„LPC – Outsourcing“ – vacuum case hardening with superior distortion-control as a service

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1. Introduction

For decades manufacturers of precision parts used atmosphere batch furnaces with integral oil quenches for the case hardening process.

In recent years, Low Pressure Carburizing (LPC) in combination with High Pressure Gas Quenching (HPGQ) has become a preferred technology for the treatment of transmission components. By using this modern process, manufacturing costs can be reduced because improved distortion control results in lower costs for hard machining and/or straightening operations.

The manufacturers have the option to either heat treat inhouse or to outsource the heat treatment.

This paper presents insight into the LPC-technology with a focus on distortion control. Ways and means how to assure quality of the treated parts are briefly described and an option for the individual labelling of treated components is introduced.

2. LPC-Outsourcing

LPC is a case hardening process which is performed in a pressure of only a few millibar using acetylene as the carbon source in most cases. During HPGQ the load is quenched using an inert gas-stream instead of a liquid quenching media. Usually nitrogen or helium are used as quench gas [LOES05, HEU13].

LPC case-hardening is applied both inhouse and externally at commercial LPC service centers. The outsourcing of LPC has become more popular in recent years. The advantages of outsourcing are:

- No investment in heat treatment equipment and the required infrastructure
- No additional staff to conduct heat treatment operations, laboratory or maintenance
- Access to the latest state-of-the-art heat treatment technologies without expenditures for development
- A certified quality control program tailored to meet customer requirements
- Heat treatment costs are predictable and generally at a fixed price.

However there are some disadvantages too, such as loss of heat treatment as a core production competence and heat treatment cannot be integrated into the production line. Higher transportation costs and possibly increased inventory management requirements should be taken into account as well. Therefore each option should be carefully analyzed to decide if the outsourcing of heat treatment is an advantage for all parties involved.

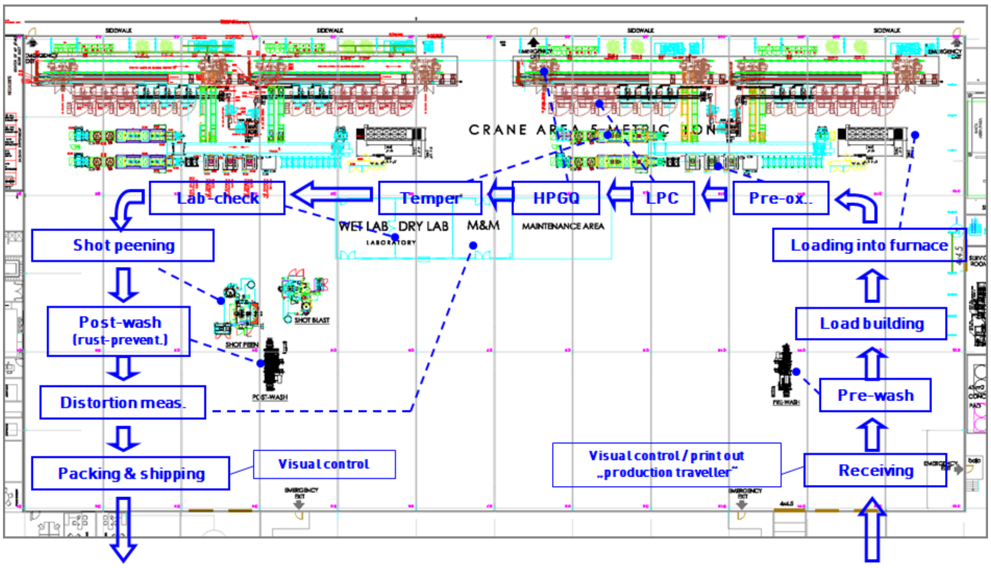

Fig.1: Flow of production in a LPC service-center

Fig. 1 shows the flow of production in a LPC-service center. ALD Vacuum Technologies group runs three service-centers: VACUHEAT GmbH near Chemnitz in Germany, ALD-TT near Detroit in USA and ALD-TT near Saltillo in Mexico. These service-centers work closely together with providers of green and hard-machining equipment. With the specific knowledge in the field of distortion control, this provides an excellent network for the development of new transmission components and prototypes. Especially for the development of new generation of transmissions for electrified vehicles such a R&D-network proves to be valuable.

3. Advanced distortion control

By applying the technology of Low Pressure Carburizing (LPC) and High Pressure Gas Quenching (HPGQ) heat treat distortion can be significantly reduced. Conventional quenching-technologies such as oil- or polymer-quenching exhibit inhomogeneous cooling conditions. Three different mechanisms occur during conventional liquid quenching: film-boiling, bubble-boiling and convection. Resulting from these three mechanisms the distribution of the local heat transfer coefficients on the surface of the component is very inhomogeneous. These inhomogeneous cooling conditions cause tremendous thermal and transformation stresses in the component and subsequently distortion. During HPGQ only convection takes place which results in much more homogenous cooling-conditions [STI95, HEU13].

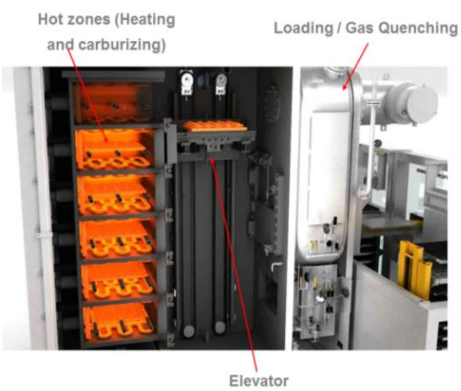

Fig. 2: Heat treat system for 2D-treatment; schematic view into the system

Significant reductions of distortion by substituting Oil-quench with HPGQ have been published [ALT05].

Lately new furnace concepts for single layer treatment have been established, see Fig.2. In the beginning, the focus was to integrate and synchronize heat treatment into the manufacturing line ("One Piece Flow production" - philosophy) with this furnace concept. In addition, recently so called "small batch production" offered by external LPC-service centers has been established as well.

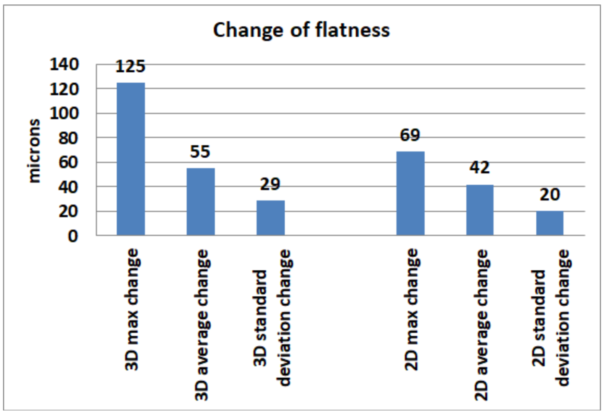

Fig. 4: Change of flatness during LPC-heattreatment of Final Drive Ring gears; comparison between 3D - treatment and 2D-treatment

In comparison to treatment of big batches in multiple layers (3D-treatment), the single layer treatment (2D-treatment) provides even more

– homogenous and rapid heating of the components,
– homogenous and rapid carburizing of the components,
– homogenous and precisely controlled gas quenching.

All the variations from layer to layer are eliminated, which leads to reductions in distortion-variation within the load [HEU11].

In the following two practical applications are given for improved distortion control when switching from 3D- to 2D-treatment [HEU18].

3.1 Final Drive Ring gears

Final Drive Ring gears from a 6-speed automatic transmission are being produced since 2006 by applying LPC and HPGQ. The parts are treated in big batches with multiple layers (3D-treatment). A distortion study was initiated to quantify the possible improvement in distortion-control when switching from 3D-treatment to 2D-treatment. The Final Drive rings gears have an outer diameter of 226 mm, a height of 32 mm, a weight of 4,2 kg, 59 external teeth and are made 4121M-material. The case hardening depth CHD after heat treat is specified as 0,7…1,1 mm, core hardness as >28 HRC and surface hardness is specified as 64…69 HR45N.

Before the distortion-data was collected, it was made sure that the metallurgical quality in terms of hardness profile, microstructure and core hardness was identical for both treatments. In this study the geometrical change during heat treatment was compared between today's multiple layer production process (3D-treatment) at 965 °C and the new single layer process (2D-treatment) at 995 °C, see Fig. 3.

3D-treatment at 965°C

2D-treatment at 995°C

Fig. 3: Final Drive Ring gears treated in multiple layers (3D) and single layer (2D-treatment)

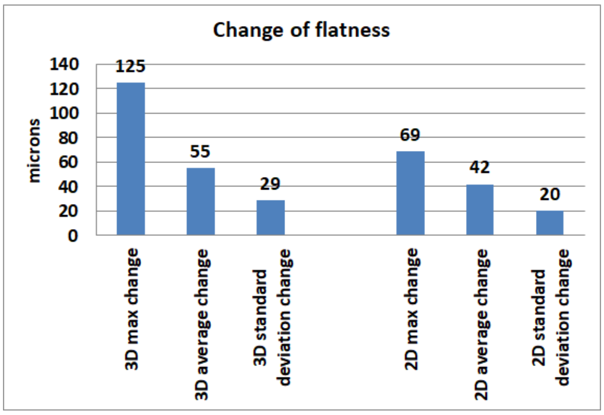

Fig. 4: Change of flatness during LPC-heattreatment of Final Drive Ring gears; comparison between 3D - treatment and 2D-treatment

Fig. 4 shows the change of flatness during heat treatment. With 3D-treatment the average change is 55 microns and with 2D-treatment the change is 42 microns, which means a reduction by 24 percent.

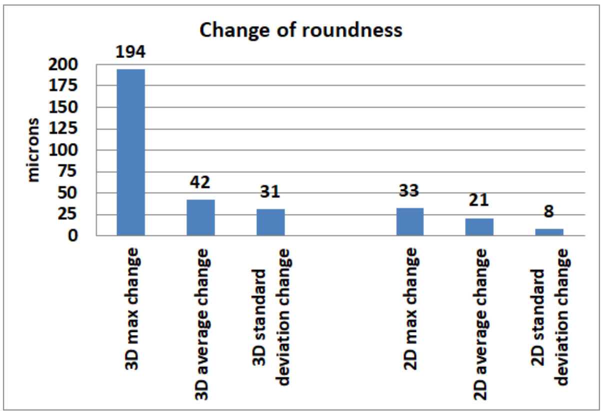

Fig. 5: Change of roundness during LPC-treatment of Final Drive Ring gears; comparison between 3D - treatment and 2D-treatment

Fig. 5 shows the change of roundness during heat treatment. With 3D-treatment the average change is 42 microns and with 2D-treatment the change is 21 microns, which means a reduction by 50 percent. Summing up, despite the fact that carburizing with 2D-treatment was performed at 995 °C and with 3D-treatment was performed at 965 °C, the control of distortion was significantly improved with 2D-treatment.

When changing production from 3D-treatment to 2D-treatment, this will result in huge cost savings for the subsequent grinding process-step.

3.2. Reaction Internal gears Type B

Reaction Internal gears "Type B" were studied as well. Again the improvement in distortion-control was quantified when switching from 3D to 2D-treatment. This "Reaction Internal gear Type B" has an outer diameter of 152 mm, 103 internal teeth and is made of 5130 material. The case hardening depth CHD after heat treat is specified as 0,3…0,5 mm, core hardness as > 25 HRC and surface hardness is specified as 64…69 HR45N.

Before the distortion-data was collected, it was made sure that the metallurgical quality in terms of hardness profile, microstructure and core hardness was identical for both treatments. In this study the geometrical change during heat treatment was compared between today's multiple layer production process (3D-treatment) at 900 °C and the new single layer process (2D-treatment) at 980 °C. For 3D-treatment 192 parts are treated in one load and for 2D-treatment 8 parts are treated in one load, see Fig. 6.

3D-treatment at 900°C 2D-treatment at 980°C

Fig. 6: Reaction Internal gear "Type B" treated in multiple layers (3D) and single layer (2D)

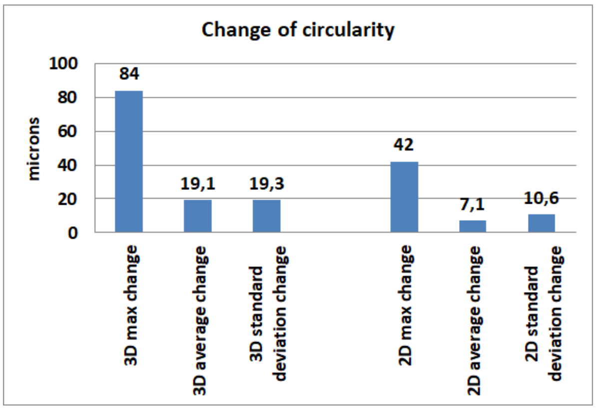

Fig. 7: Change of circularity during LPC-treatment of "Reaction Internal gear Type B"; comparison between 3D - treatment and 2D-treatment

In this distortion study 181 parts from 3D-treatment were measured and 160 parts from 2D-treatment (taken from 20 furnace-runs) were measured with a CNC analytical gear-checker.

Fig. 7 shows the change of circularity during heat treatment. With 3D-treatment the average change is 19 microns and with 2D-treatment the average change is 7 microns, which means a reduction by 63 percent.

When changing production from 3D-treatment to 2D-treatment, this improvement in control of distortion will result in significant cost savings for the subsequent grinding process-step.

4. Quality control

The quality control of the LPC-Outsourcing facilities is based on an ERP-system (Enterprise Resource Planning) with an integrated CAQ-system (Computer Assisted Quality Assurance) which records all quality-data. For each load a "production traveler" is printed and this production traveler runs together with the load through all the operations. Barcodes for each operation are printed on the production traveler. The barcodes are scanned in each work-center and the information is stored in the ERP-system indicating the time and the work-center where the load was treated. Thus it is possible to retrace exactly when a load was washed, when and in which furnace it was heat treated and whether a load was shot-blasted. Consequently complete traceability of all process steps is assured.

During the process of LPC and HPGQ the main process parameters such as temperature, process gas flows, cycle times etc. are continuously surveyed with a so-called "Process Monitoring system". In case of a significant deviation of the actual from the set value, the surveyed charge is labelled with a "Red Flag" and then sent automatically to the quarantine area. Furthermore those "Red Flag"-notifications are being sent from the furnace to the factory ERP-System which is linked digitally to the quality lab. As soon as the technician in the quality lab starts to analyze this load, he gets digitally notified that this load has been labelled with a "Red Flag" and subsequently an in-depth-testing of the load is initiated, see Fig.8.

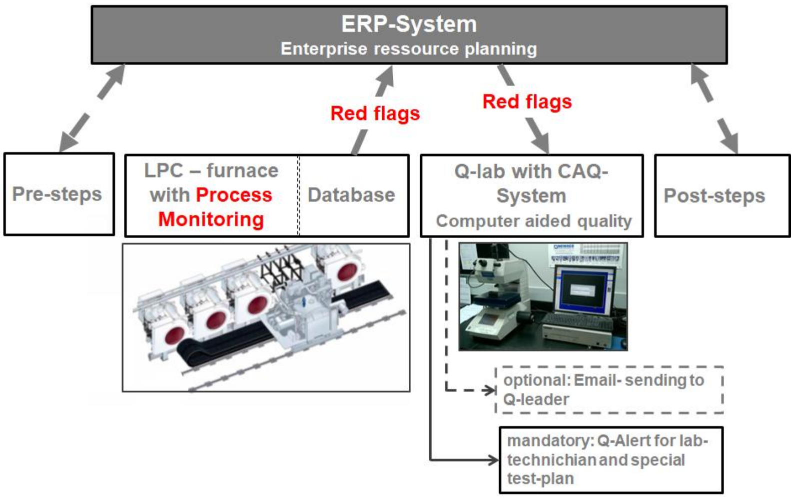

Fig. 8: Digital architecture: Process Monitoring is digitally embedded into the ERP-System and the Q-Lab

After the heat treat process, specific parts from each load are examined in the metallurgical laboratory. Parts which are especially prone to distortion can be geometrically inspected after heat treatment by a CNC measuring machine. All measured values from the laboratory are entered into the CAQ-system. Upon entering the values, the software verifies whether the entered values meet the parts specification. If a value is out of specification an error is recorded. Then the load is stopped and quarantined.

Additionally an internal complaint is created in order to detect the root cause of the error and to initiate a counter-measure.

5. Summary

Outsourcing of the LPC-process has been established for the transmission industry as an alternative to inhouse treatment.

The advantages of outsourcing are no investment in heat treatment equipment, no additional staff to conduct heat treatment operations or maintenance, access to the latest state-of-the-art heat treatment technologies and predictable and fixed heat treatment prices.

In recent years, main advances have been made in the fields of distortion control and quality control using digital methods.

If a LPC service-center, with his specific knowledge in the field of distortion control, cooperates closely with providers of green and hard-machining equipment, then this provides an excellent network for the development of new transmission components and prototypes. Especially for the development of new generation of transmission for electrified vehicles such a R&D-network proves to be valuable.

6. Literature

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