Frank Theisen (Stange Elektronik GmbH),
Magnus Bergman (Nordic Furnaces AB),
Jani Martinsson (Nordic Furnaces AB)

Program controllers for nitriding and carburizing

Key Facts

- Founded 1976
- Owner operated
- Approx. 50 employees, more than 60% engineers

Systems:

•	50 000	Controllers
•	4 000	ECS SCADA Software
•	2 000	Sensors / Probes

- Approx. 800 controllers / 200 sensors per year

Key Facts

STANGE
ELEKTRONIK GMBH

Stammhaus:

STANGE Elektronik GmbH

Gutenbergstr. 3
51645 Gummersbach
Germany

Büro Thüringen:

STANGE Elektronik GmbH
Wandersleber Str. 1b
99192 Apfelstädt
Germany

Representation Office China

STANGE Elektronik GmbH R.O.Shanghai
Room 1609B, Shenergy International Building
No.1 Middle Fuxing Road,
Huangpu District, Shanghai, 200021,
P.R.China

Office India:

STANGE Elektronik India
Powerd by Atreya Technology Solutions
SukhSwapna, R.L.117, Milap Nagar, M.I.D.C.,
Thane (Maharashtra) – 421 203
India

TÜV CERT
ISO 9001 : 2000
Reg.-Nr. 01 100 043013

AWT

IHT
INDUSTRIEVERBAND HÄRTETECHNIK

CoDeSys Automation Alliance

Agenda SHTEs värmebehandlingskonferens

STANGE ELEKTRONIK GMBH

- Carburizing
- C-Level
- Diffusion
- Nitriding
- Potential
- Nitriding case depth
- Forecast

Agenda SHTEs värmebehandlingskonferens

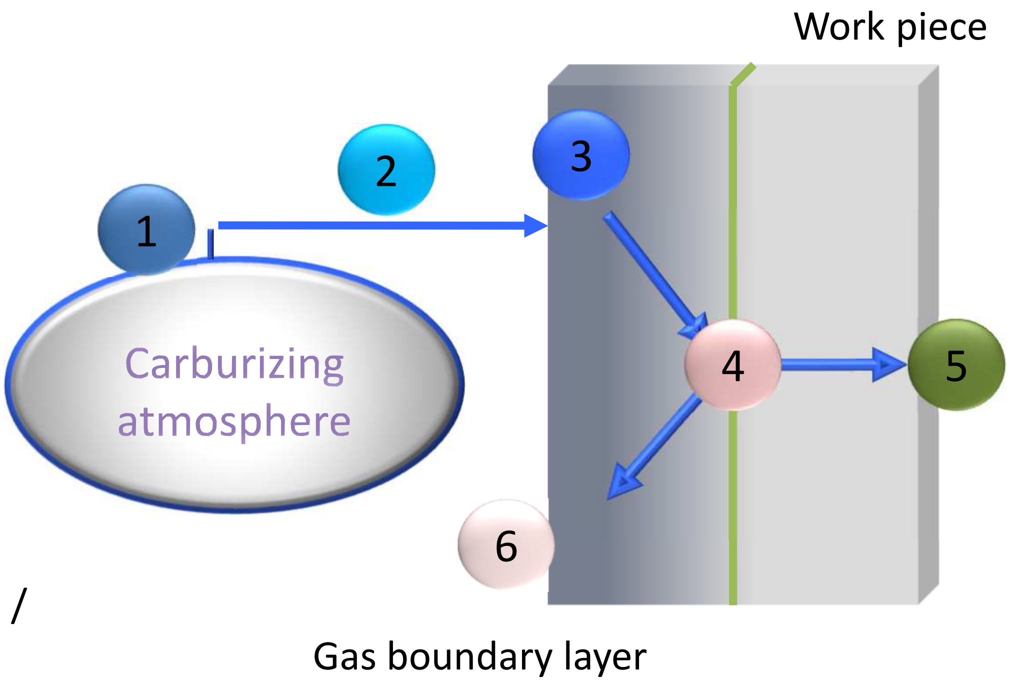
STANGE Elektronik GmbH

- Carburizing
- C-Level
- Diffusion
- Nitriding
- Potential
- Nitriding case depth
- Forecast

Carburizing

A reaction balance occurs when on the part surface as much carbon is picked up as carbon is added with a carbon containing lubrication gas.

1. Homogeneous atmosphere development
2. Gas transportation to work piece surface
3. Diffusion through gas boundary layer
4. C adsorption and reaction on the surface
5. C- diffusion Work piece
6. Desorption / Back diffusion H_2O / CO_2 / H_2



Carburizing

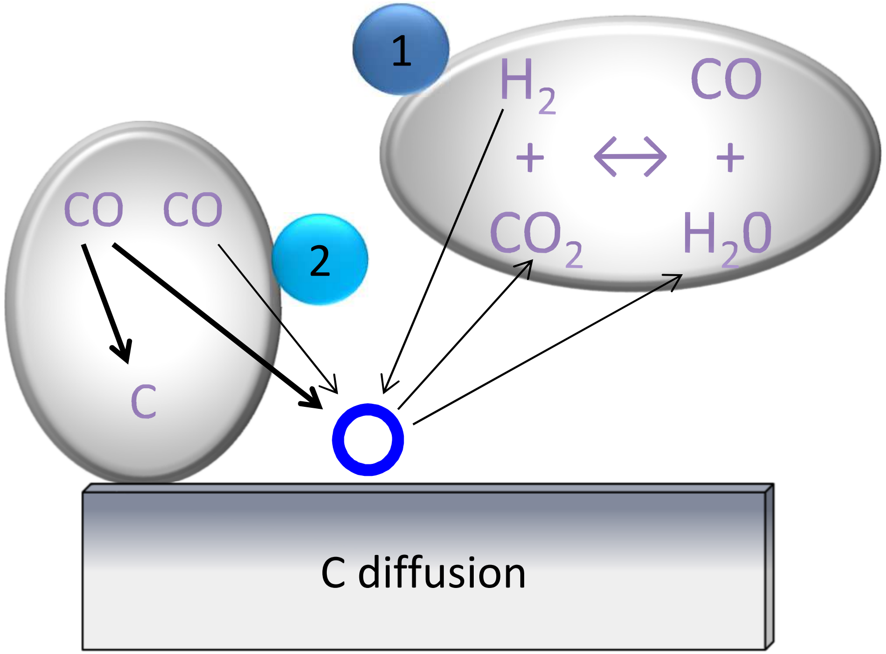
1 ❖Reaction 1 (Gas atmosphere)
Homogeneous water gas reaction

2 ❖Reaction 2 (CO-decay):
Boudouard-reaction

Legality for indirect C-level determination

$CO + H_2 \Rightarrow [C] + H_2O$
$2CO \Rightarrow [C] + CO_2$
$CO \Rightarrow [C] + ½ O_2$

Material transfer by CO



Agenda SHTEs värmebehandlingskonferens

STANGE ELEKTRONIK GMBH

- Carburizing
- C-Level
- Diffusion
- Nitriding
- Potential
- Nitriding case depth
- Forcast

STANGE Elektronik GmbH

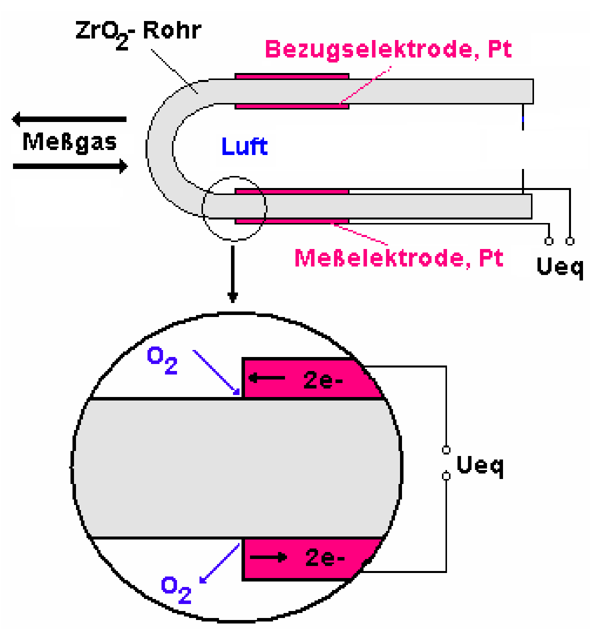
Carburizing / C-level

Sensor based process control is essential at actual quality assurance and permanent increasing quality requirements.

The carburizing process is a core technology in the area of heat treatment of metals and comes across in nearly each heat treatment shop.

Beside the use of oxygen probes also the measurement of the process gas via CO/CO_2 analysis is a current technology at carburizing processes.

Principle of gas potentiometry with ZrO_2 solid electrolyte



$$U_{eq} = \frac{RT}{4F} \ln \frac{p(O_2)'}{p(O_2)''}$$

Carburizing / C-level

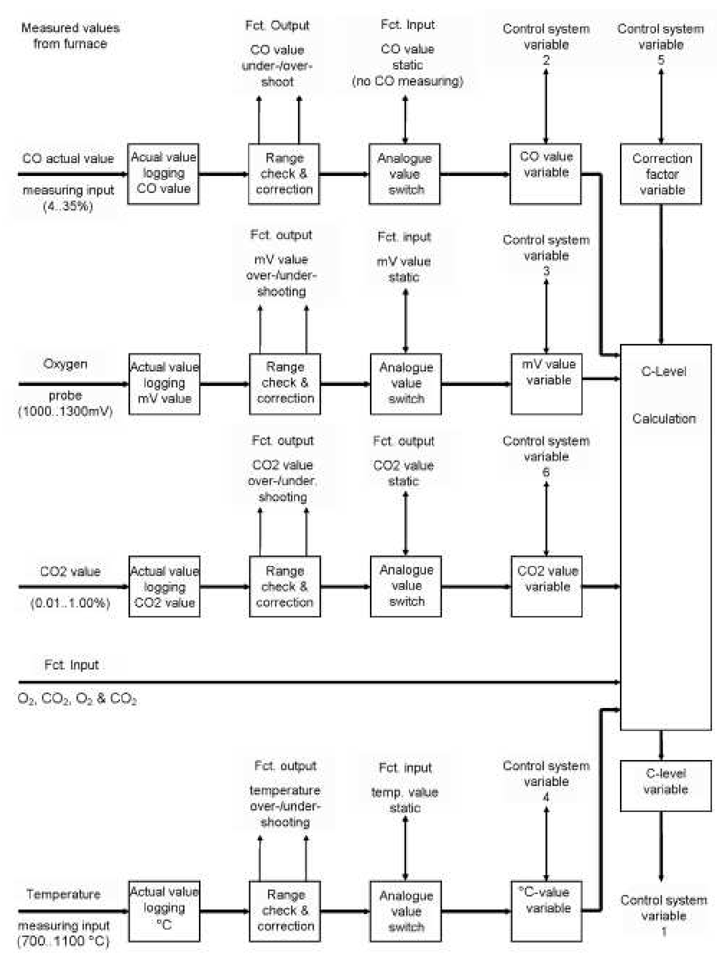
STANGE ELEKTRONIK GMBH

C-Level function

Temperature and furnace atmosphere are controlled by using a special formula for C-level calculation.

- Inputs for temperature, CO, CO2 and O2
- Consideration of correction values
- Choice between endogas and direct gassing systems

Function block C-level calculation



Calculation example:
O2 formula: CO= 20%, T= 930°C, O2= 1173mV C-level = 1.269%
CO2 formula: CO= 20%, T= 900°C, CO2= 0.5% C-level = 0.3475%

Carburizing / C-level

STANGE
ELEKTRONIK GMBH

SE-60X Series

SE-70X Series

Agenda SHTEs värmebehandlingskonferens

STANGE
ELEKTRONIK GMBH

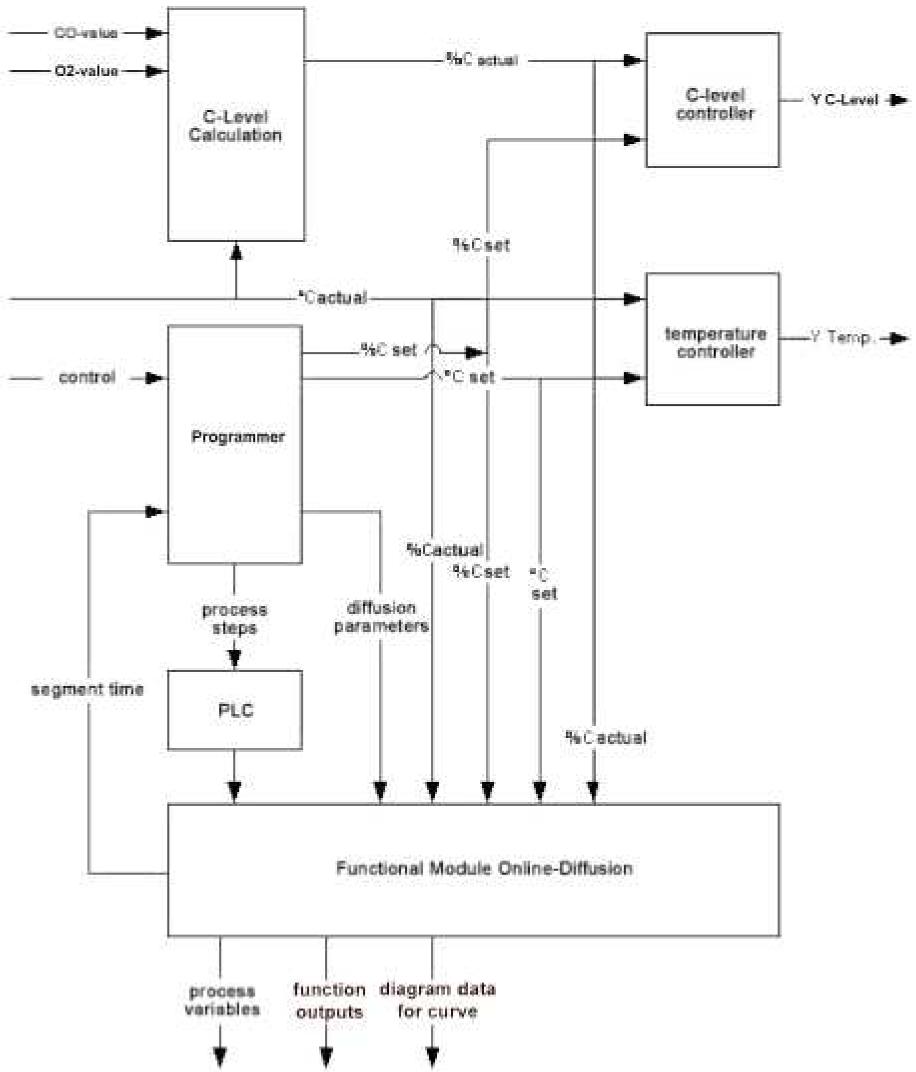
- Carburizing
- C-Level
- **Diffusion**
- Nitriding
- Potential
- Nitriding case depth
- Forcast

Carburizing / Diffusion

C-diffusion function

Temperature and furnace atmosphere (C-level) are controlled.

The optimal treatment time is cyclically determined in consideration of material parameters in the process steps "carburizing" and "diffusing" and taken over as segment time.



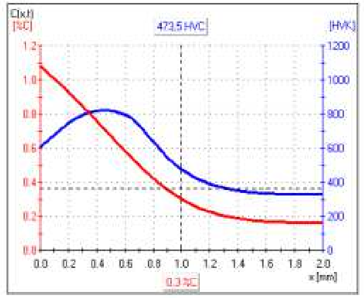
Carburizing / Diffusion

STANGE Elektronik GmbH

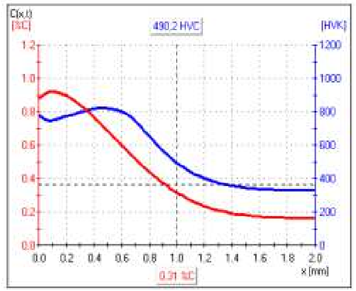
Typically the heat treatment consists of 2 phases

1.) Carburizing phase

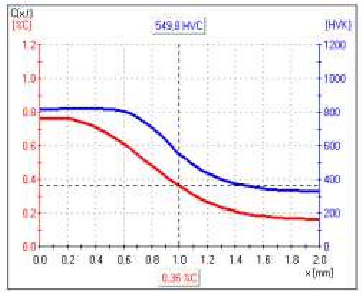
- Carburizing of the work piece boundary area
- Target is to reach the desired depth of carbon penetration.
- Desired depth ranges from 1/10 mm to approx. 8 mm maximum.
- After carburizing step the C-content has reached his maximum at work piece surface and continuously falls with increasing depth to the material base carbon content.



C-level course after diffusion start:



C-level course at diffusion end:



2.) Diffusion phase:

- During carburizing usually a high C-content (typically 1.1 %C) will be generated in order to get carbon into the material as fast as possible.
- Thereby a much too high C-content is reached and must be reduced to the typical target value (e.g. 0.7 %C).
- During diffusion phase with reduced C-level / temperature this will be reached. At the same time a uniform distribution will be reached by the diffusion.

Carburizing / Diffusion

STANGE
ELEKTRONIK GMBH

3 types of diffusion calculation

1.) Actual Calculation:
Current C-level profile in material is calculated in consideration of the actual process.
So the calculation simulates the actual situation in work piece.

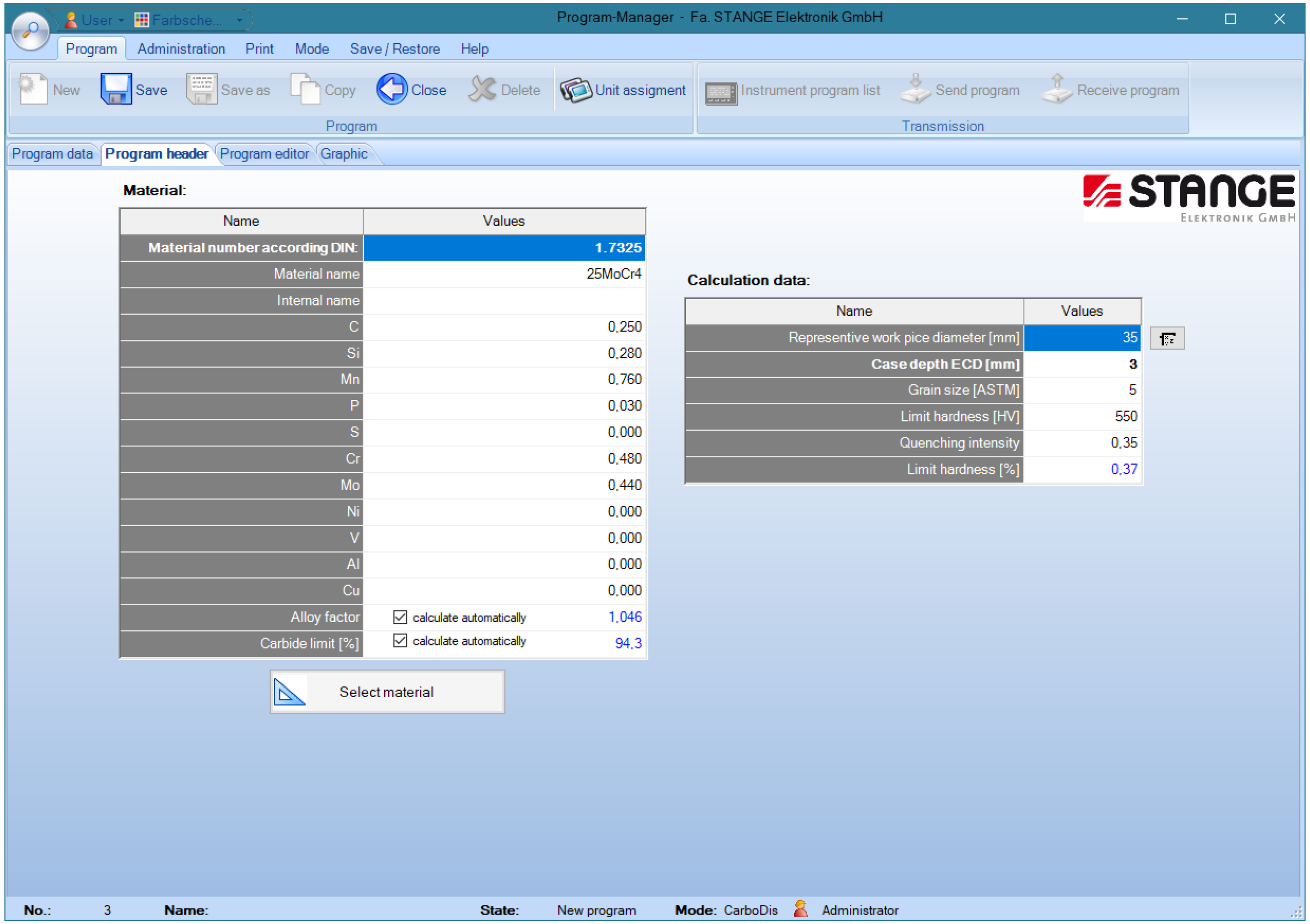
2.) Online Calculation:
The online calculation makes sure that the duration of certain treatment segments
(holding phases, carburizing, diffusion) are adjusted to the current process.
It reacts to process deviations from ideal (Offline-Calculation) and corrects temporary the carburizing and/or diffusion phase.
The holding phases calculation exclusively takes place based on %At (percent carburizing depth.)

3.) Offline Calculation:
The offline calculation is a help for program creation
Phases times are calculate and check whether the program leads to the desired target.

The holding phases calculation exclusively takes place based on %At (percent carburizing depth). If other optimization criteria are required, then the corresponding PC software must be used!

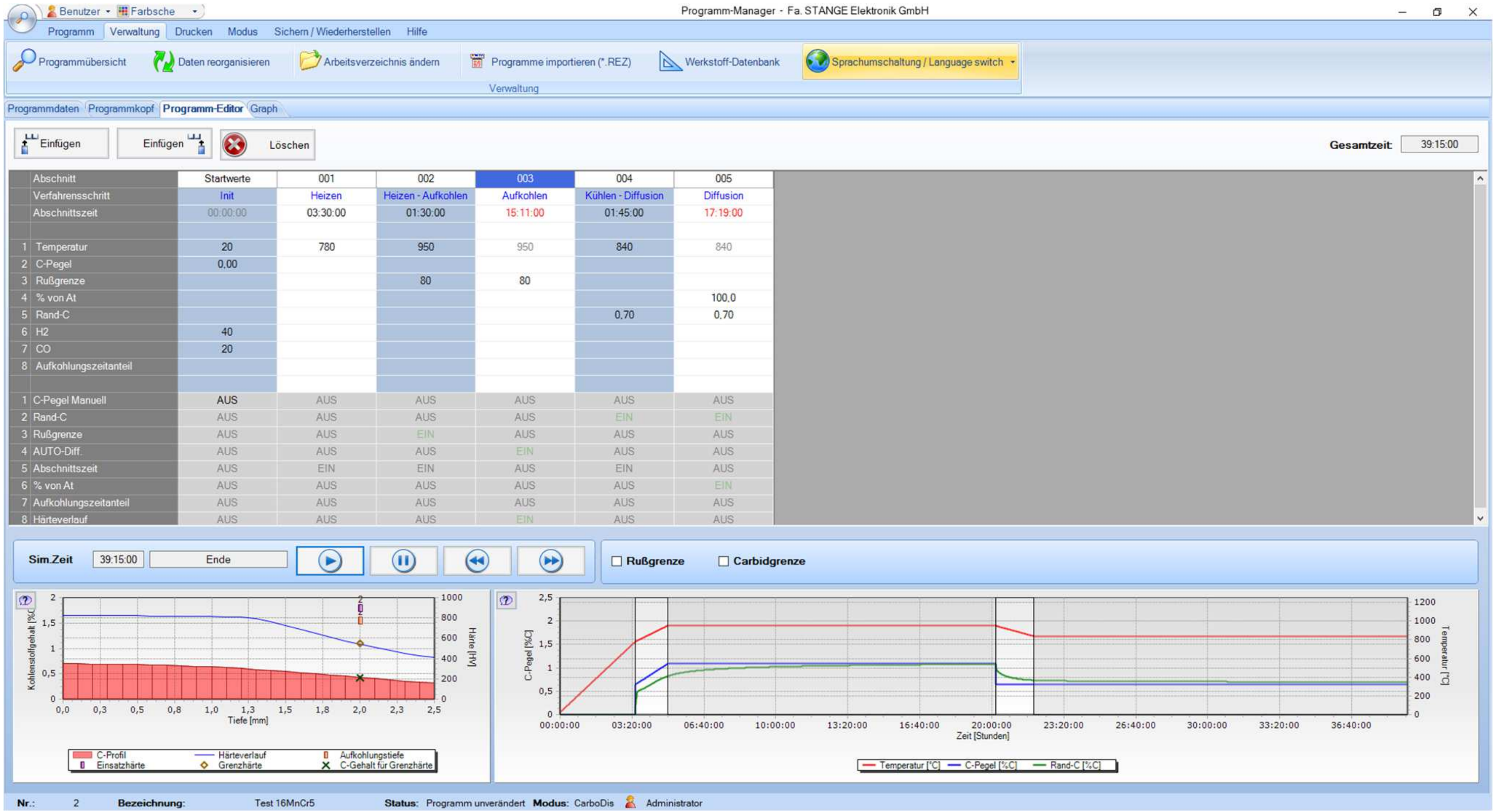
STANGE ELEKTRONIK GMBH

ECS CarboDis



Carburizing / Diffusion

ECS CarboDis



Carburizing / Diffusion

STANGE ELEKTRONIK GMBH

SE-60X Series

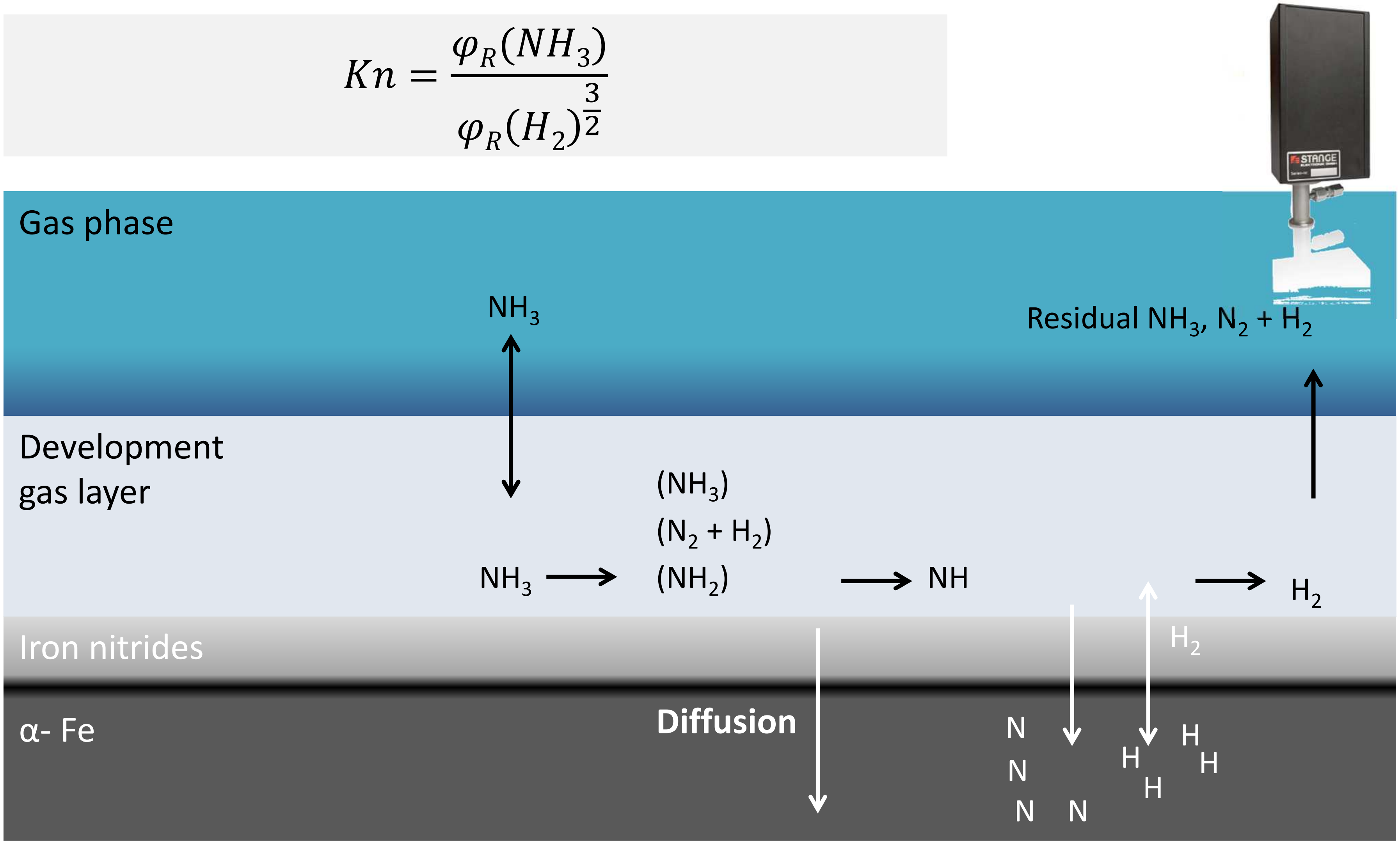
Agenda SHTEs värmebehandlingskonferens

STANGE Elektronik GmbH

- Carburizing
- C-Level
- Diffusion
- **Nitriding**
- Potential
- Nitriding case depth
- Forcast

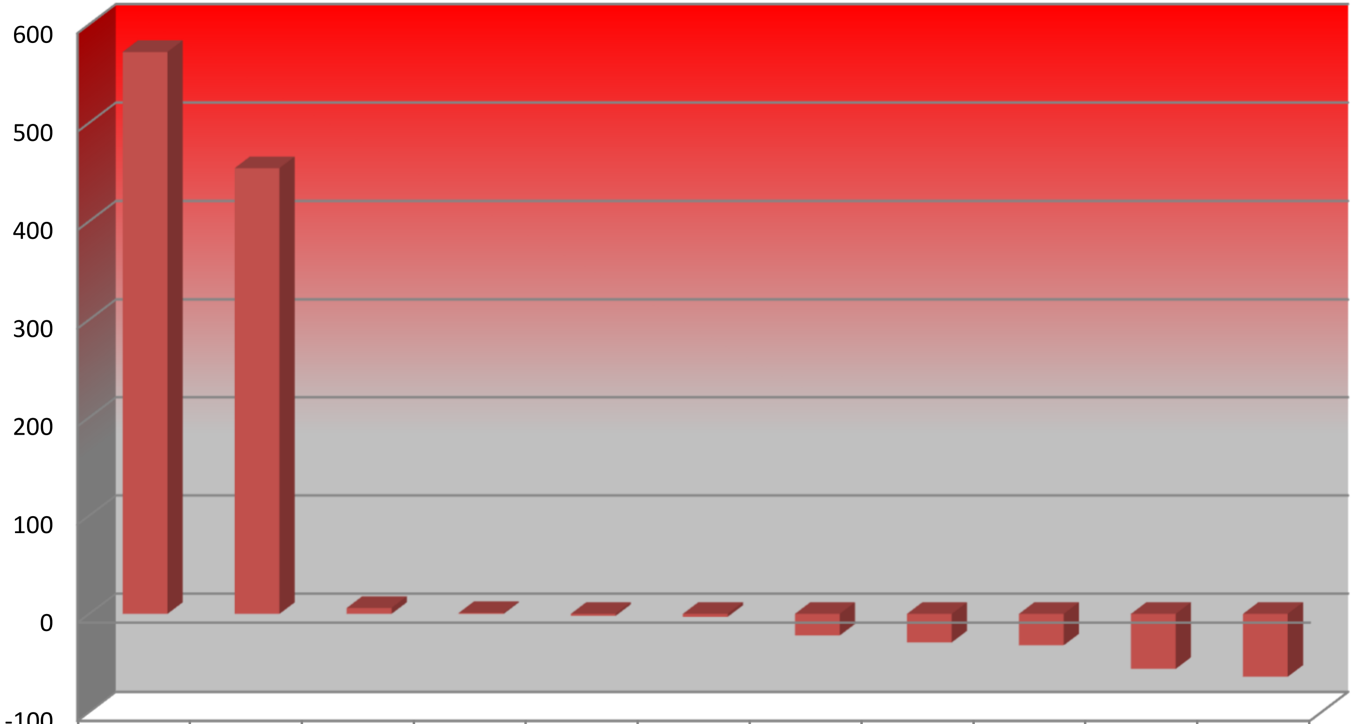
Nitriding

$$Kn = \frac{\varphi_R(NH_3)}{\varphi_R(H_2)^{\frac{3}{2}}}$$



Nitriding

Base heat conductivity

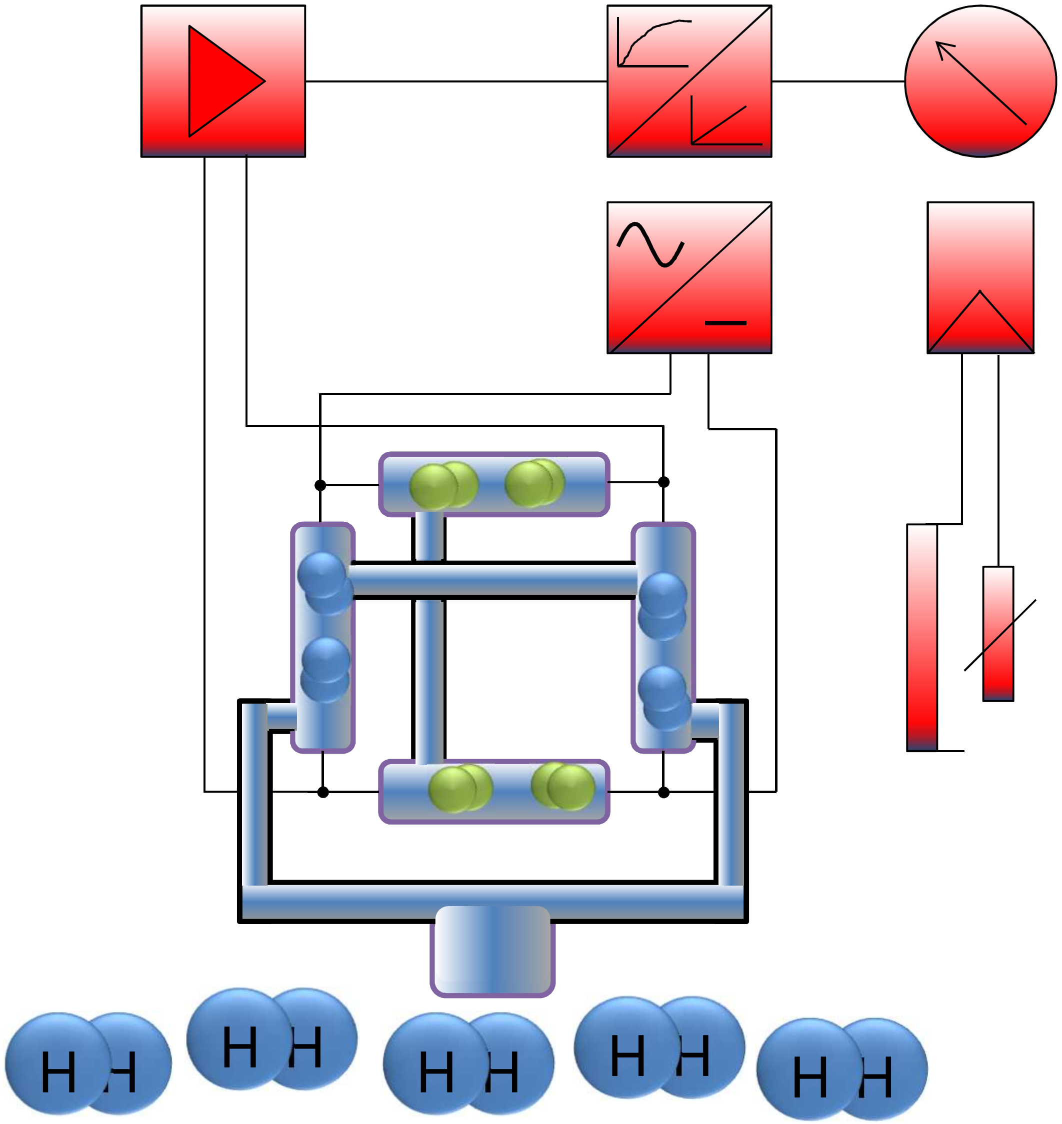


	H2	He	NH3	O2	N2	CO	H2O	CO2	Ar	SO2	Cl2
Series1	572	454	6	1	-2	-3	-22	-29	-32	-56	-64

Relative heat conductivity of different gases compared with air (at 100°C). (from the documentation of Hartmann & Braun AG, Frankfurt).

Nitriding

STANGE
ELEKTRONIK GMBH



Nitriding

- Continuous measurement
- No exhaust gas via the sensor
- Simple mechanical connection via KF16
- Linear 4-20 mA output according to the measurement range
- High endurance plus 1 year warranty
- Simply to check

Agenda SHTEs värmebehandlingskonferens

STANGE Elektronik GmbH

- Carburizing
- C-Level
- Diffusion
- Nitriding
- **Potential**
- Nitriding case depth
- Forcast

Nitriding / Potential

Pre conditions
Knowledge about characteristics of parts at nitriding in relationship of material and nitriding conditions as base for the selection of material and requirement of the technological parameters.[1]

The characteristics is dedicated by the

- parts,
- alloy components,
- matrix of the base material,
- treatment temperature,
- holding time,
- nitriding atmosphere,
    - nitriding potential (Kn),
    - carbon potential (Kc) and
    - oxidation potential (Ko).

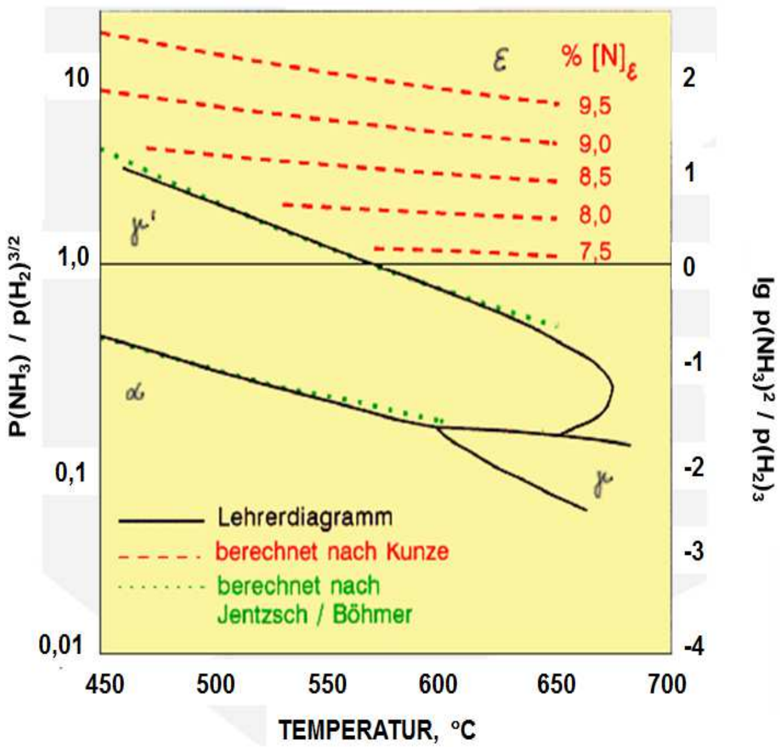
		CL	SH		NHD		
		VS	RH	ΔH	Nht	Rht	ΔX/Nht
Nitriding conditions							
	T ↑	↑	=↓	=↓	↑	↑	↑
	t ↑	↑	=↓	=↓	↑	↑	↑
	Kn ↑	↑	=	=	=	=	=
Material							
Zusatz:	Cr ↑	↓	↑	↑	↓↓	↑	↓
	Al ↑	↑	↑↑	↑↑	=↓	↓	↑
	C ↑	=↑	↓	↓	=↓	↓	↑
Gefüge:	N	=	=↑	↑	=	↑	↓
	$V(T_A\uparrow)$	=	↓	↓	=	↓	↑

microstructure N normalized / V (TA) tempering temperature

[2] HTM 47 (1992) page 229 ; Spies und Bergner

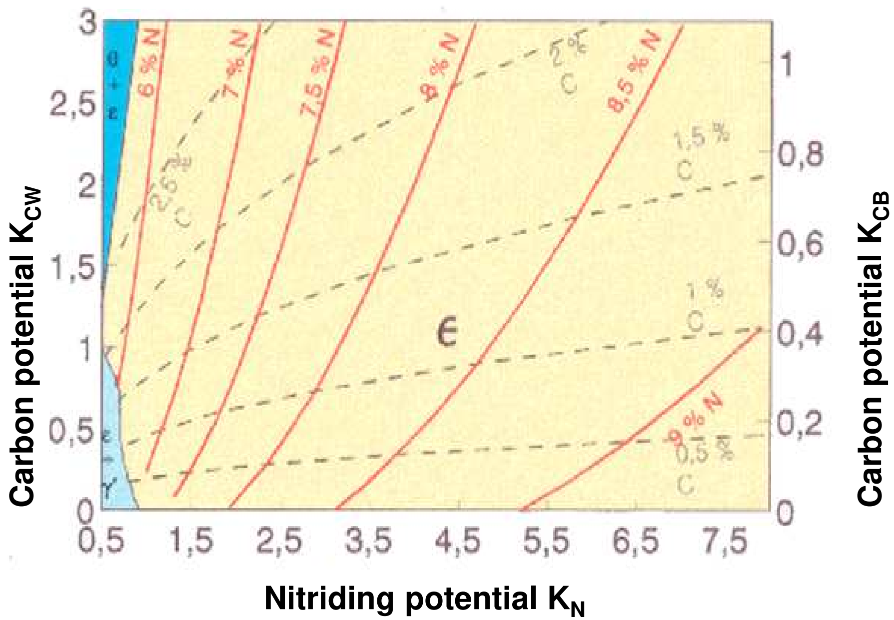
Nitriding / Potential

Only the kind of layer can be shown with the Lehrer- or Kunze- diagram.
The thickness and the growth can‘t be shown with this method!



Lehrer diagram

Nitrogen and carbon concentriation in ε phase at 570°C



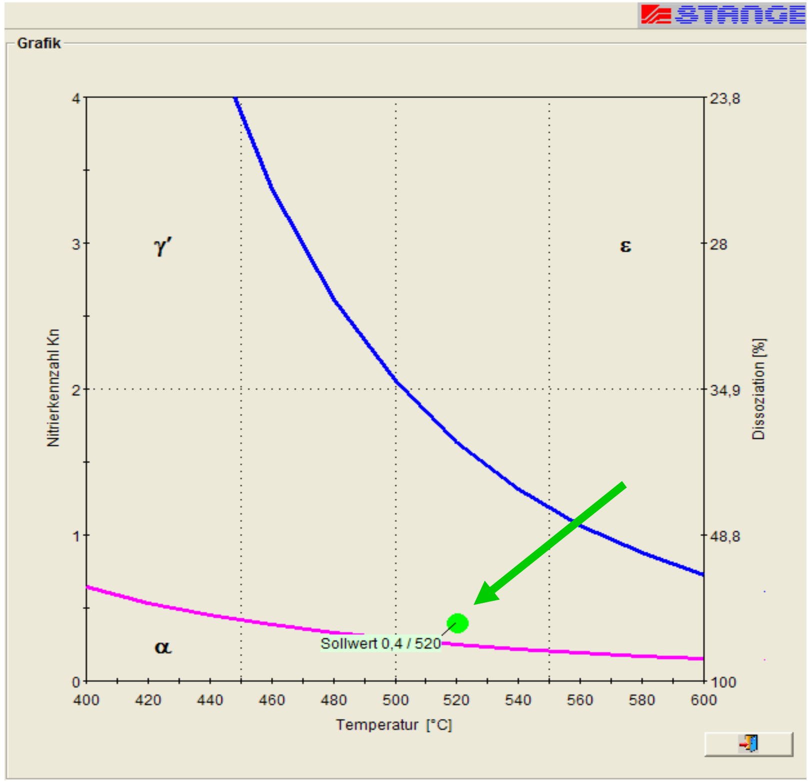
Phase limits according Naumann a. Langscheid;

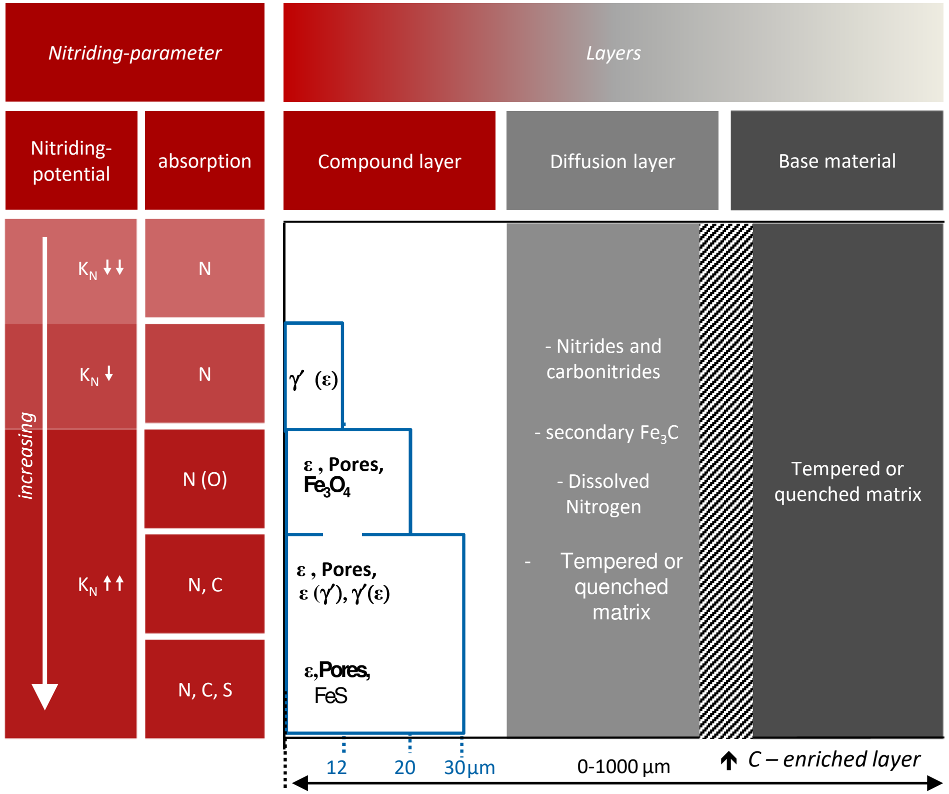
Nitrogen- a. carbon concentriation according n. Kunze

Nitriding / Potential

STANGE ELEKTRONIK GMBH

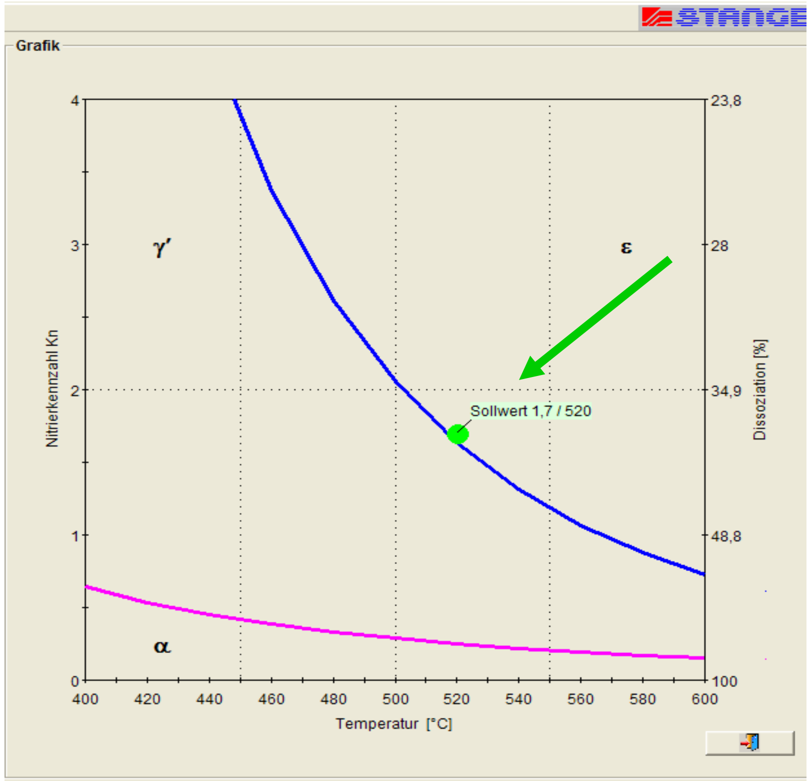
The thickness and phase structure of the compound layer as well as the thickness and hardness distribution of the diffusion layer can be changed in large ranges by the variation of the nitriding potential K_N, carbon potential K_C, oxidation potential K_O and the choice of the base material.

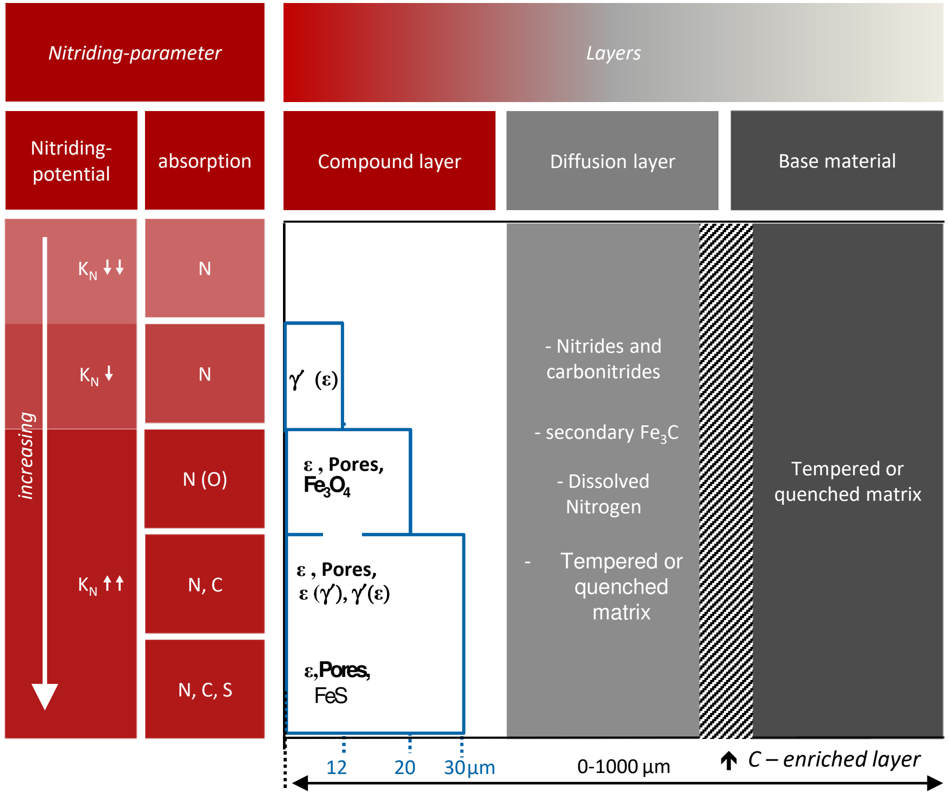




Nitriding / Potential

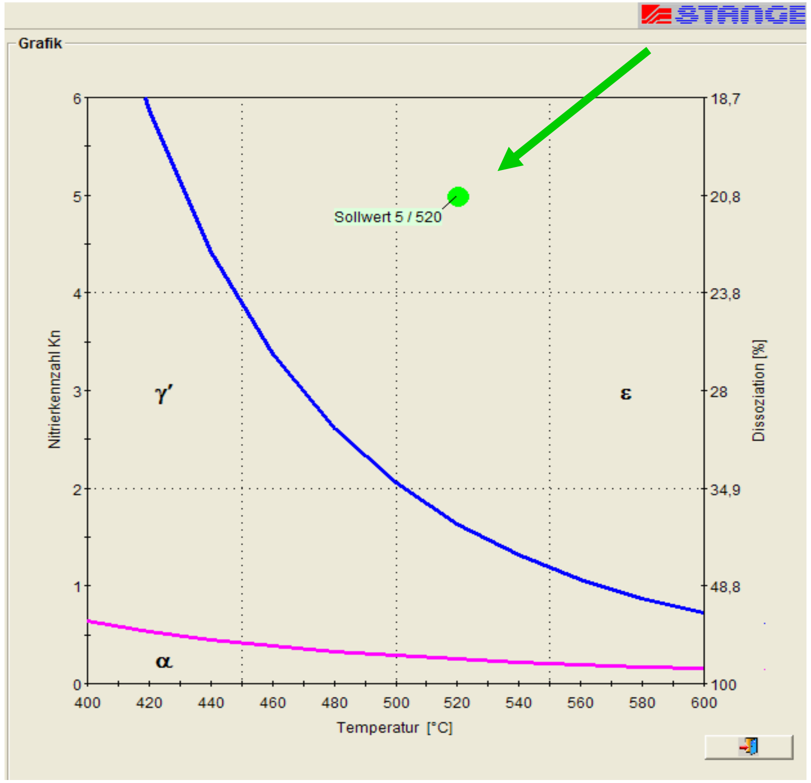
The thickness and phase structure of the compound layer as well as the thickness and hardness distribution of the diffusion layer can be changed in large ranges by the variation of the nitriding potential K_N, carbon potential K_C, oxidation potential K_O and the choice of the base material.

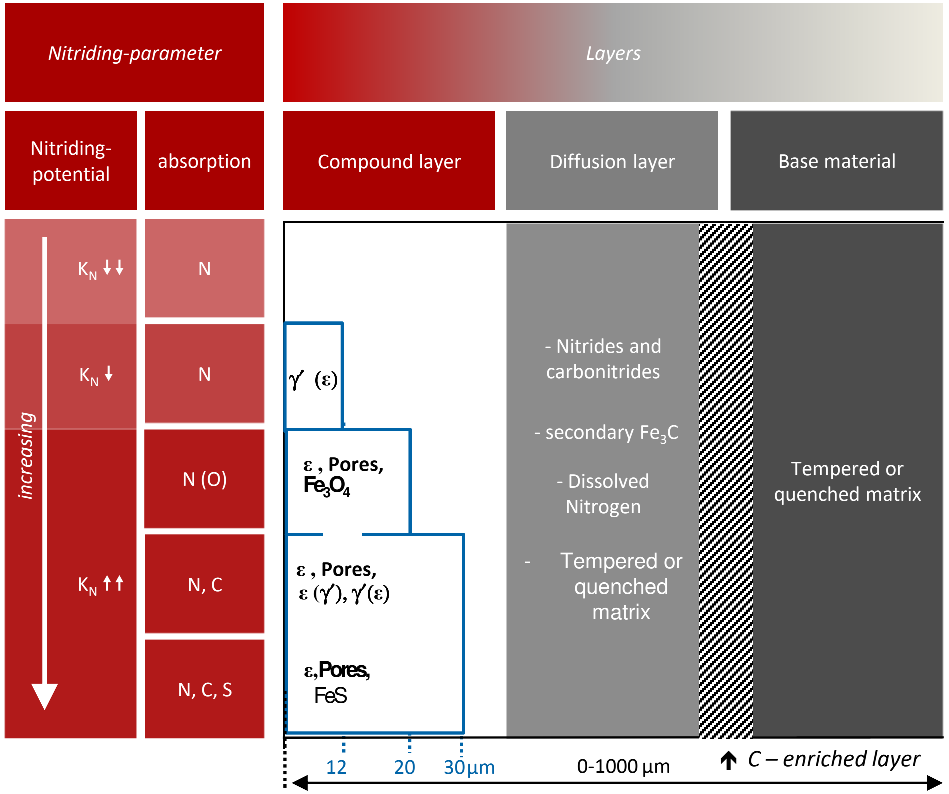




Nitriding / Potential

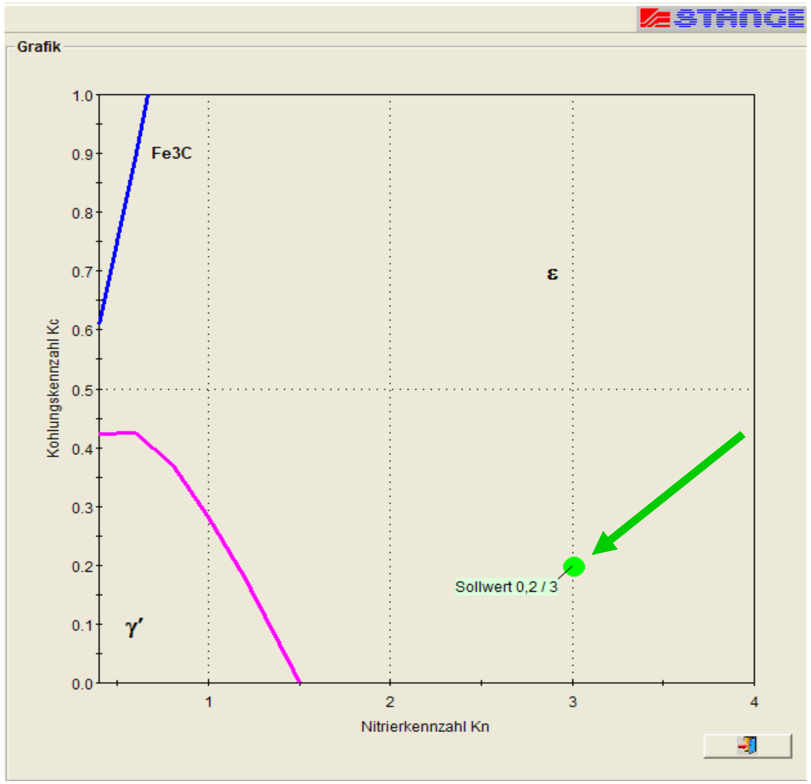
The thickness and phase structure of the compound layer as well as the thickness and hardness distribution of the diffusion layer can be changed in large ranges by the variation of the nitriding potential K_N, carbon potential K_C, oxidation potential K_O and the choice of the base material.

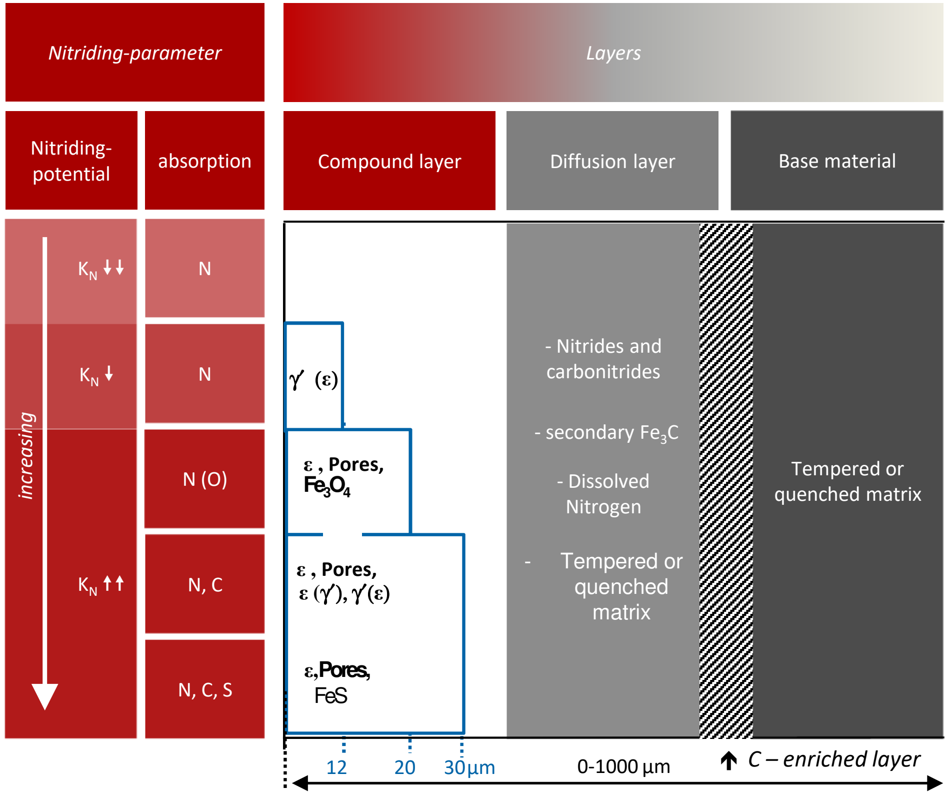




Nitriding / Potential

The thickness and phase structure of the compound layer as well as the thickness and hardness distribution of the diffusion layer can be changed in large ranges by the variation of the nitriding potential K_N, carbon potential K_C, oxidation potential K_O and the choice of the base material.

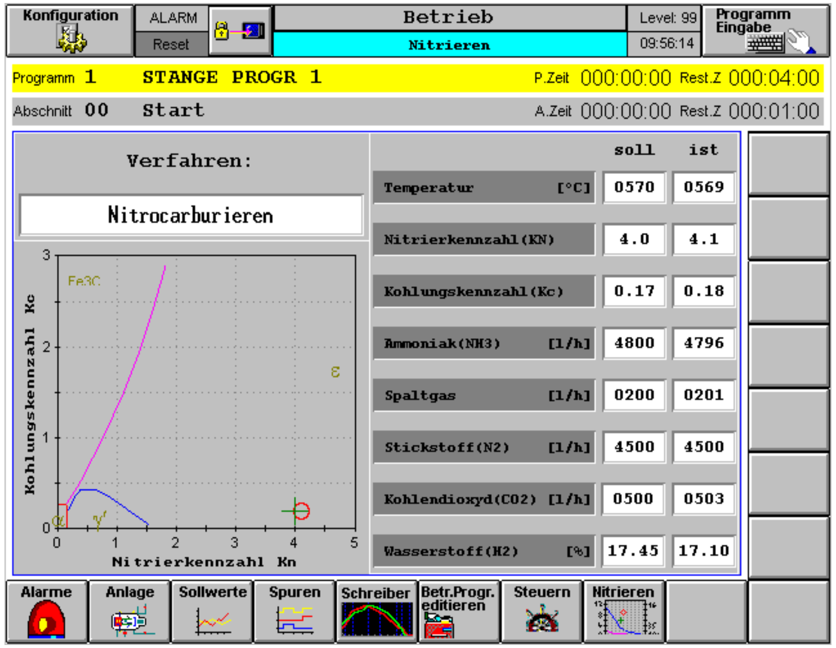


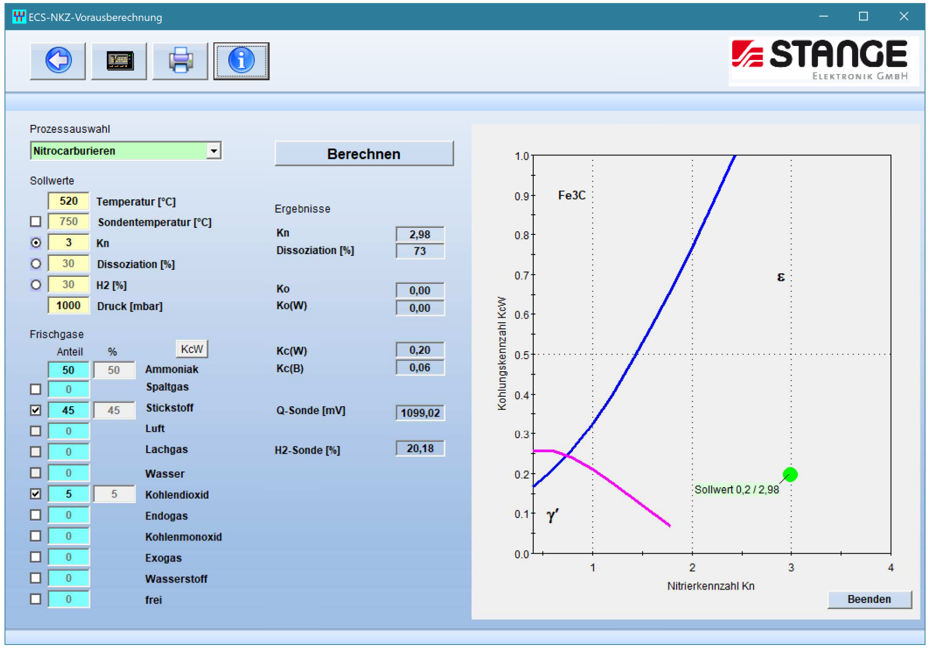


Nitriding / Potential

STANGE ELEKTRONIK GMBH

With the Lehrer- or Kunze- diagram the user can recognize in real time the layer creation of compound layer ε + γ´, γ´ depending of Kn, Kc, Ko and temperature.





Nitriding / Potential

SE-60X Series

Agenda SHTEs värmebehandlingskonferens

STANGE
ELEKTRONIK GMBH

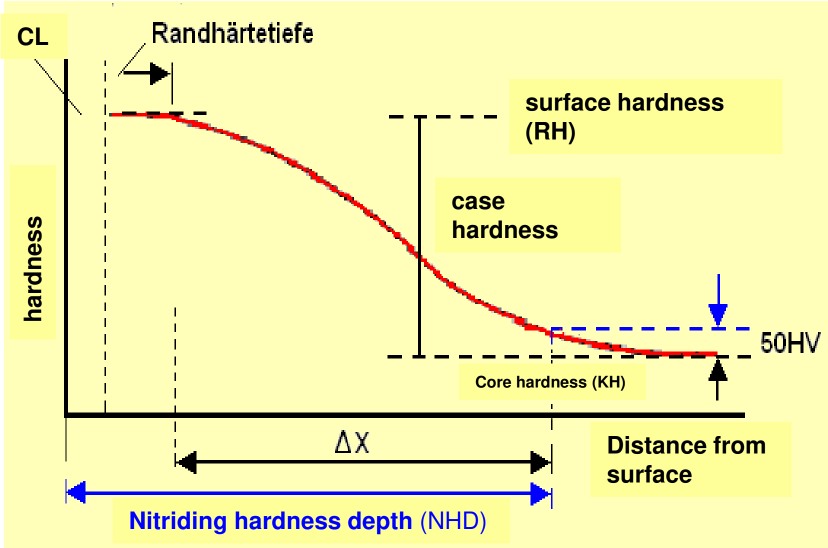
- Carburizing
- C-Level
- Diffusion
- Nitriding
- Potential
- **Nitriding case depth**
- Forcast

Nitriding / Case Depth

	CL	SH	ΔH	NHD	Rht	ΔX/Nht
Nitriding conditions						
T ↑	↑	=↓	=↓	↑	↑	↑
t ↑	↑	=↓	=↓	↑	↑	↑
Kn ↑	↑	=	=	=	=	=
Material						
Alloy Cr ↑	↓	↑	↑	↓↓	↑	↓
Al ↑	↑	↑↑	↑↑	=↓	↓	↑
C ↑	=↑	↓	↓	=↓	↓	↑
Micro structure N	=	=↑	↑	=	↑	↓
V(TA↑)	=	↓	↓	=	↓	↑

Schematic diagram of nitriding conditions and base material relating to nitriding result [2]

Definition for nitrided layers



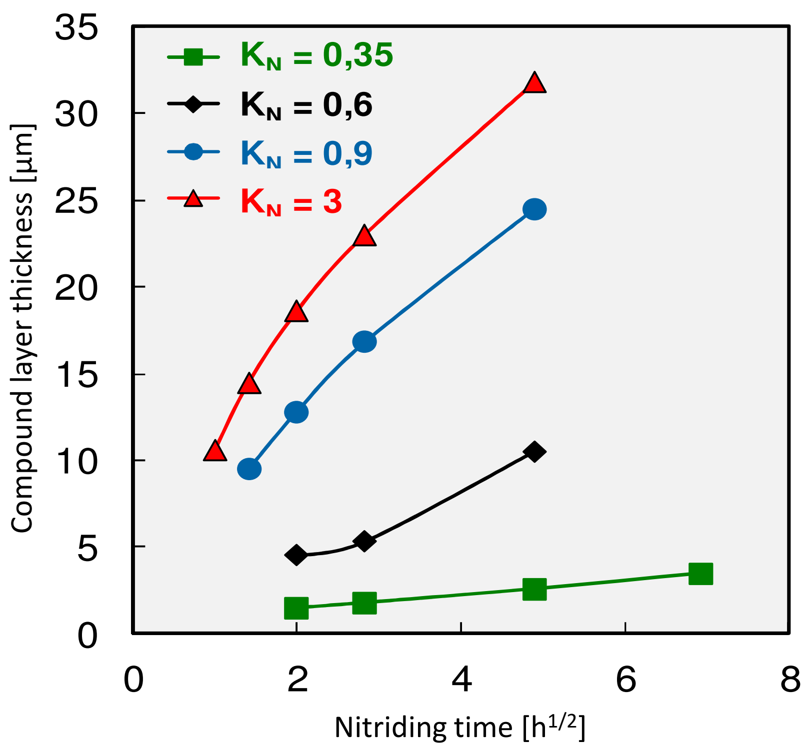
microstructure N normalized / V (TA) tempering temperature

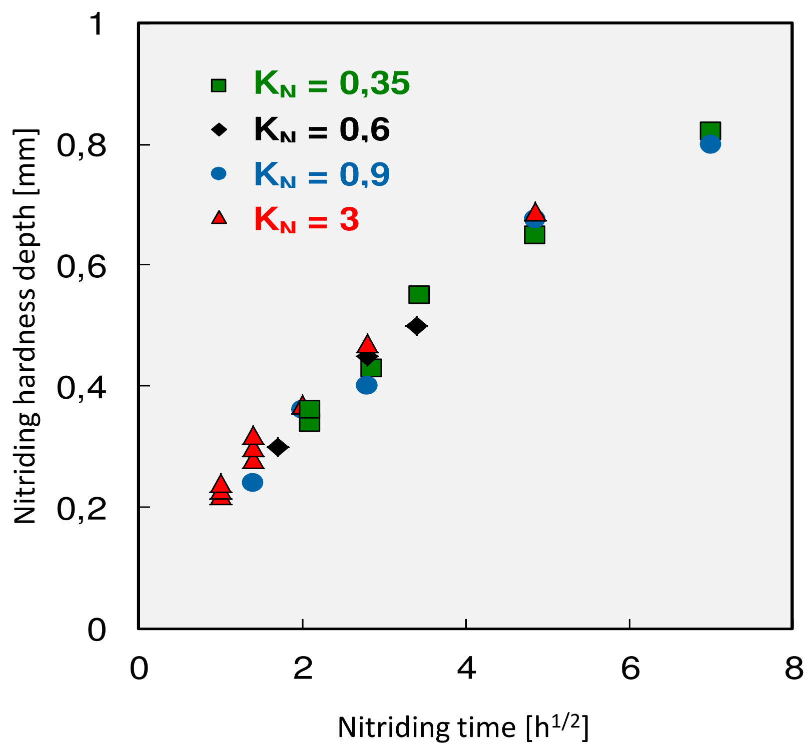
[2] HTM 47 (1992) page 229 ; Spies und Bergner

Nitriding / Case Depth

Grow of the compound layer vs. nitriding case depth

Steel: 42CrMo4 (V) (1.7225 / ~4140 SAE) 570°C (1058°F) / 1....48h / KN = 0.35......3,0





If Kn increases the compound layer grows too

Graphics courtesy of IWT, TU Bergakademie Freiberg

Nitriding / Case Depth

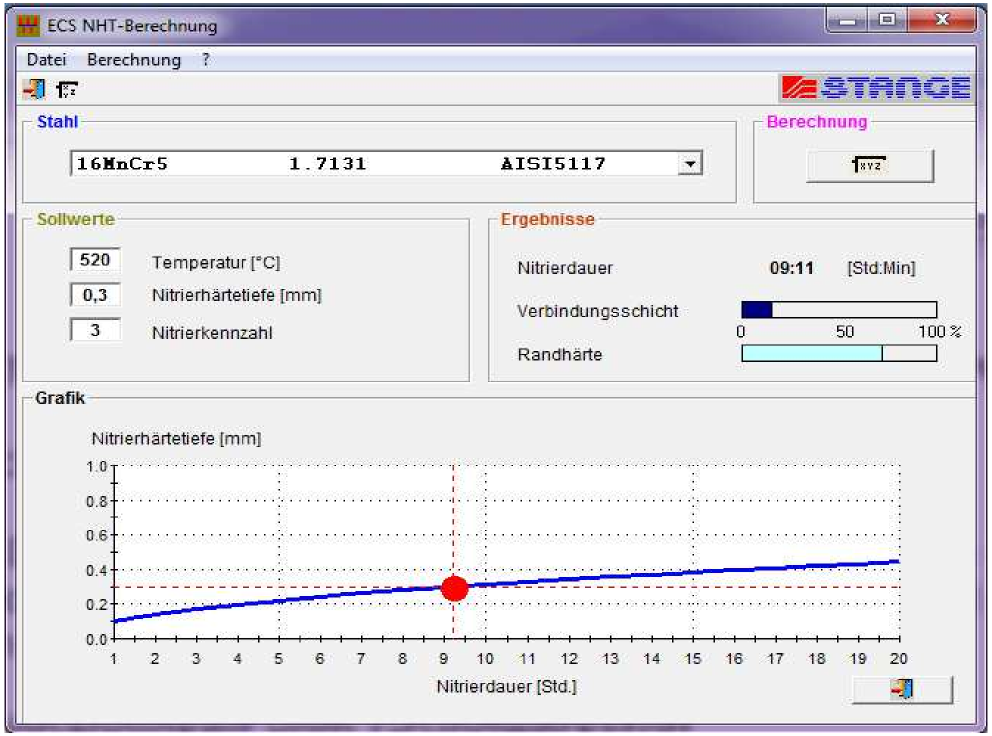
STANGE
ELEKTRONIK GMBH

The calculation of the nitriding hardness depth can be realized with our pc software

„ECS NHT – calculation"

The diffusion of nitrides and carbonitrides into the material is practically not depending on a certain nitriding potential.
With Kn > 1 the NHD can be calculated safely.

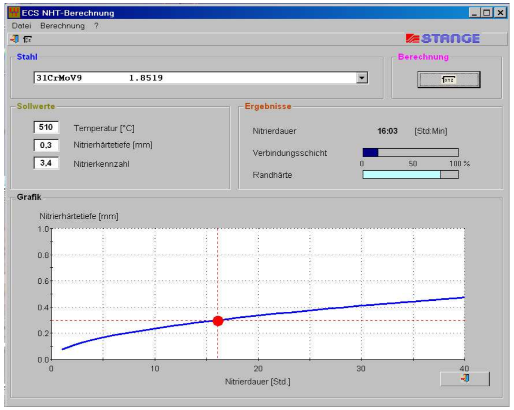
In accordance to the base material and soaking temperature the NHD as well the soaking time can be calculated.

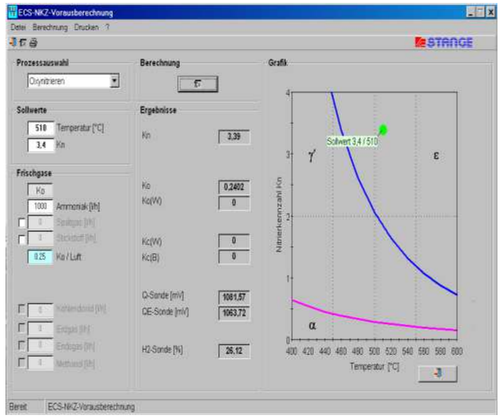


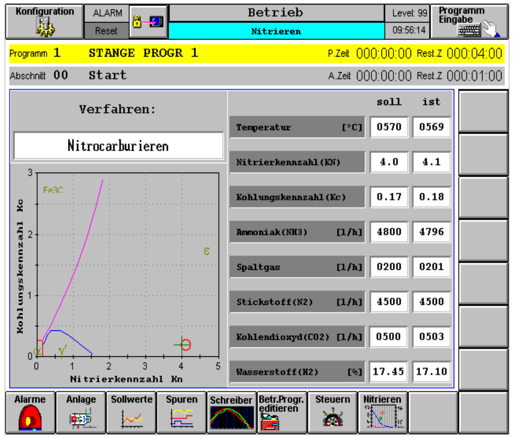
Nitriding / Case Depth

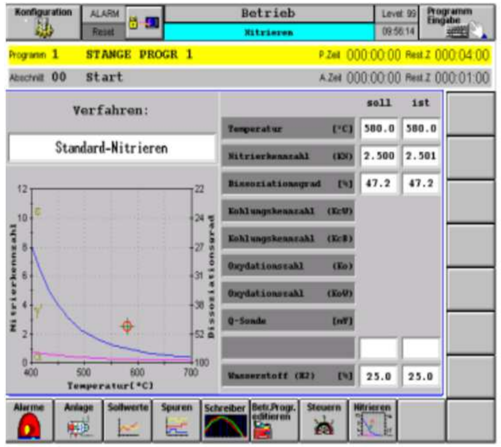
STANGE ELEKTRONIK GMBH

With our software program Nitriding Potential Calculation NKZ as well Nitriding Case Depth Calculation already good tools are available to achieve reproducible results





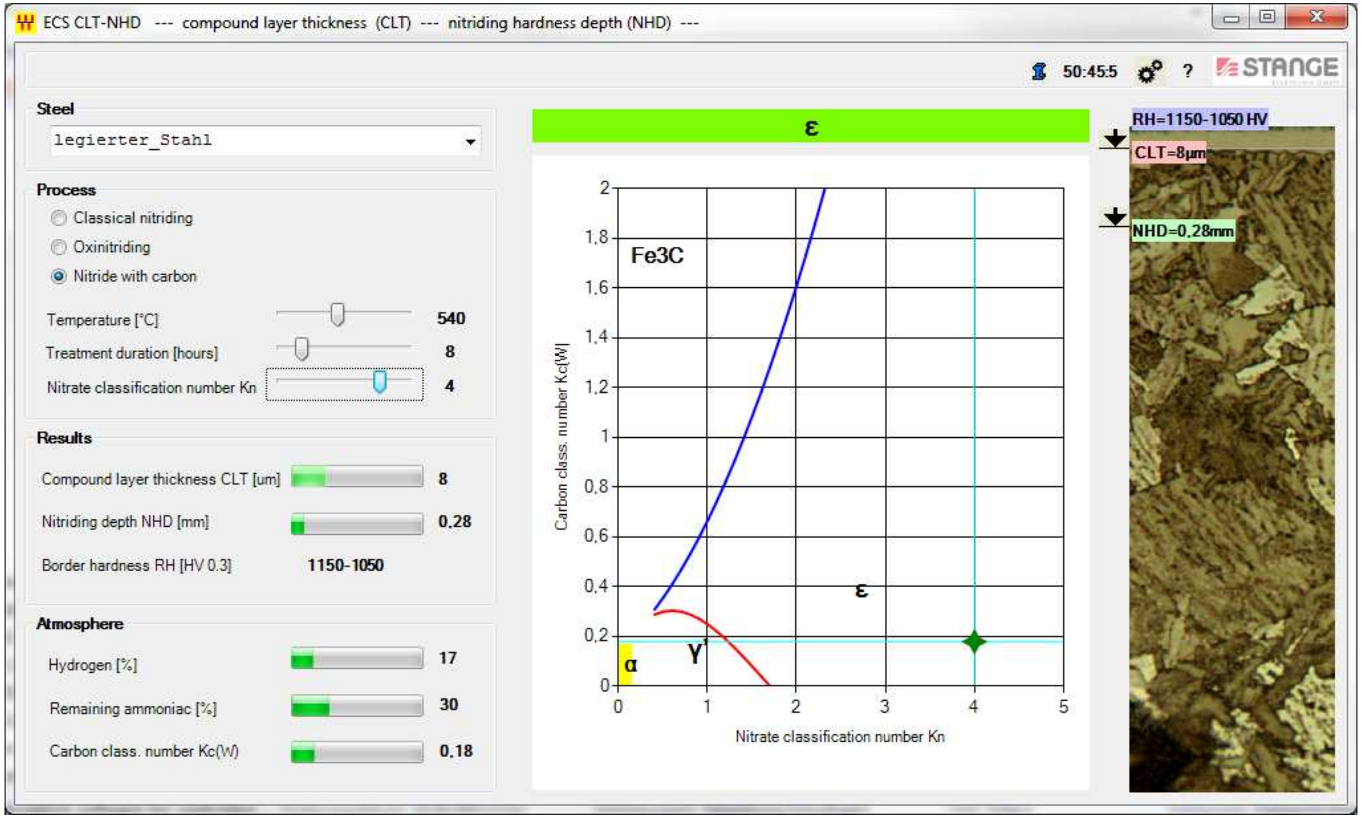




Nitriding / Case Depth

STANGE ELEKTRONIK GMBH

With the collected knowledge about diffusion processes and development of a material database like the calculation of the nitriding hardness depth =>
calculate the **growth of the compound layer**



Nitriding / Case Depth

STANGE
ELEKTRONIK GMBH

The calculation of the **growth of the compound layer** is based on many practical test results on different furnaces with different batches.

How we did this:

- Definition of the steel pieces and analysis of the alloying components
- Definition of the technological limits (temperature, time, nitriding potential)
- Definition of the technologie (nitriding, nitrocarburizing / oxynitriding)
- Test procedure / analyse of the results
- Comparision with other tests and results from praxis.

Nitriding / Case Depth

The principles which was won by the tests should give an orientation for the calculation of the

compound layer, nitriding hardness depth and case hardness.

They can‘t recognize the special environment at the user like:

- Pre treatment of the material like, washing, pre oxidation, etching
- Surface condition (grinded, turned, blasted...)
- Tempered / matrix
- Furnace specification like temperature distribution, gassing….

Further items:

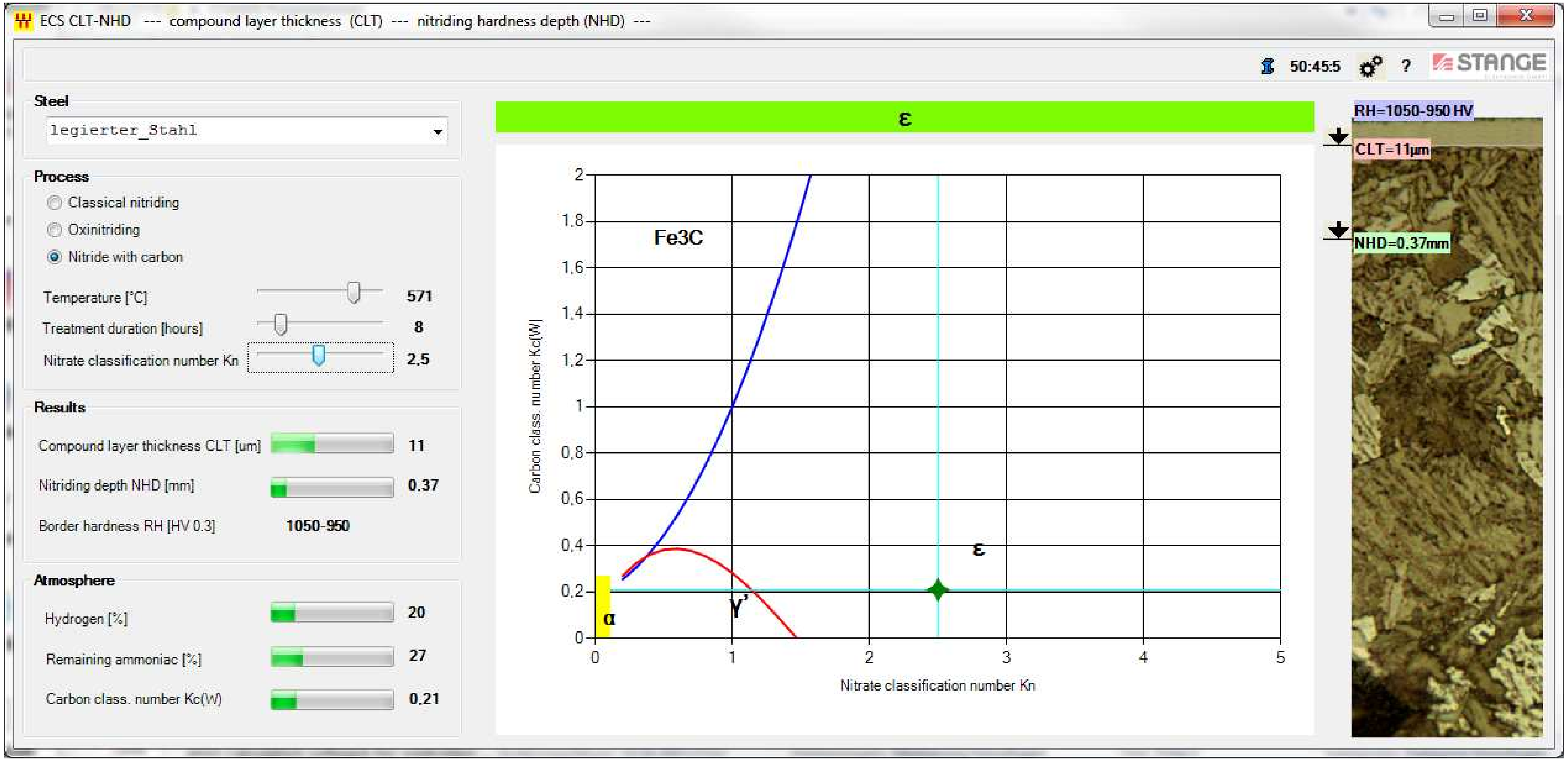
- *Thermodynamics and kinetics influences at creation of the nitriding*.

Controlled nitriding requires the control of both groups of influencing variables.

These influences are following usually certain tendencies in praxis.
These tendencies can be comprised with the help of corresponding correction factors.

Nitriding / Case Depth

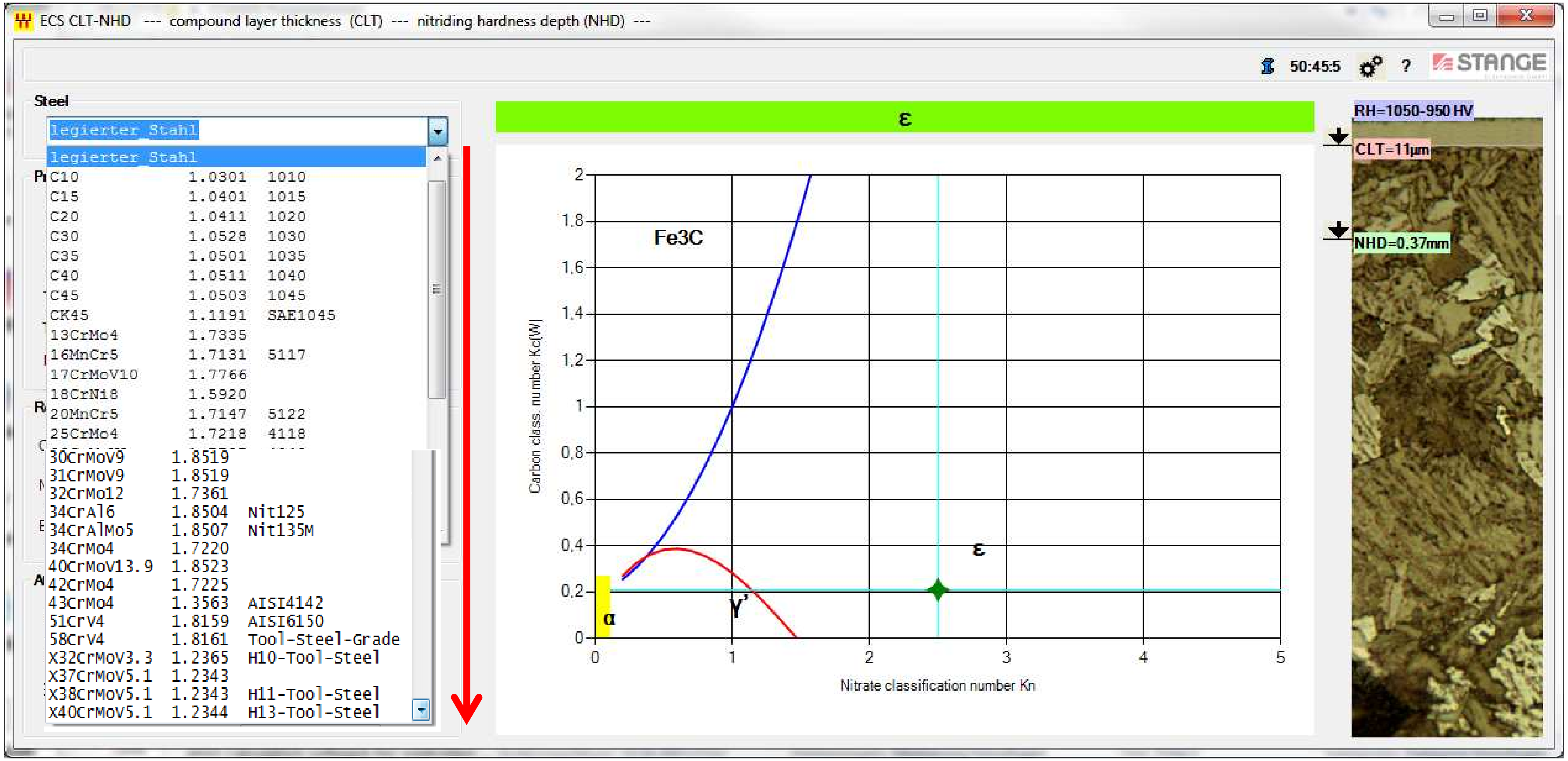
The pc software ECS CLT-NHD is the direct link between the part requirements and technological parameters of a nitriding treatment.



Nitriding / Case Depth

STANGE ELEKTRONIK GMBH

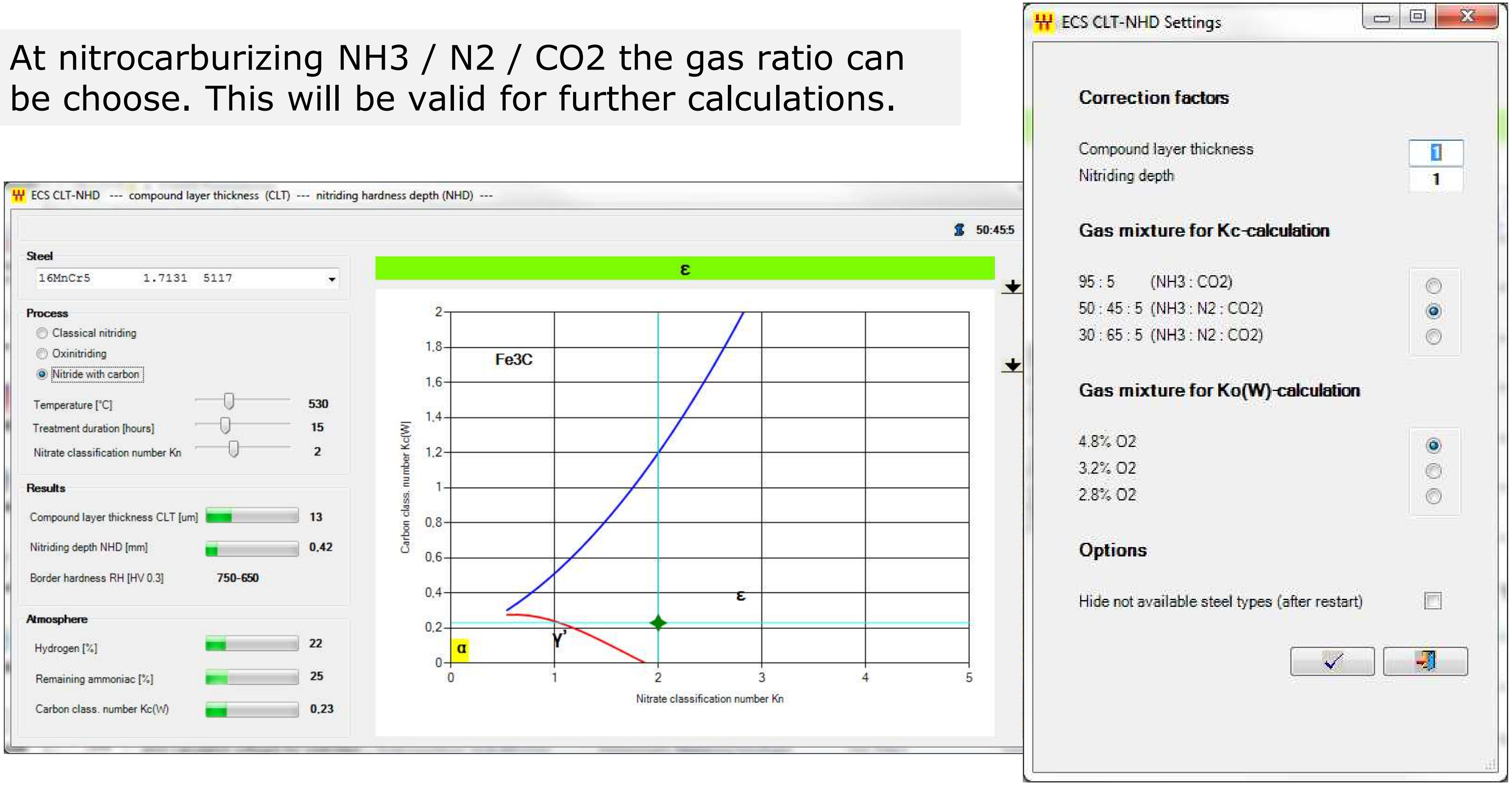
A material database with following steels is integrated:



Nitriding / Case Depth

By correction factors it is possible to correct the achieved results according to the compound layer growth and nitriding hardness depth.

At nitrocarburizing NH3 / N2 / CO2 the gas ratio can be choose. This will be valid for further calculations.



Nitriding / Case Depth

STANGE ELEKTRONIK GMBH

- For one steel mark we need to measure the compound layer thickness CLT, nitriding hardness depth NHD and hardness CH from following tests:

- Nitriding processes: Classical nitriding, oxy nitriding and nitrocarburizing
-> = 3 tests

- Per nitriding process we need to test at several treatment temperatures in the range between 480 °C up to 590°C (minimum 9)
-> 3 x 9 = 27 tests

- With each treatment temperature we need to test several treatment times in the range between 1h to 50h (minimum 10)
-> 27 x 10 = 270 tests

- The tests should be done with two different nitriding potentials (ideal: Kn 3 and Kn 0,8)
-> 270 x 2 = 540 tests

- For getting good base values to create interpolations between the several results every test need to be double checked with minimum one further test
-> 540 x 2 = 1080 tests!

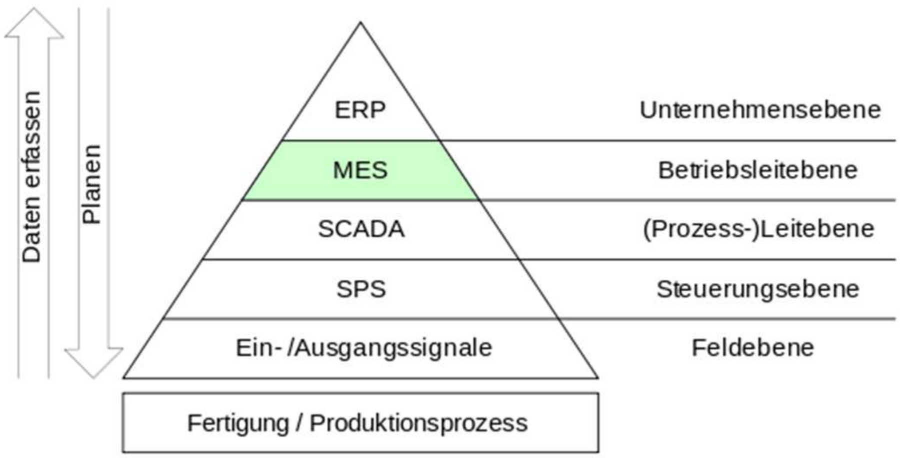
In total we need 1080 tests to for one steel mark in our database.

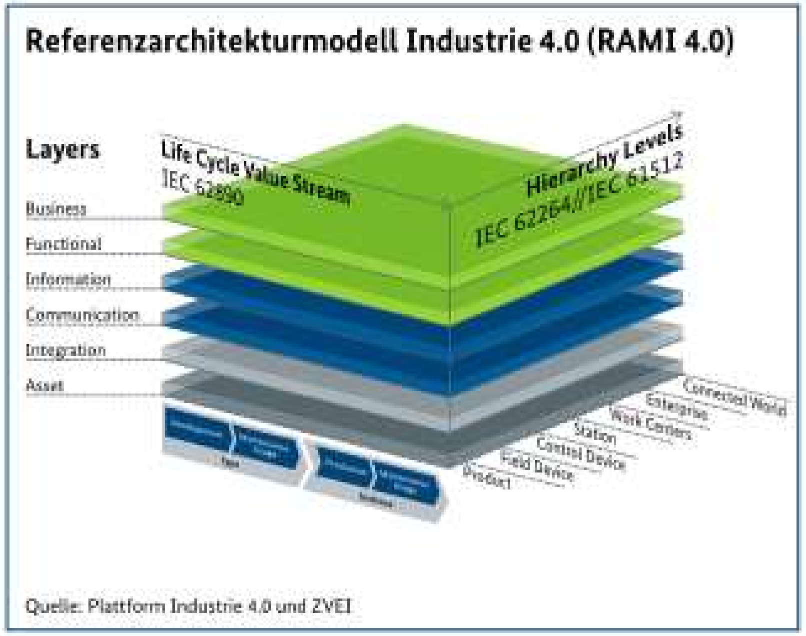
Agenda SHTEs värmebehandlingskonferens

- Carburizing
- C-Level
- Diffusion
- Nitriding
- Potential
- Nitriding case depth
- **Forecast**

Forecast

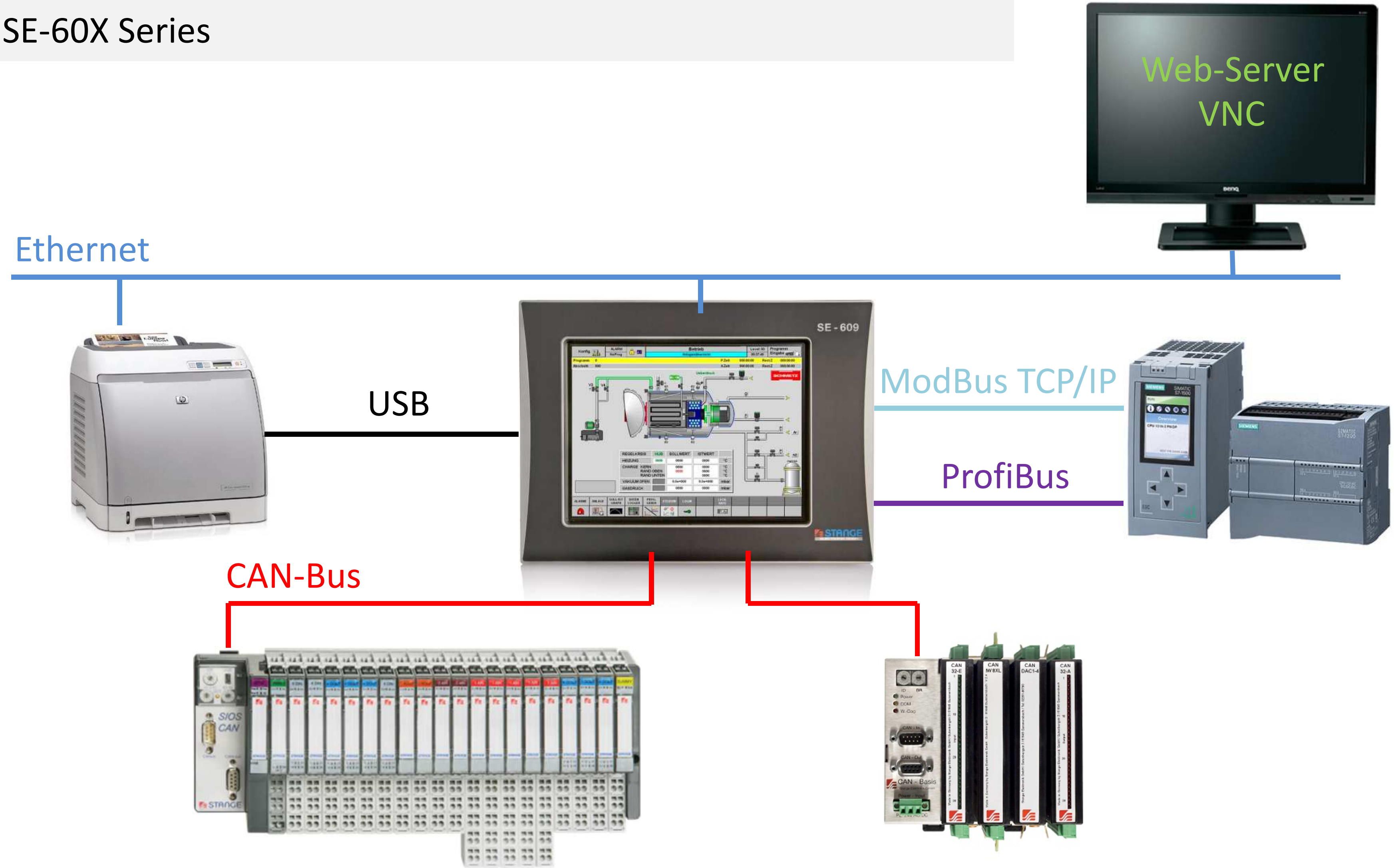
- Implementation of CLT-NHD calculation into controller software
- Implementation nitriding potential control into 7th generation
- Implementation CoDeSys / OPC-UA into 7th generation (Industry 4.0)





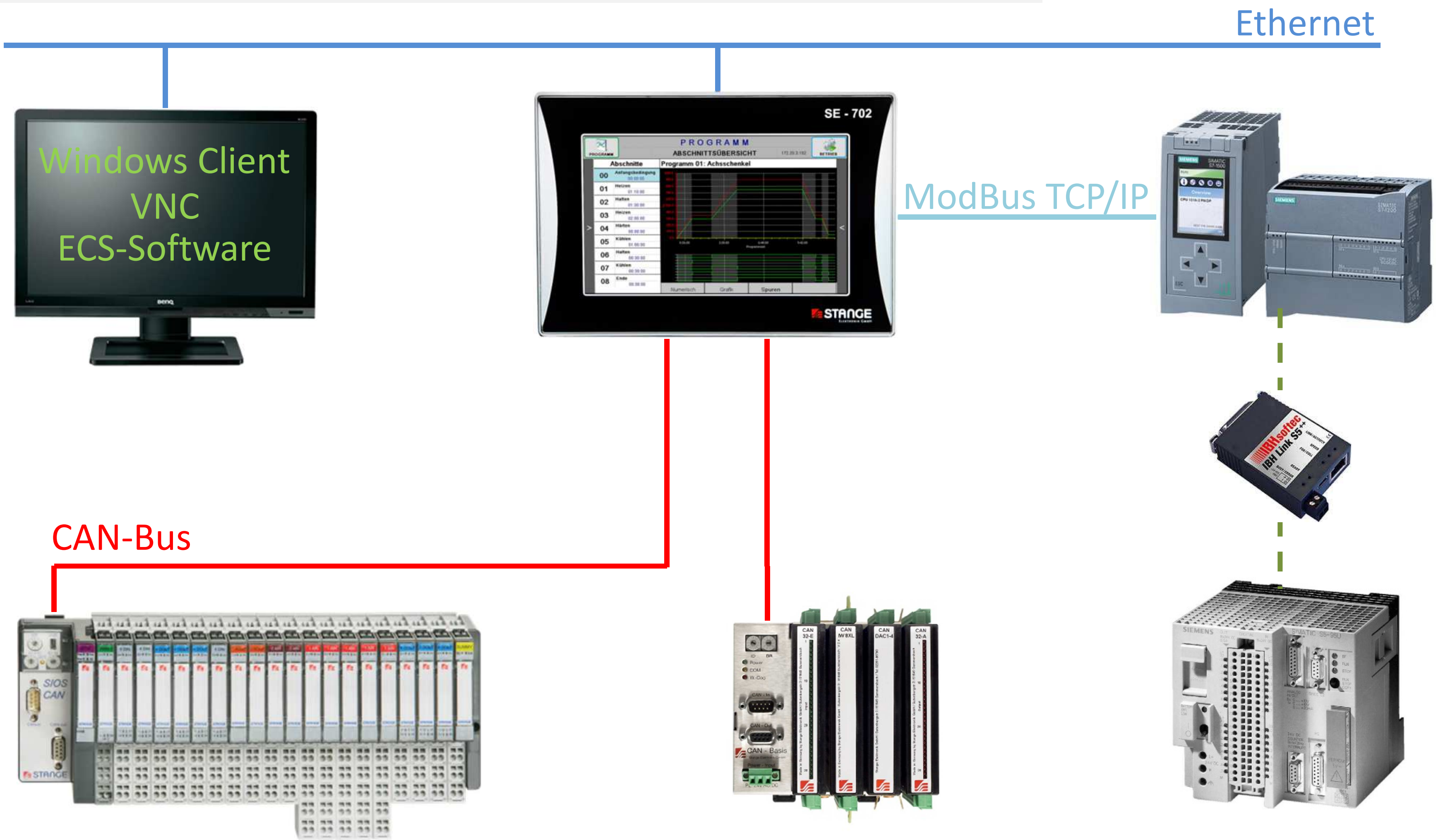
Carburizing / C-level

SE-60X Series



Carburizing / C-level

SE-70X Series



STANGE
ELEKTRONIK GMBH

Many thanks for your time!

Special thanks to „**Prof. Spies & Partner**" as well „**TU Bergakademie Freiberg Institute for Material Science**" for the support during the development of the pc software for calculation of the nitriding hardness depth and compound layer thickness.

Find us on:

www.stange-elektronik.com