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CHINA NATIONAL TECHNICAL DEVELOPMENT CENTRE OF GEARS

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THE PEOPLE'S REPUBLIC OF CHINA

Technical report : Gear materials and heat treatment.*

Prepared for the Government of the People's Republic of China
by the United Nations Industrial Development Organization,
acting as executing Agency for the United Nations Development Programme

Based on the work of Mr. Urs Wyss
UNIDO Expert

Backstopping officer : H. Seidel, Engineering Industries Branch

United Nations Industrial Development Organization
Vienna

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* This document has not been edited.

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1. INTRODUCTION

The first part of the assignement performed between 29th May and 5th June, 1987, (see Report, dated 1987-08-10) was mainly based on lectures on theoretical principles and some practical experiences but not sufficient allowance could be made for the field application because of lack of time. Therefore in the 2nd part from October to 15th November 1988 priority was given to practical application, especially to the reliable performance of the drip feed method of gas carburizing (item 2 of the list of content). The other subjects indicated in the list of content (item 3...10) have been presented as lectures and discussions and importance documents have been left at the Materials and Heat Treatment Department of ZRIME.

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2. RELIABLE PERFORMANCE OF DRIP FEED CARBURIZING

2.1. Preliminary remarks

The small carburizing furnaces are still in the same condition as I found them during the first part of my assignement in 1987. That means: The containers for methanol and isopropanol (or acetone) are arranged immediately above the furnaces (which may be dangerous). The carbon potential is controlled according to a CO_2-content of the funace atmosphere and measured by an infraread analyzer. Adding the two liquids is still made by fixing a distinct number of drops per minute of methanol and adapting the feed rate of isopropanol manually to the desired CO_2-content. In such a way the personnel has had an opportunity in the past to obtain a good feeling for the procedure but it cannot be regarded as an industrial method which would require an automatic control of the CO_2-content (or oxigen potential).

First I have observed the execution of a carburizing cycle as it is usually performed by the personnel, whereby I have noted and discussed inadequate measures.

Furnace: pit type, usable dimension Ø 450 x 600 mm.

Pieces to be carburized: 4 gears Ø 240/160 x 120 mm, z = 24
1 double gear Ø 400, z = 34
Ø 155, z = 16
steel: 18Cr2Ni4W

desired total carburizing depth: 1.7 to 2.1 mm

2.2. Loading: The work pieces are loaded when the carburizing furnace is preheated to the desired carburizing temperature of 925 °C. After closing the cover lid the feeding of methanol is immediately started. The heating rate of the pieces is rather high. Depending on the mass and shape of the pieces there is a risk of some deformation: For critical pieces (large differences in wall thicknesses) it is to be recommended to load the funace at a lower temperature (500..700°C). But under this condition it is necessary to start feeding methanol only when the thermocouple shows 750°C and then it would be an advantage to purge the furnace immediately after loading and closing the furnace with nitrogen to avoid too a great scaling effect.

2.3. Heating up, purging: Methanol and isopropanol are fed only drop by drop. This applied feeding rate corresponds to approximately 120 ml/h which is extremely low for purging. Inspite of the low feed rate the pressure in the furnace corresponds to 40..50 mm water columne whereas 10..20 mm would be sufficient. By increasing the feed rate to useful 300..600 ml/h in the purging periode the pressure would be much too high if only the small gas outlet is opened . This gas outled which is also used to extracting sample gas should have a larger diameter so that the exhaust rate can be increased. Another possibility would be to additionally exhaust the gas during the purging periode through the tube which is used for the shim stock test. In such a way the feed rate can remarkably be increased during the purging periode and the necessary time can be reduced.

2.4. Connecting the infraread analyzer:

The infraread analyzer is connected and sample gas is extracted from the furnace 2 hours after the furnace temperature has reached 925°C. At the begin the the CO_2-content is as high as 8 % (even higher) which corresponds to a water vapour content of approximately 11 % and a dew point of 50°C. This means that condensation of water appears at room temperature, e.g. in the tubes and filters. The filter near the furnace is filled with cotton. This cotton begomes humide or even wet and can absorb a small amount of CO_2. Therefore the CO_2-content measured by the infraread analyzer may be a little lower than in reality in the furnace. This may lead to a C-potential which is a little lower than intended. After 40 minutes the CO_2-content amounts to 0.40 % and this is the moment from which the staff used to calculate the carburizing time. Within 10 to 25 minutes a CO_2-content of 0.22 % is reached. The staff uses this CO_2-content to control the desired C-potential of 1.0 to 1.1 %. But according to the formula

$$\lg \frac{p_{CO}^2}{p_{CO_2} \cdot a_C} = - \frac{8817}{K} + 9.071 \qquad (1)$$

a CO_2-content of 0.22 % at 925°C, based on a CO-content of 33 % would lead to a a C-potential of 1.23 %, which is very near to the soot limit. In addition, as the solubility limit of carbon in austenite of the applied steel is lower than that of plain carbon steels the set CO_2-value is too low. In any case it is dangerous to work with so high a C-potential resp. with so low a CO_2-content because of soot and carbide formation.

2.5. Carburizing (boost) periode:

The feeding of methanol and isopropanol is made drop by drop empirically and a nearly constant CO_2-content can be maintained with only very small waves of the recorded line which are due to the temperature regulation. A foil test sample was sooty and showed a carbon content of 1.26 % what approves the statement that the CO_2-content of 0.22 % is too low and could lead to carbide formation. The feed rate of methanol can be increased to 200..300 ml/h during the carburizing periode as compared with the very low feed rate applied up to now.

2.6. Diffusion periode: After 8 h the CO_2-content has been increased to 0.30 % with the intention to decrease the C-potential to a value of 0.80 %. But according to formula 1 (section 2.4) the necessary CO_2-content for a C-potential of 0.80 % would be 0.39 %. Therefore the case carbon content must become too high (0.98 % C). By using pure methanol in the diffusion periode it may be difficult, even impossible, to reduce the C-potential within a useful short time. Therefore methanol with a water addition of 3..4 % should be used.

2.7. Cooling: Before the load is transferred into the cooling pit (which is water cooled) the furnace temperature is decreased to 850 °C while methanol is fed without controlling the C-potential. With decreasing temperature the corresponding CO_2-content of the gas has to be increased and should be at 850 °C 0.90 % to maintain the desired C-potential of 0.80 %.

We can assume that after the diffusion periode the C-potential was too high (0.98 %). During cooling to 850 °C and feeding methanol it is very probable that the CO_2-content did not increase high enough to decrease the C-potential. Therefore the surface carbon content must have been far too high.

To reach the desired surface carbon content some more considerations have to be taken into account, see section 2.9. To be sure that the desired surface carbon content is attained the temperature of 850 °C should be maintained constant for approximately 1.5 h while the corresponding CO_2-content of the gas is controlled. After that the load can be transferred into the cooling pit.

A better solution than a water cooled cooling pit would be a heatable cooling pit to have the possibility to interrupt the cooling at 600 °C for an isothermal transformation of the austenite into ferrite and pearlite. But for the applied 4 % Ni-steel with 2 % Cr the necessary transformation time would be extremely long and therefore a continuous cooling is acceptable. The case will transform into martensite and some retained austenite will be left. After cooling to room temperature an annealing treatment has to follow at 610..640 °C to improve the machinability.

2.8. Reheating to hardening temperature: The staff used to perform this treatment just by feeding methanol without controlling the C-potential. This is very dangerous because of the decarburizing effect. The reheating periode to the hardening temperature has to be used also to adjust the surface carbon content to the desired value.

After loading the preheated furnace (850 °C) with the carburized pieces the furnace has to be purged fast with methanol (containing 3..4 % water). The feed rate may be as high as 400..600 ml/h (small furnace 400, larger furnace 600 ml/h). When the hardening temperature is nearly reached the C-potential can be controlled by feeding acetone according to the CO_2-content which corresponds to the desired C-potential.
From sections 2.6 and 2.7 emerged that the surface carbon content would be far too high. But reheating to hardening temperature was performed up to now obviously under decarburizing conditions so that the high carbon could not be noticed. The too high surface carbon content after carburizing must be the reason why this decarburizing effect was not very harmful.

2.9. Necessary surface carbon content: The applied steel with 4 % Ni and 2 % Cr will show very high amounts of retained austenite and ev. carbides if the C-potential during the diffusion periode is too high. A test sample taken from the load after cooling to room temperature proved this and showed a surface layer of 100 % retained austenite and some carbides.

To avoid too much retained austenite the surface carbon content for this steel should be not higher than 0.75 %. The necessary C-potential must be lower and can be calculated e.g. according to S. Gunnarson:

$$\lg \frac{C_p}{C_L} = 0.055\cdot\%\,Si + 0.014\cdot\%Ni - 0.013\cdot\%Mn - 0.040\cdot\%Cr - 0.013\cdot\%Mo$$

(No factor could be found for W but its effect may be similar to that of Mo)

The alloy factor (C_L/C_p) for this steel will be approximately 1.07 so that the C-potential corresponding to the equilibrium C-content of 0.75 % may be as low as 0.70 %.

2.10. Measuring the case depth: The first measurement was made through a microscopical examination of a test sample whereby the total case depth (approximately the visible end of the transition zone) is estimated. This is only a rough and non accurate method. Correct values can be attained by measuring the hardness profile for which the necessary equipment is available in the Materials Department.

2.11. Is the applied steel best suited ? The applied steel with 4 % Ni and 2 % Cr (+ W) is overalloyed for the size of the treated pieces, also for high duty applications. Too much alloying elements are waisted. To ecomomise alloying elements the upper alloy content of case hardening steels can be derived according to my paper "Relationship between carbon- and hardness profiles in case hardened steels".

2.12. Recommendation: For testing more often directly the carbon potential of furnace atmospheres with iron foils (0.05..0.10 mm thick) and for determining carbon profiles of test samples it is necessary that the Heat Treatment Department can dispose of its own instrument and a suitable analytical balance for checking the carbon content. It is essential that the responsible staff has such an equipment in hand so that test results are rapidly available. This is also very important during the launching periode of the new gas carburizing furnace which will be computer controlled. The test results have to be carefully evaluated and recorded. In such a way valuable information and experience can be gained within a short time.

3. NEW PIT TYPE GAS CARBURIZING FURNACE

A new pit type gas carburizing furnace, manufactured by "THE XIAN ELECTRIC FURNACE INSTITUTE", is now installed in the Heat Treatment Department but is not yet put in operation. A computer system for controlling the carbon potential and the carbon profile is also ready but the necessary soft ware is still lacking. The usable dimension of this furnace is Ø 1200 x 2400 mm.

I found the following deficiencies:

a. The exhaust gas tube ends at the bottom of the cover lid above the upper baffle. From the space between upper baffle and the cover lid is extracted the sample gas for the infraread analyzer. This tube should end somewhat below the upper baffle to extract the sample gas which has already passed the load.
b. The cooling water channel (rectangular tube) is closed. This closed channel will soon be plugged with lime precipitation. An open water channel which allows cleaning would be better.
c. The cooling pit is water cooled and does not allow an isothermal transofmation to ferrite and pearlite. A heatable cooling pit would be an advantage.

4. DISTORTION

The influence of the hardenability of steels as well as the basic influence of carburizing and hardening on the tendency of the shape and size distortion has been explained and discussed. Several figures representing such examples have been left at the Heat Treating and Materials Department.

5. SELECTION AND SPECIFICATICN OF THROUGH HARDENING STEELS

The influence of microstructure resulting from hardening and tempering on the mechanical properties has been explained. It was emphasized that the hardenability is the key-property for selecting through hardening steels. National and international standards are based on this property. The contents of a guideline for selecting through hardening steels and of a specification, taking into account various test methods and requirement levels, have been explained. One example of a specification including a guideline was left at the Materials Department of ZRIME.

6. SELECTION AND SPECIFICATION OF CARBURIZING STEELS

The selection of carburizing steels for various dimensions and quenching severities especially as a function of the case hardenability has been explained and discussed thoroughly. The calculation of the case hardenability has been demonstrated. A specification for a carburizing steel taking into account various requirement levels was left at the Materials Department of ZRIME.

7. ULTRASONIC TESTING

Internationally applied guideline containing also acceptance criteria for gears from steels forgings and rolled bars have been shortly discussed. A corresponding document was left at the Materials Department of ZRIME.

8. QUALITY ASSURANCE

There is no quality assurance system established in the Materials and Heat Treatment Department and obviously also not in ZRIME which would correspond to one of the below menticned models. It is strongly to be recommended that a quality assurance system according to ISO 9000... is implemented under the guidance of a responsible engineer (full time job).

The following documents have been explained, discussed and left to the Materials and Heat Treatment Department:

ISO 9000: Quality management and quality assurance standards - Guide lines for selecting and use.

ISO 9001: MODEL ONE for quality assurance in design/development, production, installation and servicing. It is used when the contract specifically requires design effort and the product requirements are stated (or need to be stated) principally in performance terms.

ISO 9002: MODEL TWO for quality assurance in production and installation. This model is more compact. It is for use when the specified requirements for products are stated in terms of an already-stablished design or specification.

ISO 9003: MODEL THREE for quality assurance in final inspection and test. It applies to situations where only the supplier's capabilities for inspection and tests (conducted on product as supplied) can be satisfactorily demonstrated.

9. LECTURES

On 30th October 1988 I have given lectures to the relevant staff of THE LUOYANG MINING MACHINERY PLANT in Luoyang and on 8th October 1988 to the HENAN BRANCH OF THE HEAT TREATMENT INSTITUTION OF the Chinese Mechanical Engineering Society in Zhengzhou on the following subjects:

- Relationship between carbon- and hardness profiles in case hardened steels
- Principles of distortion.

On 11th November 1988 I have given to the relevant staff of THE XIAN METALLURGICAL MACHINERY WORKS in Xian Lectures on the following subjects:

- Survey on the application field of various heat treatment methods in respect of bending endurance linit, pitting endurance limit and costs.
- Relationship between carbon- and hardness profiles in case hardened steels and selection of such steels as a function of dimension and quenching severity.

All these subjects have been presented and thoroughly discussed also with the staff of the Materials and Heat Treatment Department.

10. CONCLUSION AND RECOMMENDATIONS

I have got a very good impression of the young staff of the Materials and Heat Treatment Department composed of very motivated and capable young Engineers guided by Mr. Chen Guomin. This crew should approach step by step from their habitual practice to the recommended procedure, recording and evaluating the test results of all carburizing cycles carefully and continuously.

Based on my observations I recommend the following:

a. Concerning the reliable performance of drip feed carburizing:
   - Increasing the feed rate of methanol to accelerate the purging process (section 2.2/2.3) after loading the furnace.
   - Increasing also the feed rate of the carburizing liquid (isopropanol or acetone) carefully to reduce the time to attain the necessary CO_2-content of the furnace atmosphere. This recommendation refers as well to the reheating to hardening temperature (2.8.)
   - Correct CO_2-values have to be set during the whole carburizing cycle taking into account also the alloy factor "C_L/Cp" (2.5...2.9).

b. The applied steel for the treated gears seem to be rather overalloyed. A carburizing steel with a lower alloy content would be sufficient (2.11.).

c. The Heat Treatment Department has to be provided with an equipment for checking the carbon content of steels (2.12).

d. It is suggested to make a few improvements on the new pit type gas carburizing furnace made by the Xian Electric Furnace Institute (3)

e. A quality assurance system has to be implemented at ZRIME (8).

APPENDIX A

Schedule

Date	Day	Place	Aktivities
21.10.88	Fri	Vienna	Briefing in Vienna. (Zurich-Vienna-Zurich)
24.10.	Mon	Zurich	Departure 12.45 h } SR 192
25.10.	Tue	Beijing	Arrival 11.25 h }
26.10.	Wed	Beijing	Briefing UNIDO-Office (Mr. K.S.Stephens, Ph.D.)
27.10.	Thu	Beijing	Discussion plan for instructions with Mr. Chen G.M. Director Materials and Heat Treatment Dep. ZRIME 19 h Departure by train for Zhengzhou
28.10	Fri	Zhengzhou	morning: arrival, rest afternoon: welcome at ZRIME by directors, free general discussions
29.10	Sat		Work in the Materials and Heat Treatment Department afternoon travel by car to Luoyang
30.10	Sun	Luoyang	Lectures and discussions at Luoyang Mining Machinery Plant.Afternoon works visit
31.10.	Mon		Sigthseeing Luoyang; afternoon back to Zhengzhou
01.11. through 05.11.	Tue Sat	Zhengzhou	Work in the Materials and Heat Treatment Department of ZRIME
06.11.	Sun	Kaifeng	Sightseeing
07.11. 08.11.	Mon Tue	Zhengzhou	Work in the Materials and Heat Treatment Department of ZRIME
09.11.	Wed		Some work, leave-taking, evening train for Xian
10.11.	Thu	Xian	Visit Xian Metallurgical Machinery Works. Lectures, work visit
11.11.	Fri		continue work visit
12.11.	Sat		morning: sightseeing, afternoon departure by air for Beijing
12.11.	Sat	Beijing	Arrival
13.11.	Sun		rest, writing report
14.11.	Mon		writing report, rest
15.11.	Tue		evening departure for Zurich
16.11.	Wed	Zurich	Arrival

APPENDIX B

List of Senior Staff Members met at the ZRIME

Mr. Zhu Ji-Jun	Director ZRIME
Mr. Wu Jixun	Chief Engineer
Mr. Wang Shengtang	Director Gear Division, responsible for UNDP
Mr. Tao Yan-Guang	Vice Chief engineer
Mr. Tang Dingguo	Chief Engineer, Gear Division, Professor
Mr. Chen Guomin	Director Materials and Heat Treatment Departm.
Mr. Ma Xinqing	Director Heat Treatment Department
Mr. Chen Bao Jia	Vice Director, National Gear Quality Control Centre
Mr. Li Zazhou	Director 2nd Department Gear Division

List of Participants at the Instructions in the Materials and Heat Treatment Department

Mr. Chen Guomin	Director Materials and Heat Treatment Department
Mr. Ma Xinqing	Director Heat Treatment Department (partially)
Mr. Chen Nai Lu	
Mr. Gao Jie	
Mr. Gao ...	
Mr. Ma Xiang Dong	
Mr. Niu Wan Bin	
Mr. Yian Man Gang	
Mr. Zhang ..	
Mr. Ching ..	
Mr. Guo Wen Xing	Senior Engineer, Taiyuan Heavy Machinery Plant
Mr. Lin Yahgtuo	Nanjing High Speed Gear Factory

and others

Senior Staff Members met at the Luoyang Mining Machinery Plant

Mr. Zhong Fu Xin	Director, Senior Engineer
Mr. Yao Deguang	Director, Chief Enggineer Office
Ms. Wang Jingfen	Engineer, Comprehensive Technical Department

Senior Staff Members met at the Xian Metallurgical Machinery Works

Mr. Luo Bangzhi	Chief Engineer
Mr. Song Tieshi	Plant Office Reception Section Chief
Mr. Zhan Xiangren	Chief Engineer, Office Director
Mr. Huang LIren	Vice Master, Mechanical Engineering

APPENDIX C

List of Documents left at the Zengzhou Research Institute of Mechanical Engineering

- 2 Copies of the German version of the MAAG GEAR BOOK: Maag-Taschenbuch.
- 1 copy of the Monography "Plasma Heat Treatment - Science and Technology" containing the papers presented at the International Seminar of the IFHT, Senlis (F).
- ISO Standards on Quality Assurance:
  ISO 9000, 9001, 9002, 9003
- Example of a Quality Programme Manual
- Example of "Specification and Selection of through hardening steels"
- Example of "Specification for Carburizing Steels"
- Specification and acceptance standard for ultrasonic testing of gears.
- Figures and tables from foils for overhead projection I used for my presentations.