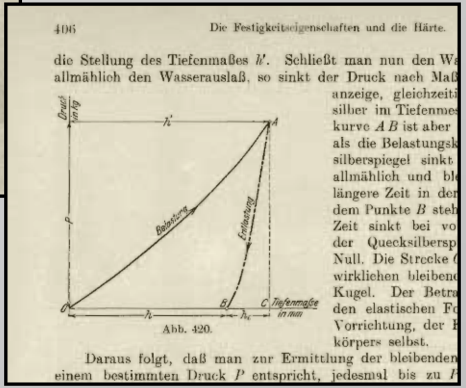
Berlin.
Verlag von Julius Springer.
1912.

Härte unter Paüfkraft





Hardness tester of Dr. Martens



406 Die Festigkeitseigenschaften und die Härte.

die Stellung des Tiefenmaßes h'. Schließt man nun den Wa
allmählich den Wasserauslaß, so sinkt der Druck nach Maß
anzeige, gleichzeiti
silber im Tiefenmes
kurve AB ist aber
als die Belastungsk
silberspiegel sinkt
allmählich und bl
längere Zeit in der
dem Punkte B steh
Zeit sinkt bei vo
der Quecksilbersp
Null. Die Strecke
wirklichen bleibend
Kugel. Der Betra
den elastischen Fo
Vorrichtung, der
körpers selbst.

Abb. 420.

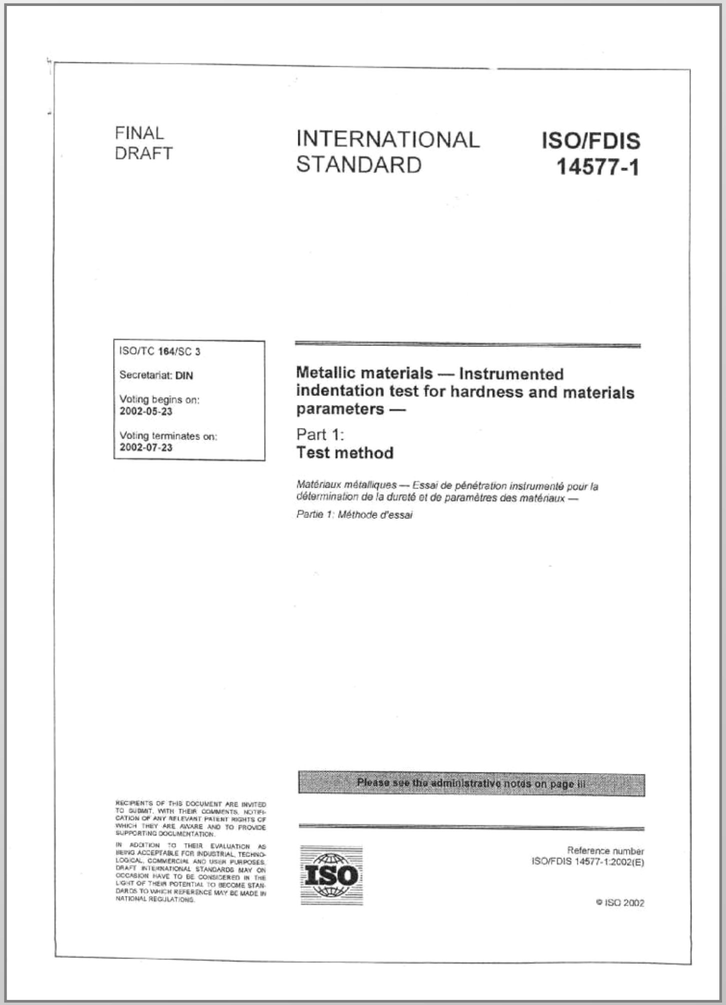
Daraus folgt, daß man zur Ermittlung der bleibenden
einem bestimmten Druck P entspricht, jedesmal bis zu

HM=F/As(h)

OUR DAYS

Taking into account of that fact, the absolute progress in the direction of perfection of hardness measurement procedure is publication of new international standard (International Standard ISO/DIS 14577-1:2000-04 “Metallic materials – Instrumented indentation test for hardness and materials parameters”).

The main advantage of the new standard is the fact, that during the process of the measurement it is recorded continuously diagram of elastic-plastic penetration and of unloading of indenter, such as by tension test.



FINAL DRAFT

INTERNATIONAL STANDARD

ISO/FDIS 14577-1

ISO/TC 164/SC 3

Secretariat: DIN

Voting begins on: 2002-05-23

Voting terminates on: 2002-07-23

Metallic materials — Instrumented indentation test for hardness and materials parameters —

Part 1:
Test method

Matériaux métalliques — Essai de pénétration instrumenté pour la détermination de la dureté et de paramètres des matériaux —

Partie 1: Méthode d'essai

Please see the administrative notes on page iii

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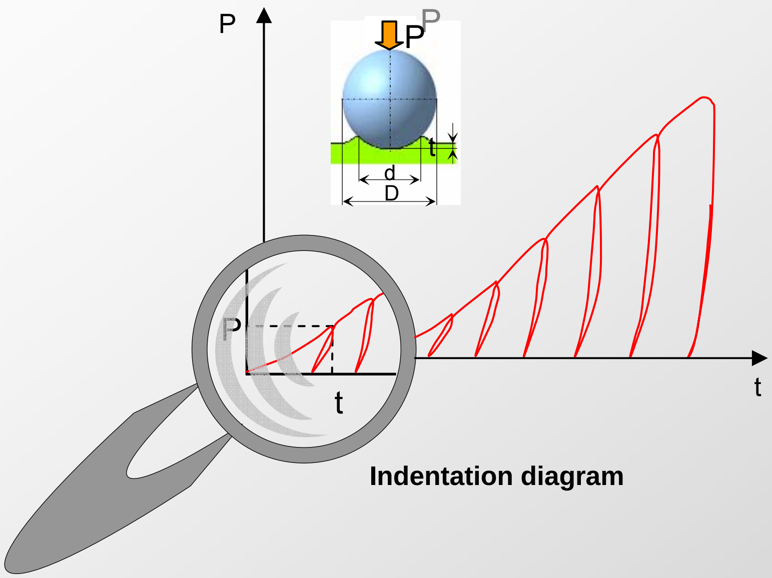
Reference number
ISO/FDIS 14577-1:2002(E)

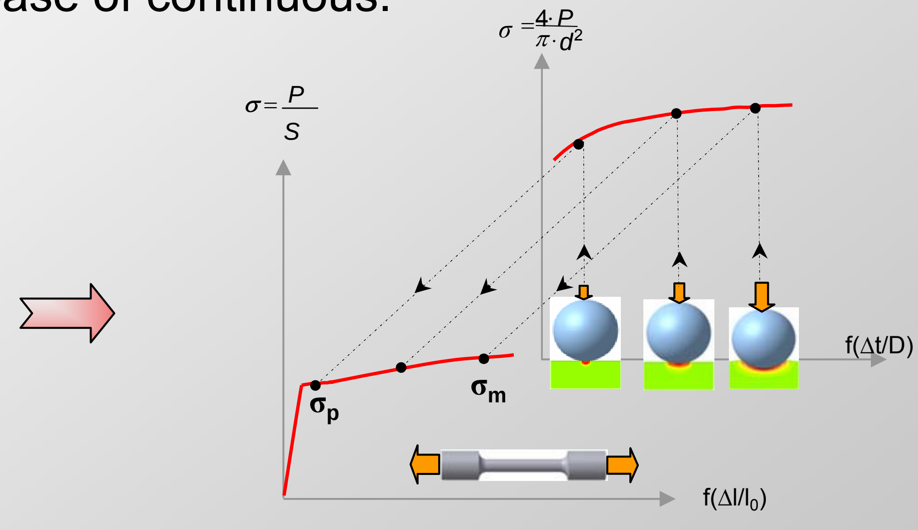
© ISO 2002

METHOD OF CONTINUOUS PENETRATION OF INDENTER

On the base of tabor ideas and by use the technology of continuous registration of the penetration diagram it is possible to set a task of reconstruction of uniaxial tension diagram on the base of continuous.



Indentation diagram



Stages of convertation of indentation diagram

How receive from the hardness diagram the mechanical properties ?

QUEST FROM HISTORY

(The new is well forgotten the old)

What is hardness?

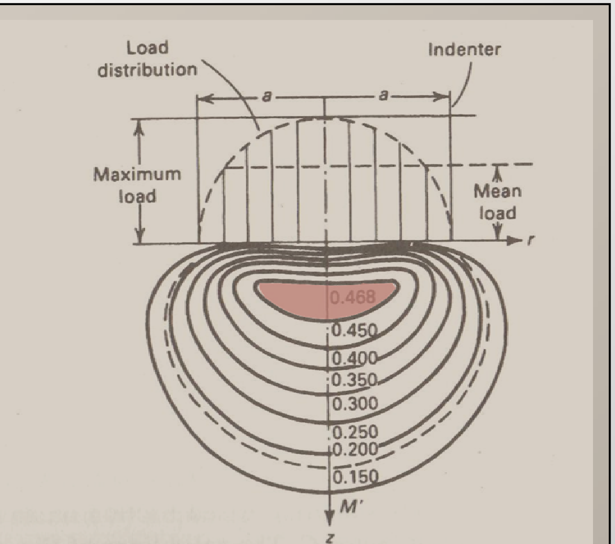
Hardness has typically been defined as the resistance of a material to permanent penetration by another harder material. Radius of the contact spot depends on making force. Axial stresses field.

Background (elastic contact)

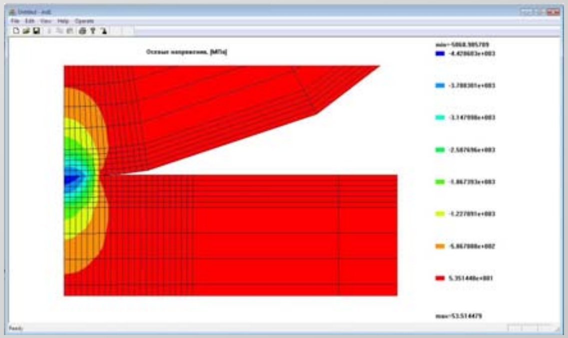
As long ago as 1881 H. Hertz found, that for elastic contact the Radius of contact is related to indenter load.

$$a = \left(\frac{3 \cdot P \cdot R}{4 \cdot E} \right)^{1/3}$$

$$P_m \approx 1.1 \cdot \sigma$$

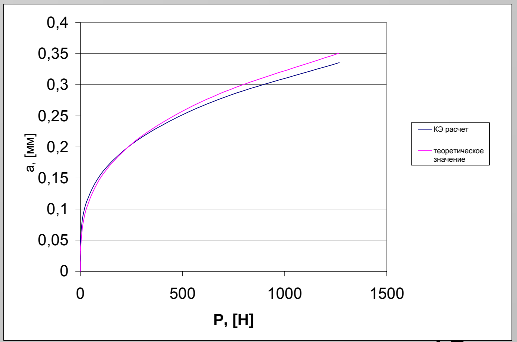


We verified it by FEM



Поле осевых напряжений.

Possible found E, σy



Радиус пятна контакта в зависимости от прилагаемого усилия

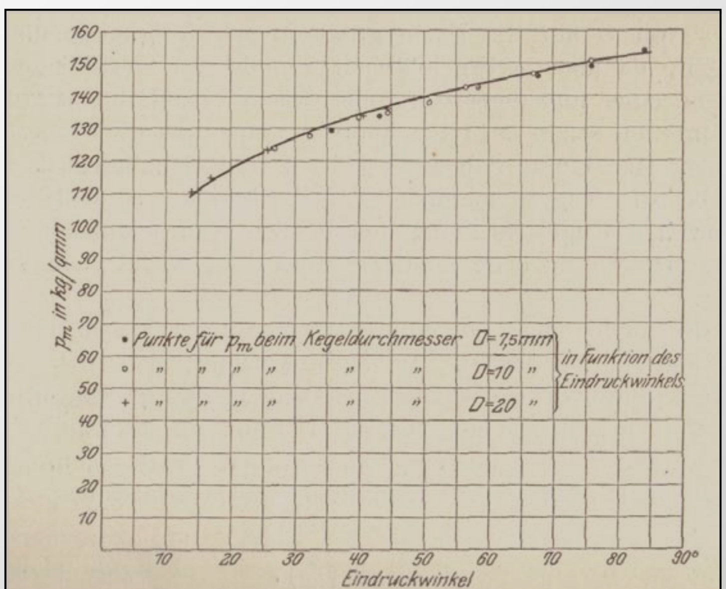
FIRST RELATIONSHIPS BETWEEN HARDNESS AND TENSILE PROPERTIES

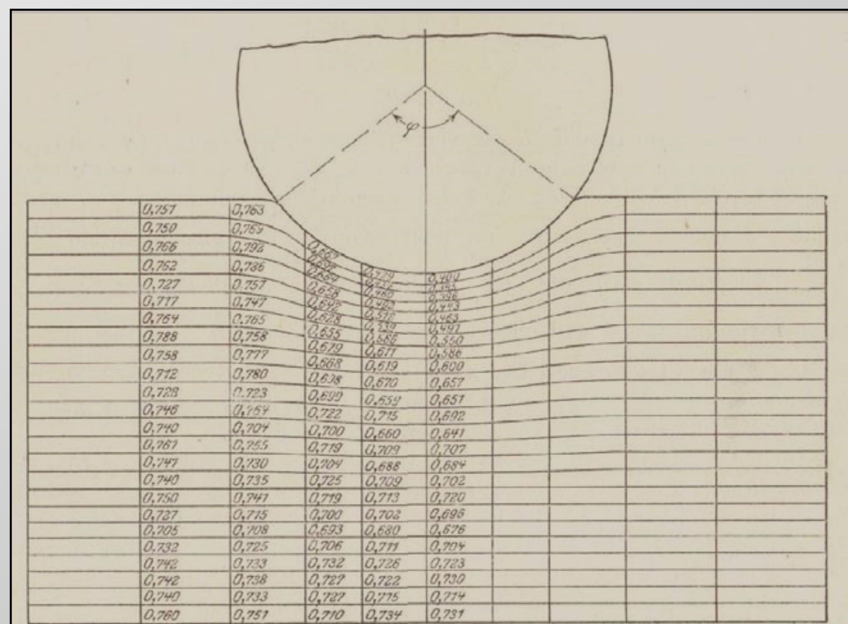
Background (plastic contact)

In 1908 Meyer fixed the dependence between ***P*** **-** indentation load and ***d*** – diameter of indentation for plastic deformation

$$P = a \cdot d^m$$

m- Mayer index = n+2 (**n** – coefficient of strengthening by tensile)

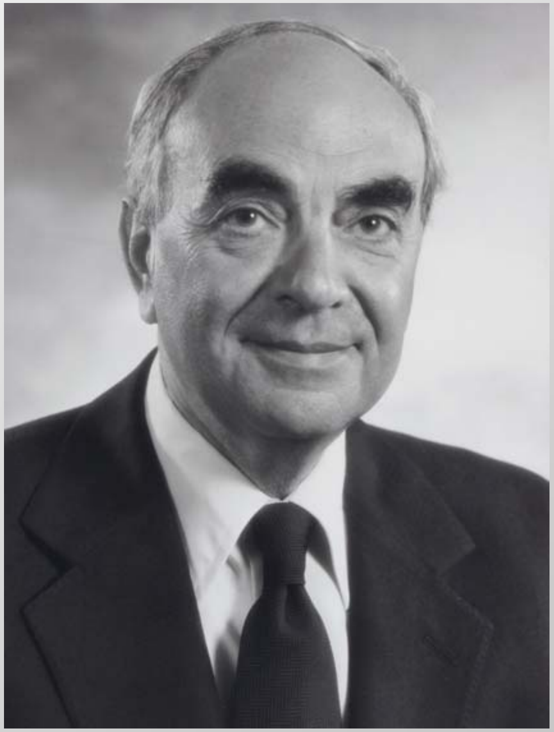


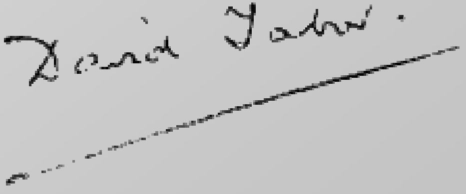


FIRST RELATIONSHIPS BETWEEN HARDNESS AND TENSILE PROPERTIES

In 1951 D. Tabor fixed the connection between stress-strain diagram (tensile diagram) and Meyer diagram similarity of coefficient by tensile n and penetration m n=m-2.

$$\varepsilon = 0.2 \cdot \frac{d}{D}$$



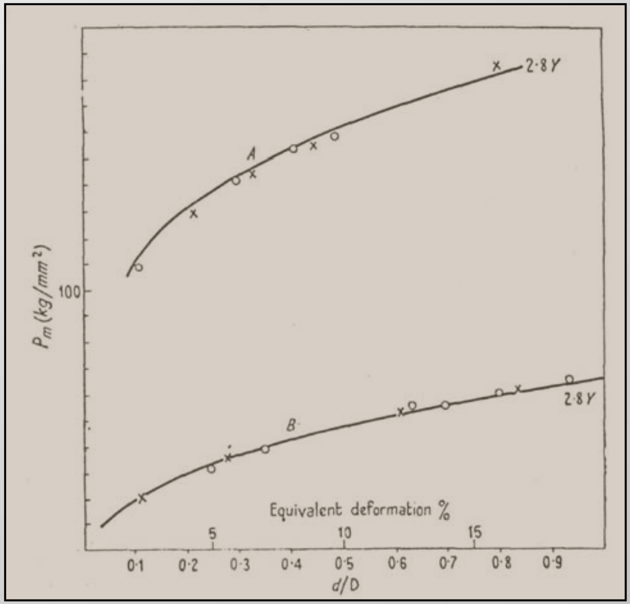


Also, it was fixed the connection between deformation and stress

$$HM = \frac{P}{\pi \cdot (d/D)^2} = c \cdot \sigma_y$$

$$1 \leq c \leq 3$$

elastic deformation — fully plastic deformation



RUSSIAN WAY

In USSR scientists began to attend to kinetic indentation method in the seventies of XX century. It is necessary to mention the schoolof Baykov Institute RAS. Dr. Bulychev and Dr. Alechin, and of course, scientific school of Moscow Power Engineering Institute, Chair of Process Metallurgy, my teacher Professor Michail Markovetz.

Д.т.н., профессор Марковец
Михаил Порфирьевич

EXPERIENCE OF CENTER OF MATERIALS SCIENCE AND LIFETIME MANAGEMENT (CMSLM Ltd.)

The works of themes (subjects) of continuous registration of the ball indenter penetration diagram were conducted by different groups (collectives):

-Oak Ridge National Laboratory (USA);
-Karlsruhe Institute of nuclear research in (Germany);
-NRI in Rez (Czech Republic);
-Institute of Nuclear Energy Research in Seul (Korea).

In CMSLM there was elaborated the methodic of conducting of the investigations by use kinetic hall indentation, which is expounded in numerous publications. (Bakirov M.B./Kontrolle. 1994. v. 10. p. 1)

This methodic was included into the branch instructions RD EO 0027-94 and into it’s republications RD EO 027-2005 “Instructions by definitions of the mechanical properties of the metal of NPS equipment by use specimen-free methods on the base of hardness characteristic.”

Ermittlung von Standard-Werkstoffkennlinien

Modifiziertes Härteprüfverfahren

Murat Bakirov

Das von diesem Unternehmen aus Ulm vorgestellte Verfahren ermöglicht es, zerstörungsfrei auch an kleinen Proben oder kompletten Bauteilen die Spannungs-Dehnungs-Kennlinie für einachsige Beanspruchung zu ermitteln. Es beruht auf einem modifizierten Härteprüfverfahren mit anschließender numerischer Auswertung.

Für die Bewertung des Werkstoffzustandes werden häufig Kennwerte herangezogen, die im Zugversuch unter einachsiger Beanspruchung ermittelt wurden. Dabei ist die Probenentnahme oft äußerst schwierig, wenn diese an kompletten Bauteilen erfolgen muß und dafür nur wenig Material zur Verfügung steht. Dieses trifft besonders dann zu, wenn der Werkstoffzustand nach einer Wärmebehandlung des Bauteils oder nach einer bestimmten Betriebsdauer einer Baugruppe beurteilt werden muß. Für diesen Bereich eignet sich das hier beschriebene Verfahren. Bei diesem wird, im Unterschied zu den verschiedenen bereits bekannten Umbewertungen von Werkstoffhärte in andere Kennwerte, eine kontinuierliche Eindringkurve ermittelt und numerisch mit der Finite-Elemente-Methode (FEM) in eine Spannungs-Dehnungs-Kennlinie umgesetzt.
An austenitischen und perlitischen Stählen wurde eine gute Übereinstimmung der berechneten Spannungs-Dehnungs-Kennlinie mit der an der gleichen Probe im Zugversuch ermittelten nachgewiesen. Auch für andere Werkstoffe ist das Verfahren einsetzbar.

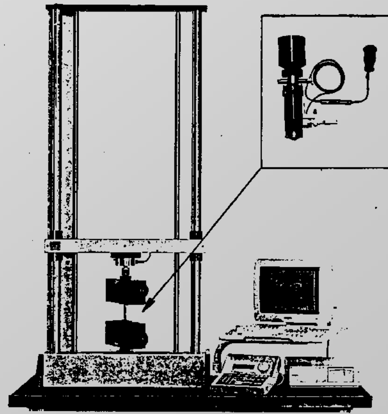


Abb. 1 Zusatzvorrichtung mit Eindringtiefe-Sensor und Eindringkörper zum Anbau an eine CNC-Universalprüfmaschine

Meßwerterfassung

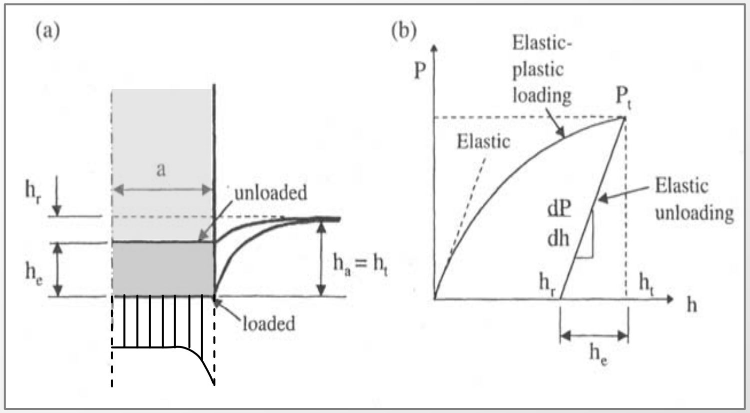
Für die kontinuierliche Berechnung einer Spannungs-Dehnungs-Kennlinie muß das Kraft-Eindringtiefe-Diagramm sowohl beim Be- als auch beim Entlasten aufgenommen werden. An eine CNC-Universalpfümaschine dieses Unternehmens aus Ulm wird eine spezielle Zusatzvorrichtung mit Eindringtiefe-Sensor und Eindringkörper adaptiert und die Probe zwischen Zusatzvorrichtung und Druckplatte eingelegt. Kraft- und Eindringtiefe-Sensor sind analoge Standardmeßsysteme mit Klasse 1 nach DIN (relativer Fehler kleiner 1%). Als Eindringkörper dienen Wolframcarbid-Kugeln mit Durchmessern von 2,5 bis 5 mm. Die Universalprüfmaschine bringt die Beanspruchung auf und erfaßt die Signale des Kraft- und des Eindringtiefe-Sensors. Das durch die Maschine digitalisierte Kraft-Eindringtiefe-Diagramm wird zur Weiterverarbeitung in einer ASCII-Datei gespeichert.

Berechnungsverfahren

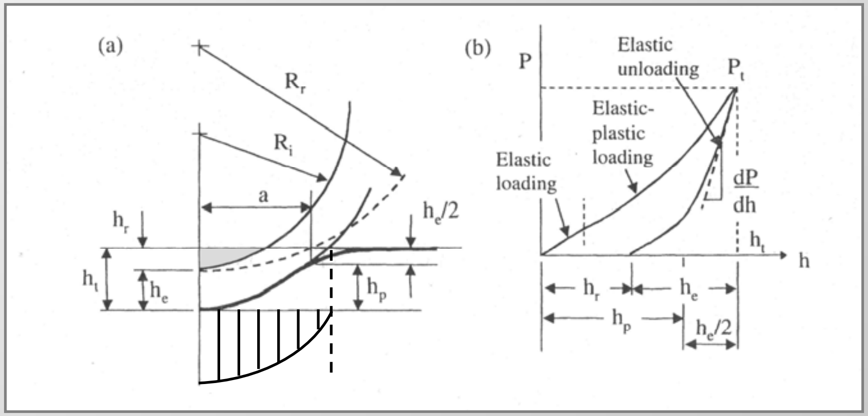
Im Gegensatz zur direkten Lösung des räumlichen elastisch-platischen Modells benötigt man bei der FEM Matrizen, die einen Zusammenhang zwischen den Verhältnissen von Härte und Elastizität bzw. von Spannung und Dehnung zum Ziel haben. In der vorgeschlagenen Methode ist dieser Zusammenhang Berechnungsparameter. Die Methode basiert auf der Umkehr des räumlichen elastisch-plastischen Modells. Sie erlaubt die Erstellung von nichtlinearen Spannungs-Dehnungs-Diagrammen sowohl innerhalb als auch außerhalb des elastischen Bereichs ohne Anwendung von festen Korrelations-Abhängigkeiten. Als zusätzliche Bedingung geht in die Berechnung das aus dem Experiment bekannte Verhalten des Eindringkörpers bei Belastung P und dazugehöriger Eindringtiefe h ein. Dazu benötigt man Versuchsdiagramme bei kontinuierlichem zyklischen Eindringen eines Eindringkörpers als Basisdaten. Die Aufnahme solcher Diagramme ermöglicht die Bestimmung sowohl des plastischen als auch des elastischen Anteils an der Gesamteindringtiefe. Als Eindringkörper wurde eine Kugel gewählt. Das ermöglicht eine vollständige Information über das Werkstoffverhalten bei einer lokalen Verformung unter Berücksichtigung der

INITIAL ANALYSIS OF INDENTATION DIAGRAM FOR DIFFERENT SHAPES OF INDENTERS (ISO 14577)

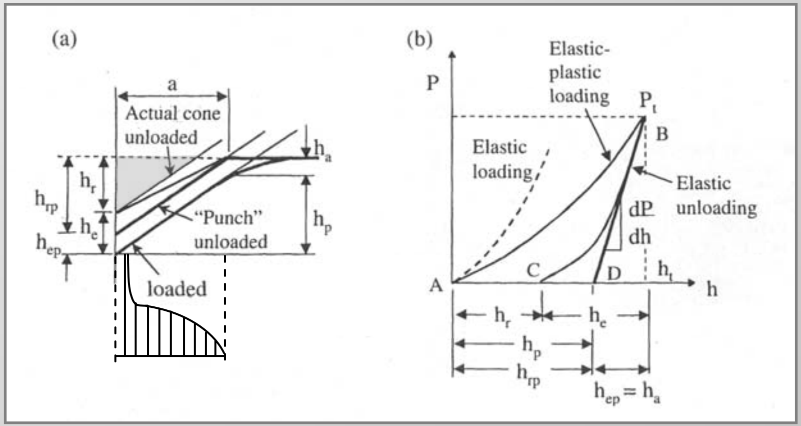
1 Cylindrical indenter



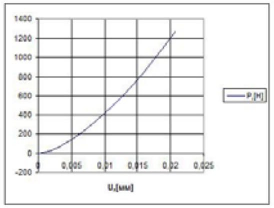
2 Ball indenter (Brinell)

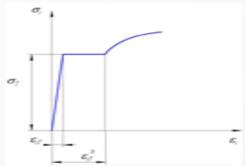


3 Sharp indenters (Vickers, Ludvick, Knupp, Berkovich)

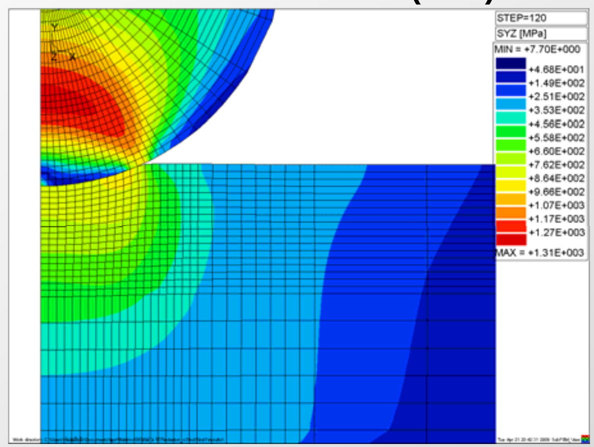


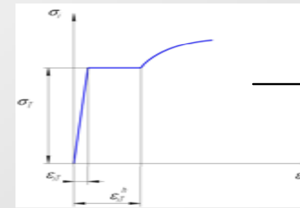
METHODIC OF CALCULATION

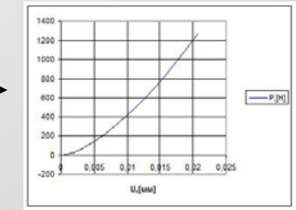




Nuclear calculation by use final element method (FEA)



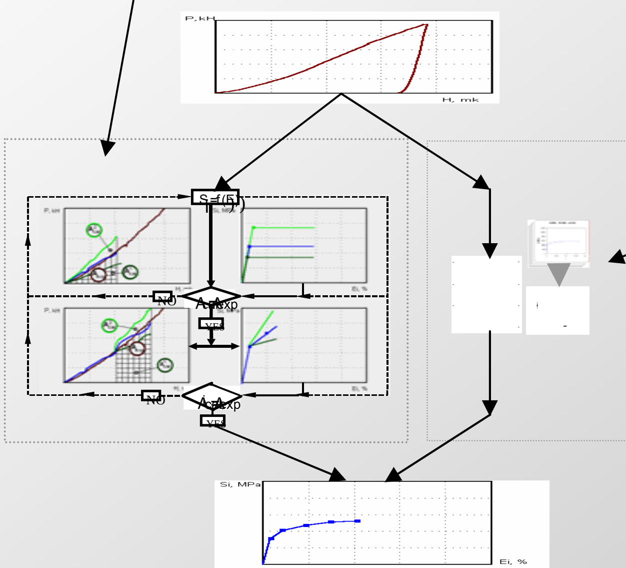




Inverse solution by use consistent approximations method

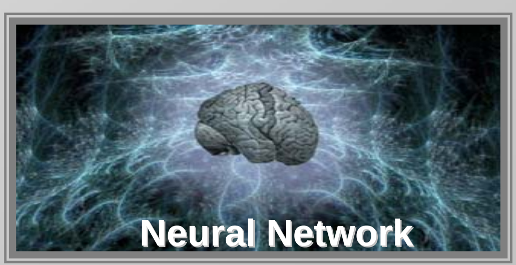
Direct solution

Accumulation of data base of finished solution

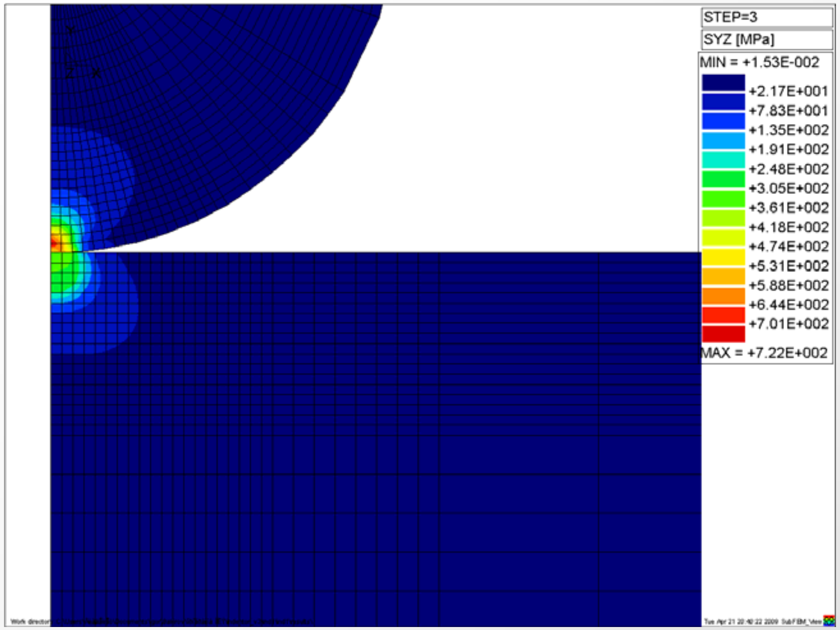


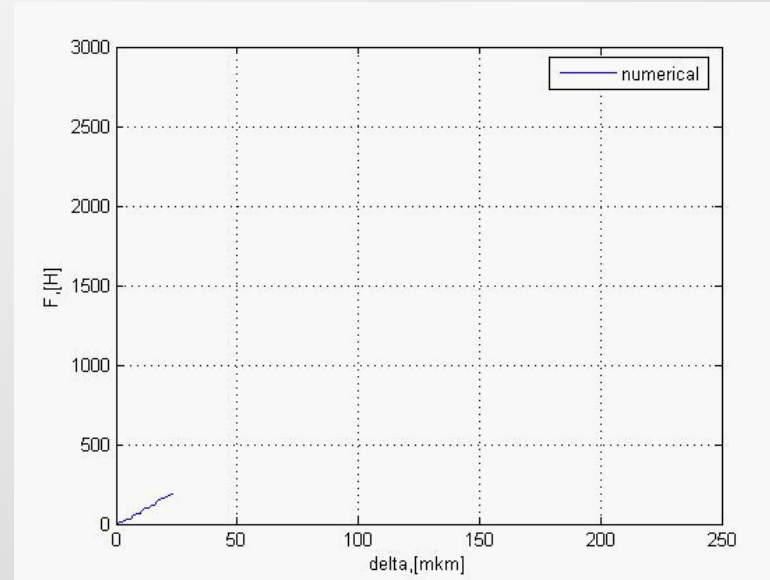
Inverse solution by use method of selection from data base of indentation diagram with the least quadratic deviation

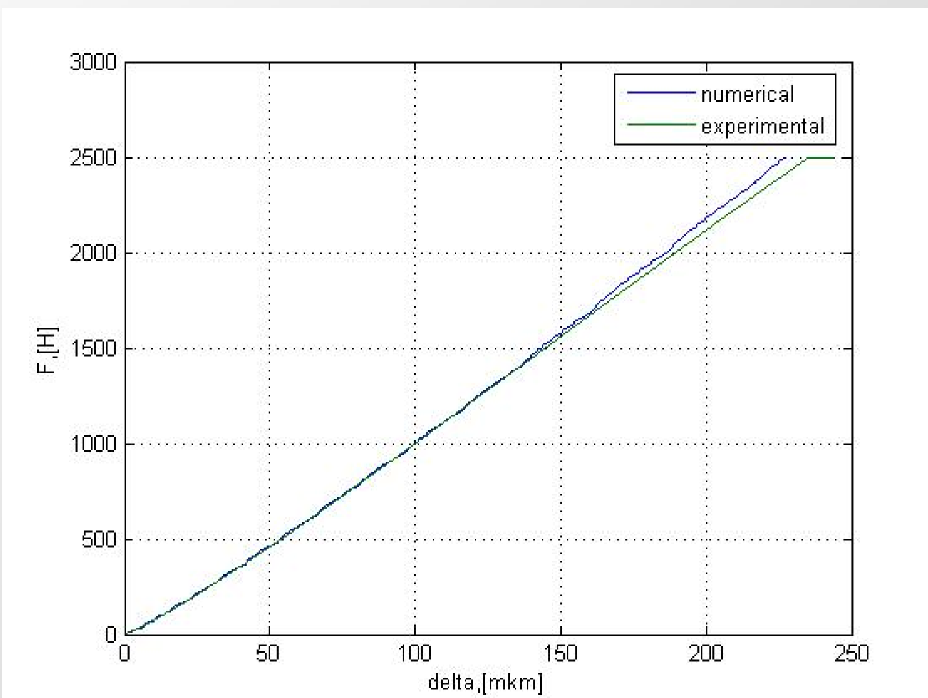
Training of neural network

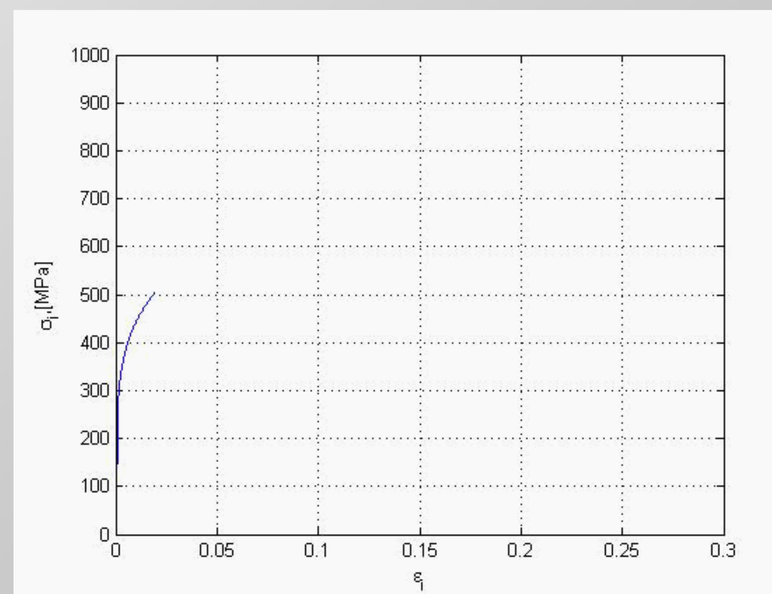


Inverse solution by use neural network method

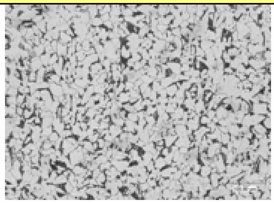
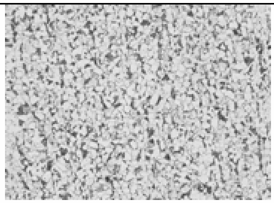
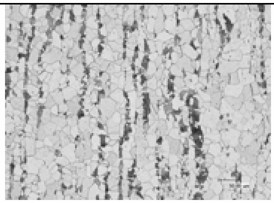
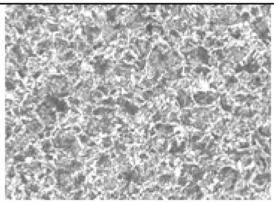
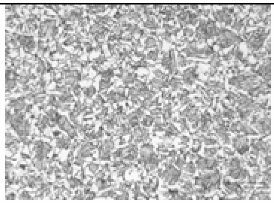

STEP=3
SYZ [MPa]
MIN = +1.53E-002
+2.17E+001
+7.83E+001
+1.35E+002
+1.91E+002
+2.48E+002
+3.05E+002
+3.61E+002
+4.18E+002
+4.74E+002
+5.31E+002
+5.88E+002
+6.44E+002
+7.01E+002
MAX = +7.22E+002

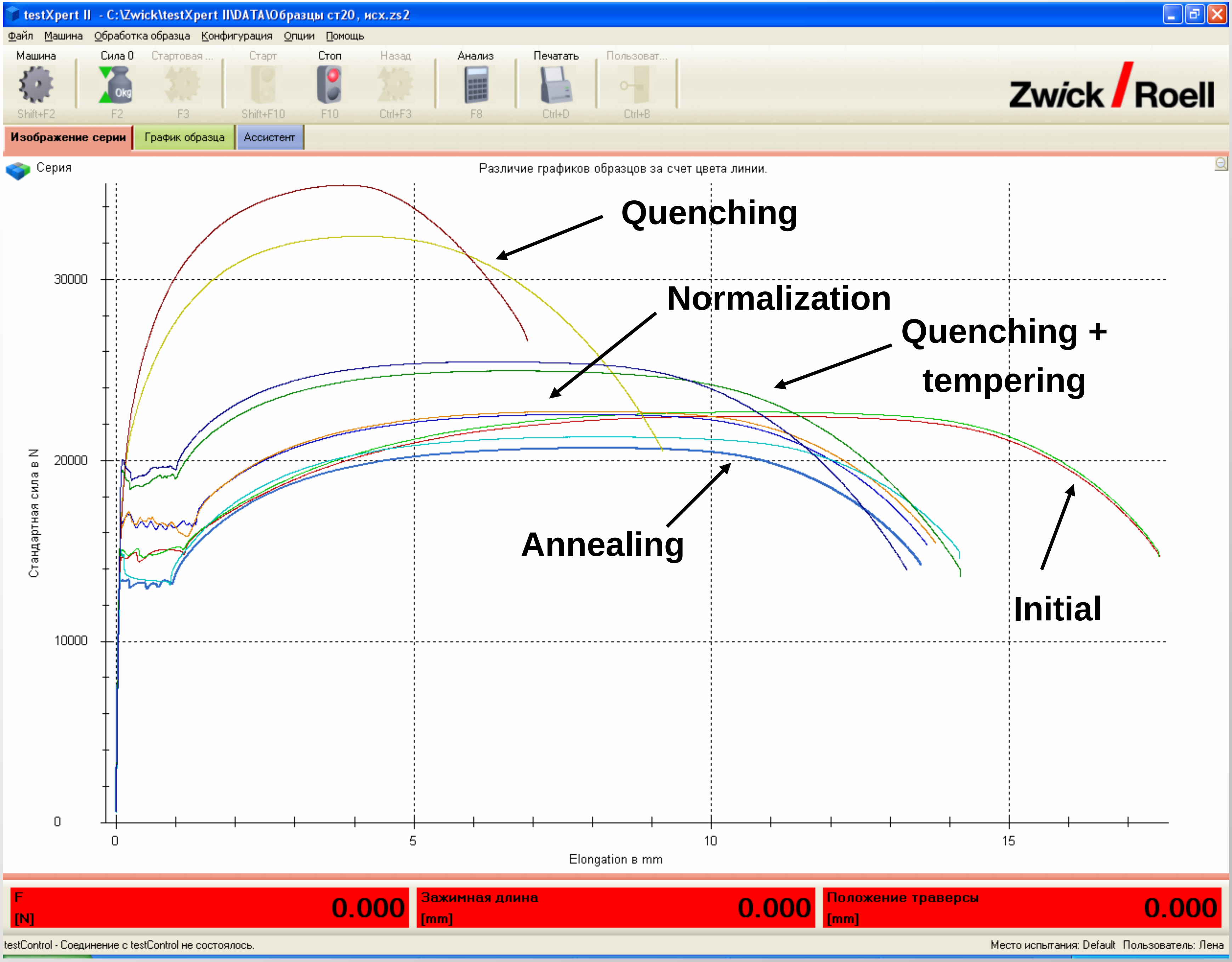

numerical
F,[H]
delta,[mkm]


numerical
experimental
F,[H]
delta,[mkm]


σi,[MPa]
εi

TYPES OF HEAT TREATMENTS OF SAMPLES FROM CARBON STEEL FOR THE CHANGE OF MECHANICAL PROPERTIES IN A WIDE RANGE

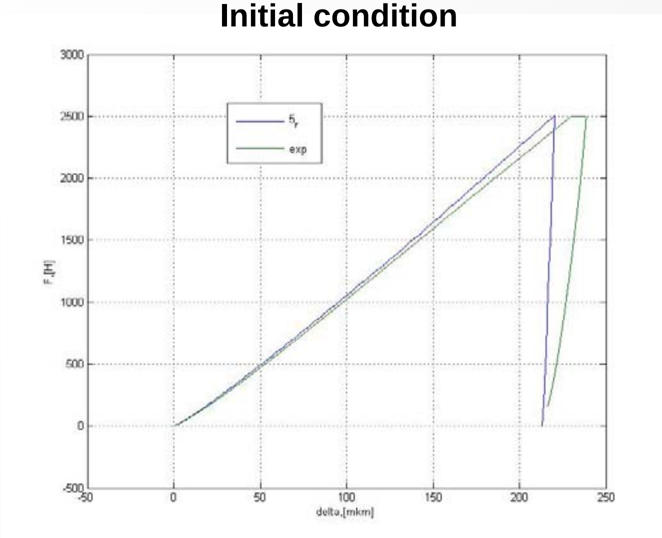
№	Thermal	t°	Time	Environment	Effect	Hardness, HV_{10}	Grain size, mkm	
1.	**Initial**					**125** ±5	25 mkm	 x500
2.	**Normalization**	900°C	1 hour	air	Removal of structure vices and general improvement of structure	**126** ±1	17 mkm	 x500
3.	**Annealing**	900°C	2 hours	охлаждение с печью	Decline of hardness and increase of plasticity	**112** ±1	~23 mkm	 x500
4.	**Quenching**	880°C	1 hour	water	Increase of hardness	**187** ±4	-	 x1000
5.	**Quenching + tempering**	880°C 600°C	1 hour 1 hour	water air	Formation of more equilibrium structure, removal of internal stresses	**159** ±3	-	 x1000



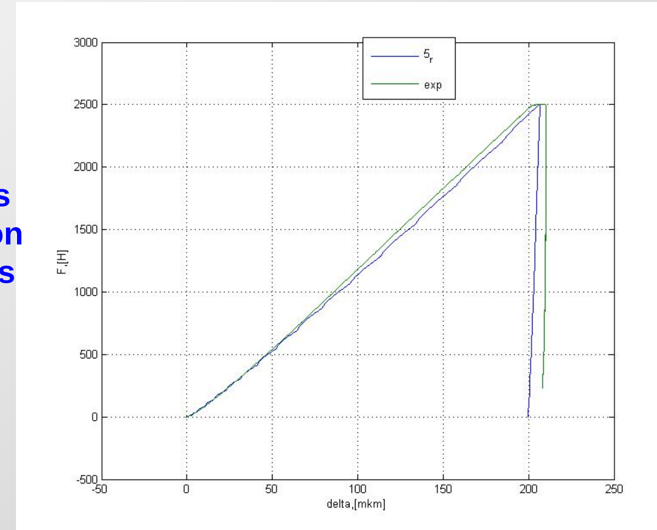
testXpert II - C:\Zwick\testXpert II\DATA\Образцы ст20, исх.zs2
Файл Машина Обработка образца Конфигурация Опции Помощь
Машина
Сила 0
Стартовая ...
Старт
Стоп
Назад
Анализ
Печатать
Пользоват...
Shift+F2
F2
F3
Shift+F10
F10
Ctrl+F3
F8
Ctrl+D
Ctrl+B
Zwick Roell
Изображение серии
График образца
Ассистент
Серия
Различие графиков образцов за счет цвета линии.
Quenching
Normalization
Quenching +
tempering
Annealing
Initial
Стандартная сила в N
30000
20000
10000
0
0
5
10
15
Elongation в mm
F
[N]
0.000
Зажимная длина
[mm]
0.000
Положение траверсы
[mm]
0.000
testControl - Соединение с testControl не состоялось.
Место испытания: Default Пользователь: Лена

RECEIVING OF INDENTATION DIAGRAM COMPARISON WITH EXPERIMENT

Initial condition

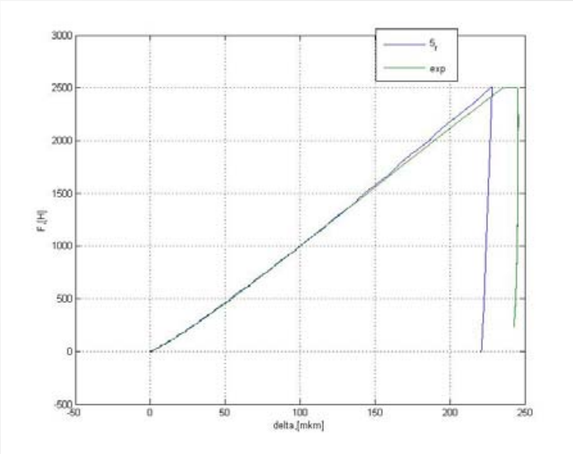


Normalization

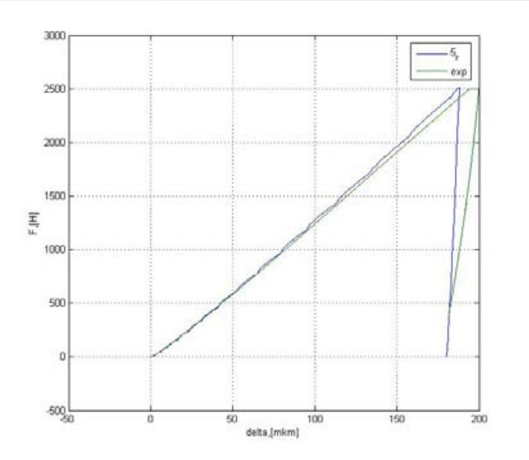


Comparison of calculations and experimental indentation diagrams for five conditions of carbon steel (indenter 2,5 mm)

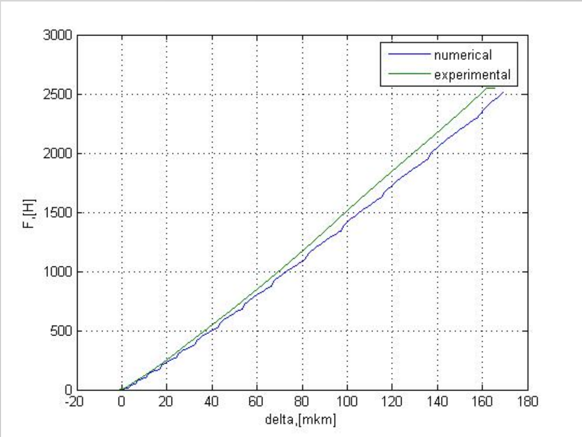
Annealing



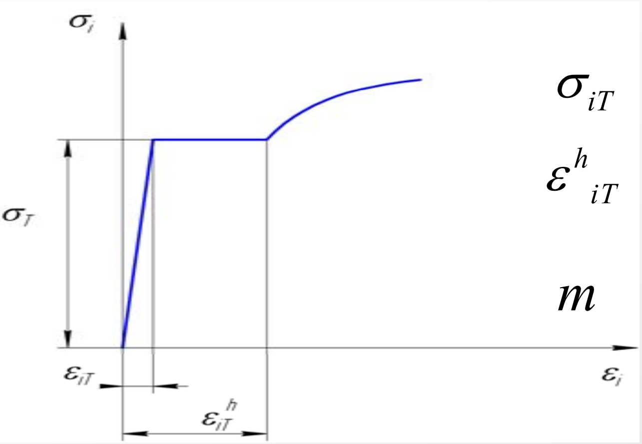
Quenching + tempering



Quenching



APPROACH OF NEURAL NETWORK



neural network for direct solution

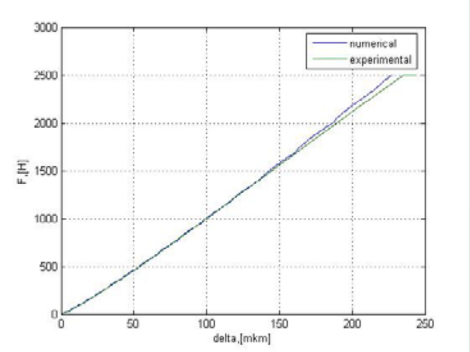
neural network for inverse solution

(h_1, F_1)

(h_2, F_2)

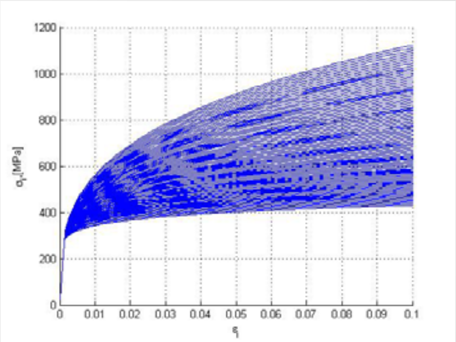
....

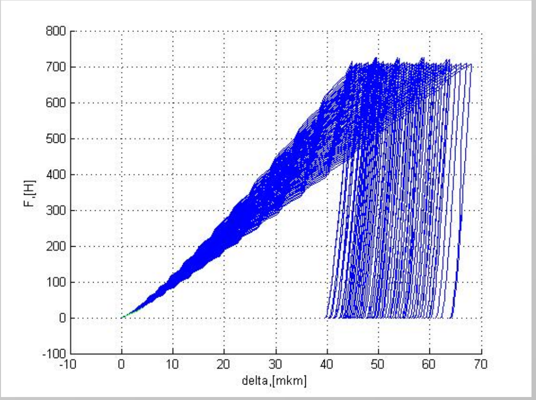
(h_i, F_i)



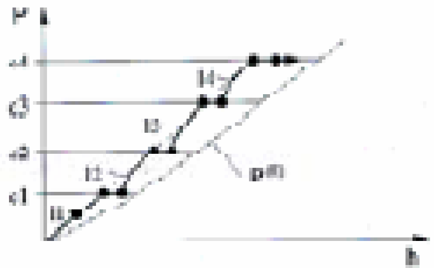
Training of neural network

Data base of numerical FEM (Finite Element Model) of direct solution

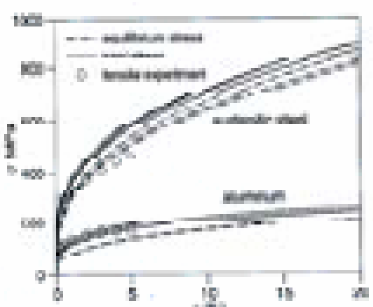




NEURAL NETWORK'S METHODIC FOR CALCULATION TENSILE PROPERTIES WITH VISCOPLASTIC PARAMETER



Training by a large set of forward analysis using FEM simulation



Spherical multi-creep indentation

↓

Neural network

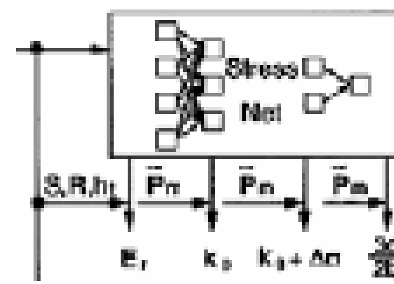
↓

Tensile properties with viscoplastic parameter

$$\sigma = \sigma_y + \frac{\gamma}{\beta}\left(1 - e^{\beta\varepsilon}\right) + OS$$

※ Time dependence

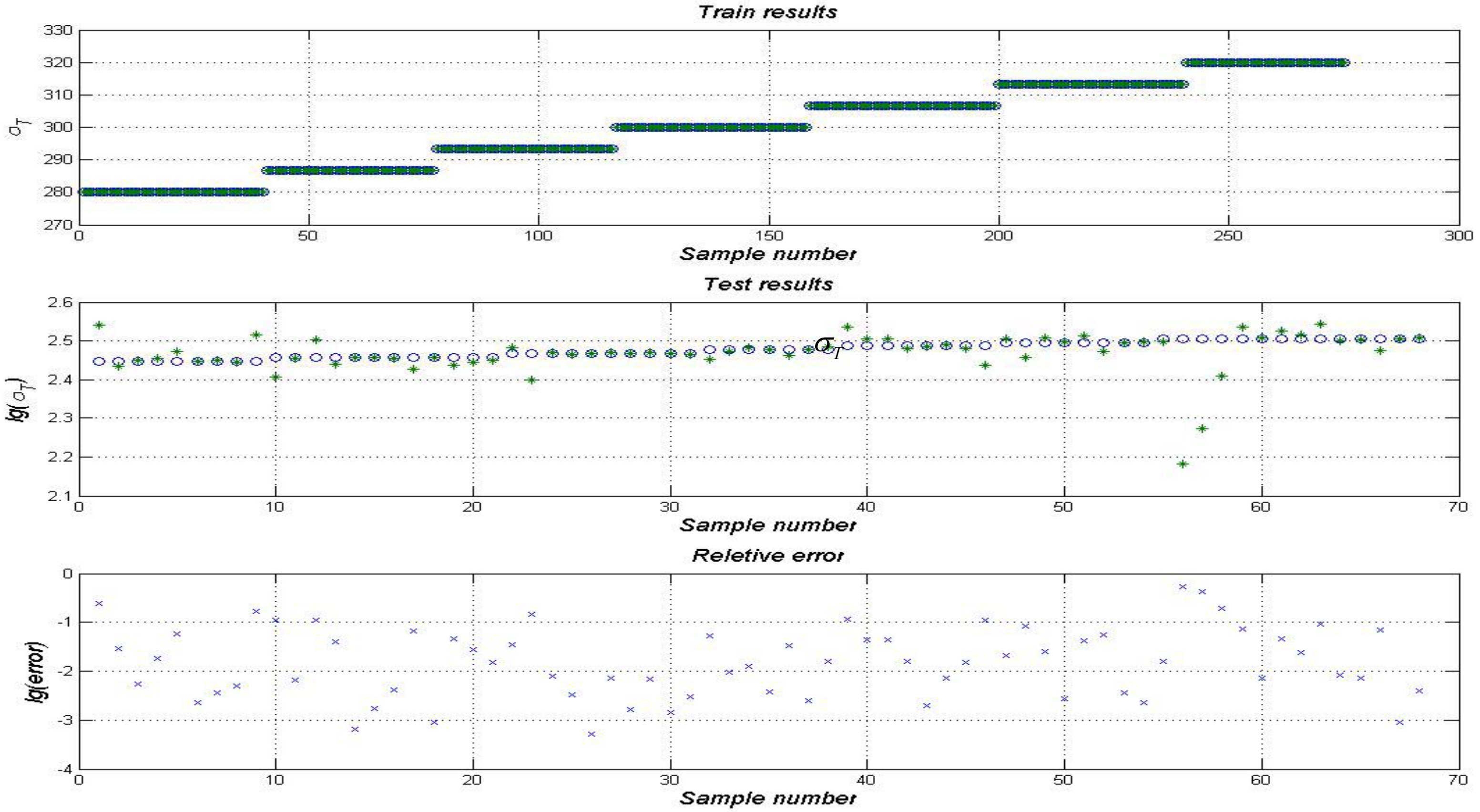
Viscoplastic material parameters



- Zero point
- Young's modulus
- Overstresses and viscosity exponent
- True stress at plastic strain of 0; 0,01; 0,02; 0,04; 0,08; 0,16; 0,32

ISO/DTR 29381:
Metallic materials — Measurement of mechanical properties by instrumented indentation test — Indentation tensile properties

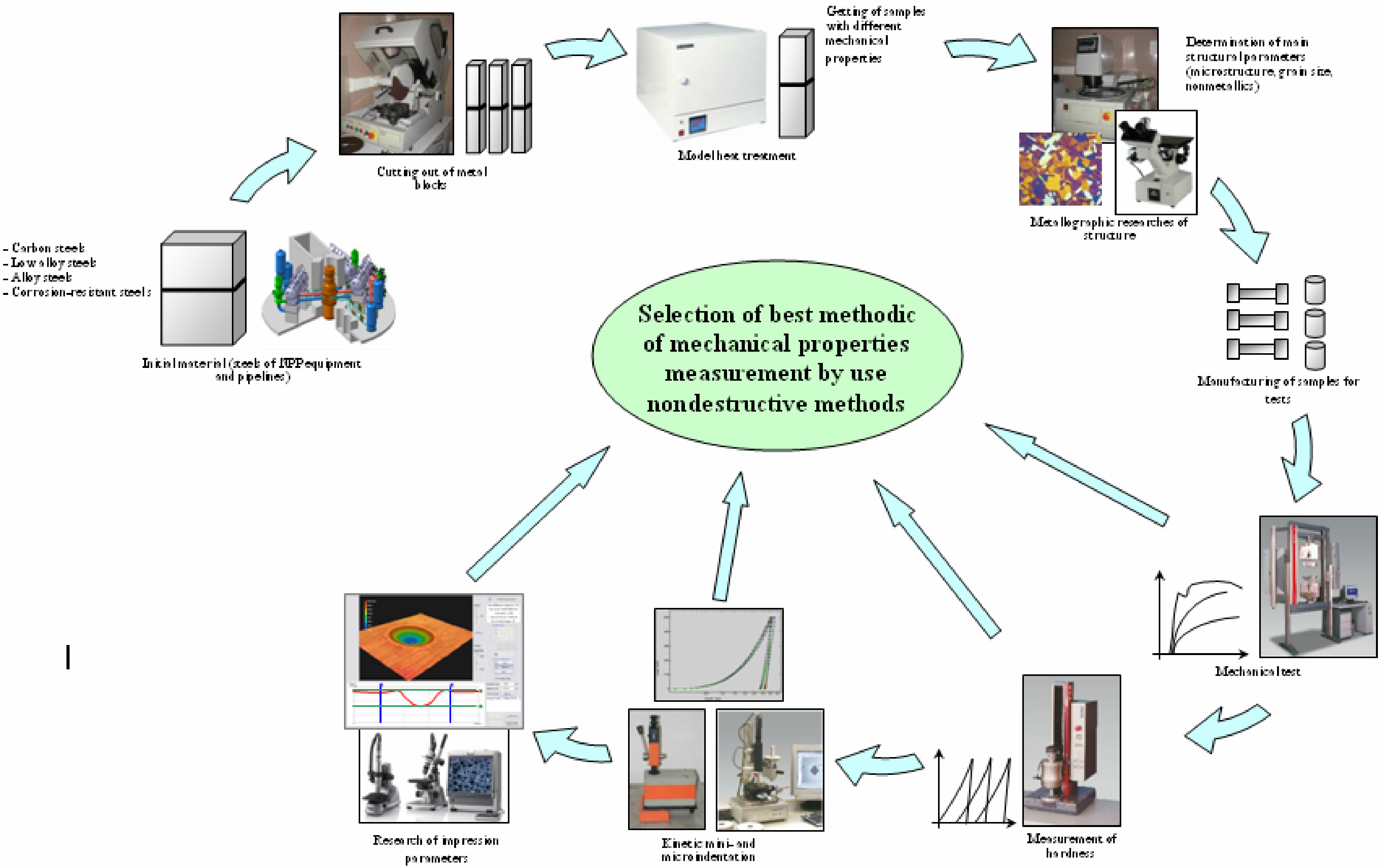
OUR EXAMPLE OF NEURAL NETWORK INVERSE SOLUTION ESTIMATION OF PARAMETERS σ_y



- On the upper diagram there are presented the results of training of neural network, on the bottom – results of testing
- By the small circles there are indicated desired parameter points by the small stars – generated by neural network

STAGES OF THE WORK: DEVELOPMENT OF UNIVERSAL METHODOLOGY OF SPECIMEN FREE NONDESTRUCTIVE INSPECTION (CONTROL) OF MECHANICAL PROPERTIES OF NPP EQUIPMENT METAL IN ALL STAGES OF LIFETIME

Development of methodic of mechanical properties measurement by use nondestructive methods



OUR PROPOSALS TO COLLABORATION

I. Creation of an expert working group under the aegis of IAEA from experts and the organizations having experience in the research and use of hardness testing of nuclear power plant materials/ageing thereof with the goal of preparing terms of reference and a proposal to submit to the IAEA.

II. Development of the program of carrying out the research.

III. Development of strategy of processing of the received data with the purpose of selection of the most effective methodic for specimen-free measurements of mechanical properties of metal of the equipment and pipelines of NPP for various classes of materials.

IV. Development of the methodology of specimen-free measurements of mechanical properties of metal and recommendations by its use on NPP.

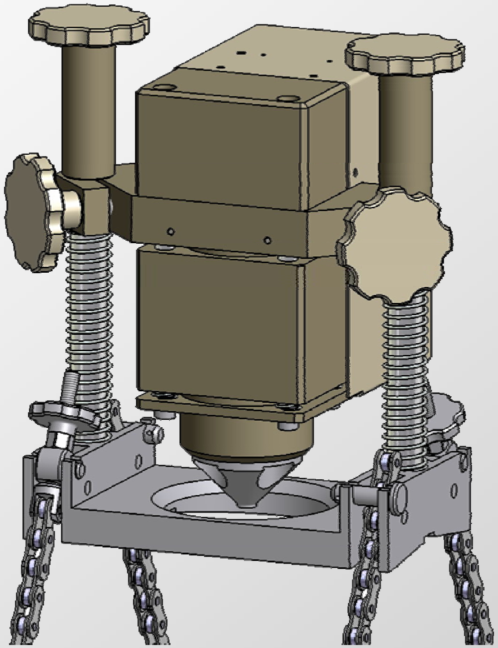
V. The analysis of operational ageing of materials of the equipment and pipelines of various types of NPP in the world. Development of an algorithm of drawing up of programs of specimen-free non destructive inspection of mechanical properties for various types of the equipment and pipelines of NPP. Development of procedures of inspection.

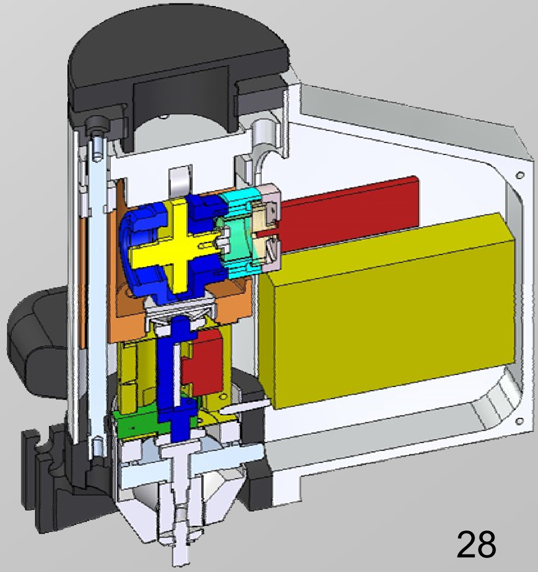
VI. Development of IAEA normative document «Development of universal methodology of specimen free nondestructive inspection (control) of mechanical properties of NPP equipment metal in all stages of lifetime». Recommendations by introduction on NPP and on manufacturers of the equipment.

VII. Development of strategy on the base of this methodic of predict the remaining life time of system, benchmarking technologies through Round Robin Test from different countries.

THE PORTABLE UNIVERSAL MEASURING DEVICE FOR INSTRUMENTED INDENTATION TEST

The patent of Germany with the purpose of the beginning of produce of such devices in Europe has received. Now in view of international standard ISO/DIS 14577-1:2000-04 «Metallic materials – Instrumented Indentation test for hardness and materials parameters» together with corporation MESS+TEST is planning to organize serial manufacturing of the device.





OUR PATENTS

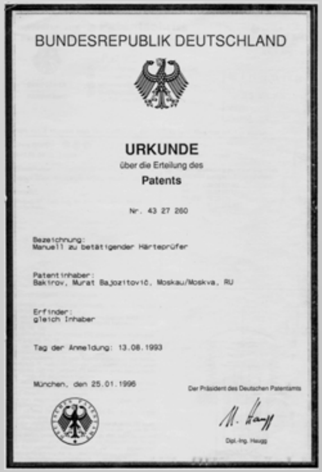

ФЕДЕРАЛЬНОЕ АГЕНТСТВО
ПО ТЕХНИЧЕСКОМУ РЕГУЛИРОВАНИЮ И МЕТРОЛОГИИ
СЕРТИФИКАТ
PATTERN APPROVAL CERTIFICATE
OF MEASURING INSTRUMENTS


The United States of America
The Commissioner of Patents and Trademarks
United States Patent


П А Т Е Н Т


ПАТЕНТ
НА ИЗОБРЕТЕНИЕ
№ 2149396


BUNDESREPUBLIK DEUTSCHLAND
URKUNDE
über die Erteilung des
Patents
Nr. 199 04 414


BUNDESREPUBLIK DEUTSCHLAND
URKUNDE
über die Erteilung des
Patents
Nr. 43 27 260

THANK YOU FOR ATTENTION!