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Development of an induction heating device for heating shaped blanks

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In order to accelerate the heating of blanks for the production of press hardened parts, an induction heating device was developed and integrated into an existing tryout production line within the framework of a cooperation of Volkswagen AG and SMS Elotherm GmbH. This prototypal device enables the investigation of induction heating characteristics in regard to an application in automotive series production. In order to allow the homogeneous heating of shaped blanks to temperatures up to 950 °C, inductors were developed that can be operated in longitudinal as well as in transverse field mode. For the purpose of minimizing overheating of edges, the inductors can be positioned dynamically. In tests already performed, the usage of a longitudinal field induction heating enables a time saving of about 50 % compared to a conventional furnace heating.

Great improvements in automotive lightweight design and hence in reducing fuel consumption is obtainable by using hot stamping. Therefore, hot stamping has increased its importance in automotive industry [1]. **Fig. 1** shows the usage of press hardened parts in the car body of a Volkswagen Golf VII.

The press hardening process requires an austenitization of shaped blanks. Referring to the state of the art, roller hearth furnaces heated by burning natural gas are used for this purpose. This heating technology is associated with low heating rates compared to alternative technologies [2].

In a cooperation between the companies Volkswagen AG and SMS Elotherm GmbH, an induction device for heating shaped blanks was developed and integrated into a tryout production line. Induction heating technology offers a great potential to accelerate the austenitization process accompanied by advantages in furnace cycle time and space requirement of heating devices.

The present paper describes the developed prototypal induction heating device as well as technological parameters, which were taken into account during the development process. Finally, heating results are shown.

STATE OF THE ART

Hot stamping is used to produce high strength car body parts. The manufacturing process includes the austenitization of shaped blanks at temperatures above 900 °C directly followed by a simultaneous forming and cooling process. Due to high cooling rates, a martensitic structure is achieved in the car body part. The state-of-the-art

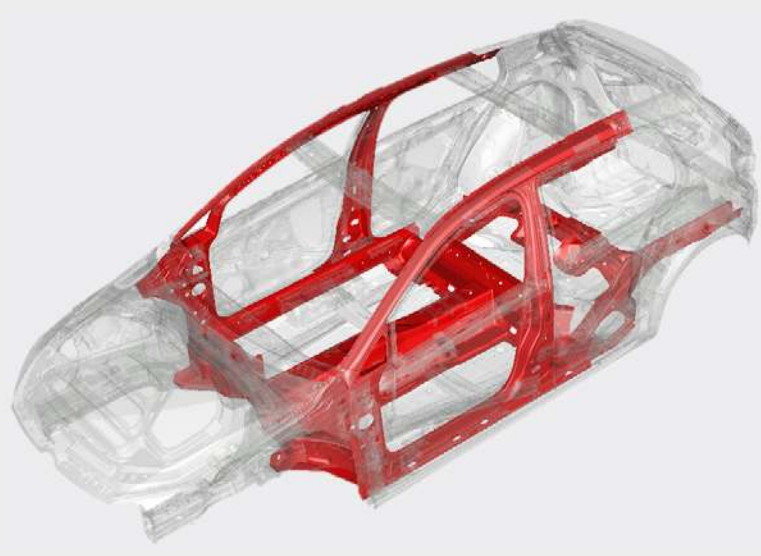

Fig. 1: Press hardened parts (red highlighted) in a Volkswagen Golf VII

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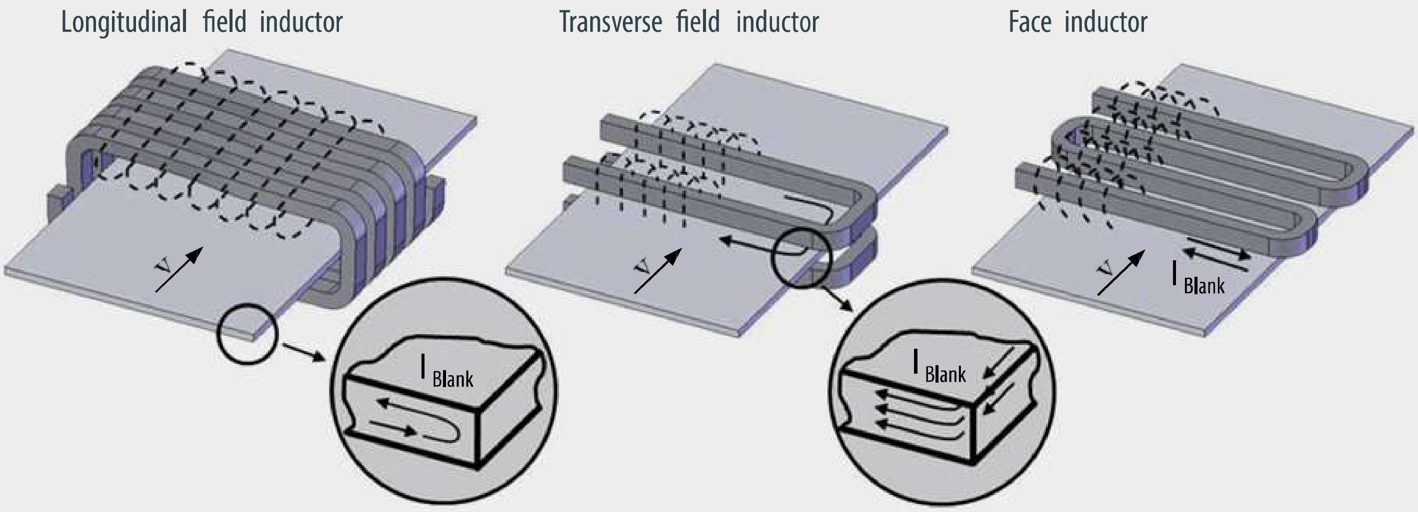

Fig. 2: Inductor designs for heating blanks [2]

material 22MnB5 enables ultimate tensile strengths above 1,500 MPa. The described process is also called direct press hardening [1].

The austenitization process is performed in roller hearth furnaces heated by natural gas or electricity to temperatures of 930–950 °C. Reaching a high heating uniformity independent of blank geometry is one advantage of roller hearth furnaces. Unfavourable is their low achievable heating rate, space consumption, investment and maintenance costs as well as scrap due to process disruptions [3]. Accelerating the austenitization process is one possibility to reduce heating cycle times and space consumption of heating devices. Concerning this, heating by induction [4-6], conduction [7], contact plates [8] as well as fluidized beds [3] was researched.

The present paper is focused on induction heating. In this case, an alternating current causes an alternating magnetic field via one or more coiled conductors (inductors). Metallic workpieces, e. g. blanks which are conveyed through this field, are heated directly due to induced eddy currents [9]. In case of ferromagnetic materials there is an additional heating due to hysteresis losses [10].

Fig. 2 shows different inductor designs for blank heating. Regarding longitudinal field inductors, magnetic field lines run parallel to blank plane. Assuming medium frequencies and blank thicknesses of 1–2 mm, longitudinal field heating enables temperatures up to Curie temperature (22MnB5: ~740 °C) and high heating homogeneity. Transverse field inductors as well as face inductors generate magnetic fields perpendicular to blank plane. These inductor designs allow heating above melting temperature of steel but come along with reduced heating uniformity especially at geometrical discontinuities and edges of shaped blanks [2].

DEVELOPMENT OF PARAMETERS IN AUTOMOTIVE SERIES PRODUCTION

The developed prototypal heating device aims at fulfilling requirements of an automotive series production. In current hot stamping process cycle times of 24 s are common, consisting of 20 s for forming and cooling and 4 s for transferring the hot blank and the pressed parts [4]. Further advancements in cooling technology of forming tools will lead to reduced cycle times [11]. Heating devices have to enable the minimum cycle time in hot stamping.

A huge variety of different sizes and geometries of shaped blanks is caused by an increasing number of different hot stamped parts (Fig. 1). Analyzing the portfolio of hot stamped parts in current and future vehicles, heating devices have to allow heating blanks with widths up to 1,500 mm, sheet thicknesses up to 2 mm and complex shapes.

In order to ensure the quality of produced parts, research on the influence of induction heating on the properties of pressed parts is necessary. To enable this research, the prototypal heating device had to be integrated in an existing tryout production line consisting of a roller hearth furnace and a hydraulic forming press.

DEVELOPMENT OF AN INDUCTION HEATING DEVICE FOR SHAPED BLANKS

Induction heating devices consist of the core components frequency converter, capacitor battery and inductor(s) as well as a process control system and a recooling plant. **Fig. 3** shows the design of the developed heating device and the tryout production line. Two inductors (4, 5), a transformer (3) and capacitors (2) are combined in one oscillating circuit. The converter provides a power of 800 kW at frequencies up to 10 kHz. In order to adjust the frequency, different capacitors can be applied. The converter's power output is voltage regulated in an area of 300–1,000 V.

The blanks are fed into the heating device via a roller conveyor (6). Shafts with mounted discs above and underneath the blank plane clamp the blanks and move them through the inductors, avoiding any contact between blanks and inductors. Both inductors can be positioned dynamically perpendicular to feed direction. The power of the second inductor (5) can be reduced by the integrated transformer (3). In order to reduce stray fields and to ensure a high efficiency, field concentrators are mounted on the inductors. A further improvement of efficiency is obtained by keeping the distance between blank and inductors small. The length of the induction heating section amounts to 1,200 mm.

For the purpose of minimizing temperature losses, blanks preheated by induction are transferred to the directly connected roller hearth furnace (7). During this transfer, the blank temperature is measured by a pyrometric line scanner. Two-dimensional temperature profiles are enabled by the translational movement of the blanks and allow process quality controls as well as further computer-aided research.

Both inductors consist of conductor loops above and underneath the blank plane. By using different adapter pieces, the current direction can be varied which allows operating the inductors in longitudinal or transverse field. **Fig 4** illustrates this special inductor design as well as the field lines of the magnetic field in longitudinal and transverse field mode.

For the purpose of analyzing the potential of induction heat-

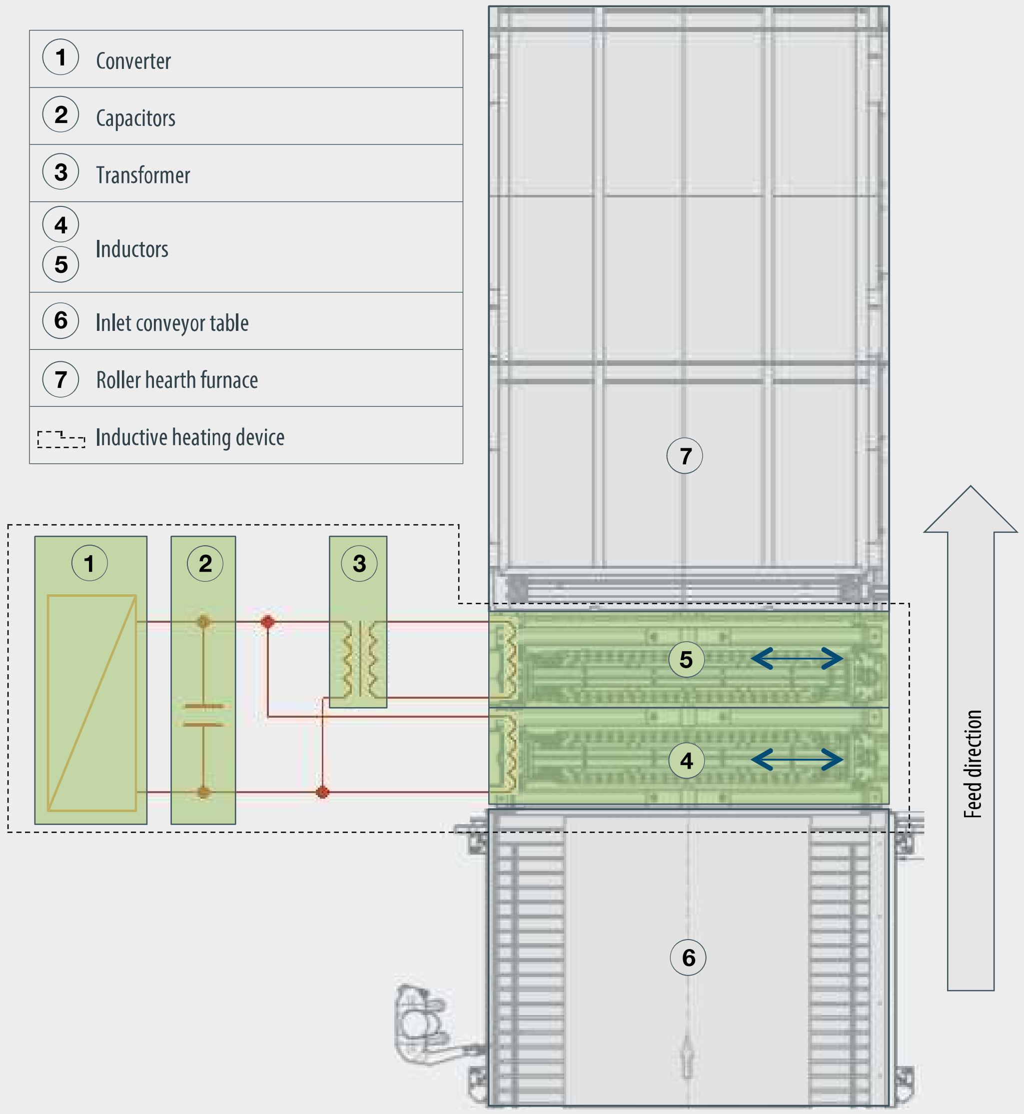

Fig. 3: Prototypal heating device and oscillating circuit

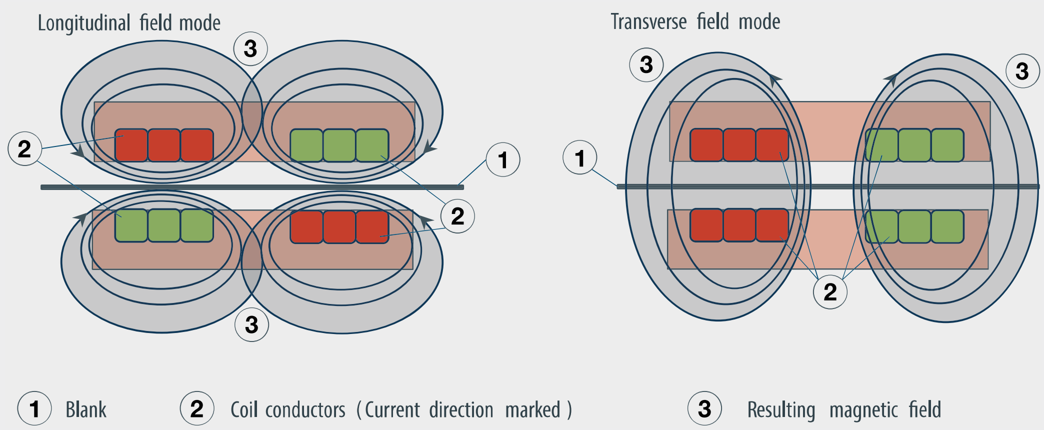

Fig. 4: Circuitry of longitudinal and transverse field inductors

Fig. 5: Temperature distribution at shaped blank (B-pillar) after longitudinal field heating

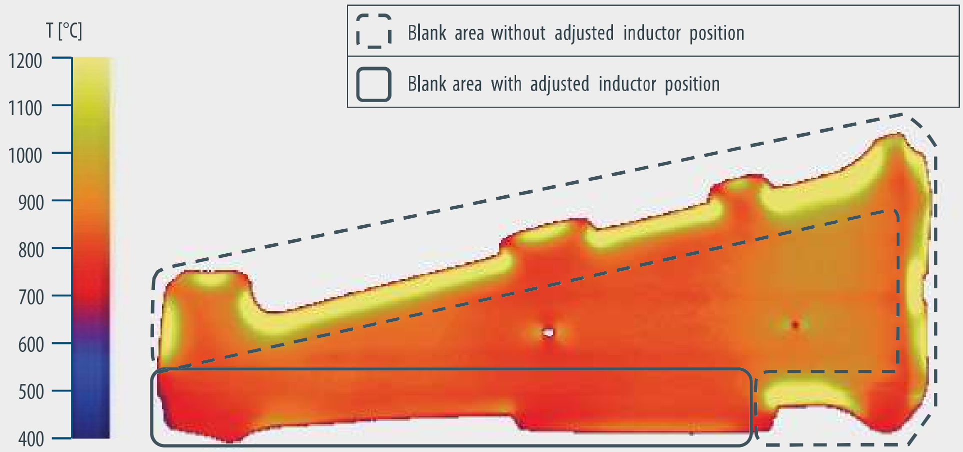

Fig 6: Temperature distribution at shaped blank (B-pillar) after transverse field heating with adjusted dynamic inductor positioning

ing in hot stamping comprehensively, three different operation modes were implemented in the prototypal heating device. The mode "longitudinal field heating" is designed for heating blanks from room temperature up to Curie temperature. It works as a "preheating booster" for the following roller hearth furnace heating. Both inductors are operated in longitudinal field at frequencies of about 7–9 kHz. Independent of blank geometry a uniform heating is obtained (**Fig. 5**). Only at edge areas slightly minor temperatures are observable.

The second operation mode called "complete heating" aims at heating blanks from room temperature up to temperatures of about 950 °C. Passing the first inductor, which operates in longitudinal field mode, the blank is heated up to Curie temperature. Running through the second inductor, which operates in transverse field mode, the blank is heated up to temperatures of about 950 °C. Heating in this operation mode is accompanied by lower temperature uniformity than in "longitudinal field heating". In particular, at edge areas the shaped blank gets overheated compared to inner areas of the blank.

The third operation mode "transverse field heating" is implemented for research activities only (**Fig. 6**). Both inductors are operated in transverse field mode and can be positioned dynamically perpendicular to feed direction of blanks. This dynamic movement is purposed to make the inductor head follow the blank shape in order to minimize the overheating described earlier. The oscillating circuit is set to frequencies of 4–6 kHz. Another feature of this operation mode is the inversion of the feed direction. Thereby, the roller hearth furnace can be operated as preheating, e. g. in order to simulate a longitudinal field preheating before transverse field heating.

In order to illustrate the potential of the induction heating technology, **Fig. 7** shows a comparison of temperature progressions of blanks heated in roller hearth furnace with and without longitudinal field preheating. Both measurements were performed with aluminium-silicon coated 22MnB5-blanks with a thickness of 2 mm. Using induction preheating, a duration of 140 s is required to reach temperatures of 950 °C. Without induction preheating a duration of 285 s is measured which means an increase of about 50 %. On the bottom right, a diagram details the induction heating process.

CONCLUSION

In order to decrease the austenitization time in hot stamping, a prototypal induction heating device was developed in a cooperation of Volkswagen AG and SMS Elotherm GmbH. In this development, parameters of automotive series production like the necessary throughput and the variety of blank geometries were taken into account. A special inductor design allows different operation modes including longitudinal and/or transverse field heating. Both inductors can be positioned perpendicular to feed direction dynamically in order to minimize overheating at blank edges. Compared to conventional furnace heating, the already evaluated longitudinal preheating allows a time saving of about 50 % in terms of reaching workpiece temperatures of 950 °C.

The prototypal induction heating device offers a wide range of opportunities for evaluating and researching the technology focused on hot stamping issues. Future analyses will show the potential of longitudinal and transverse field heating with blanks of different geometries and thicknesses. Simultaneously, a FEM model is developed in order to depict the heating process numerically. The influence of induction heating on processing properties of pressed parts is researched for the purpose of qualifying induction heating for series production.

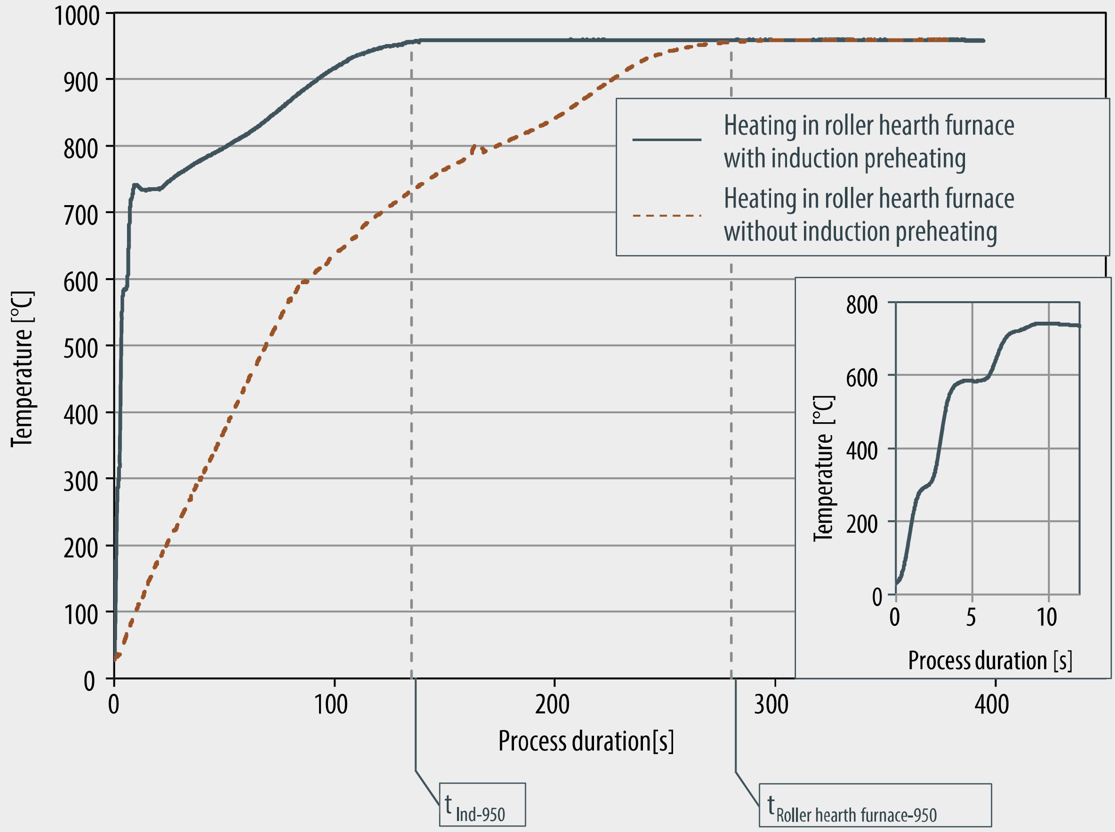

Fig. 7: Comparison of heating progression in roller hearth furnace with and without induction preheating

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