New Method for Reducing the Hole Straightness Deviation in BTA Deep Hole Drilling

Prof. Dr.-Ing. Dirk Biermann
Prof. Dr.-Ing. Dr. h. c. Klaus Weinert
Dipl.-Logist. Nadine Kessler
Institute of Machining Technology, ISF
Technische Universität Dortmund
Baroper Str. 301
D-44227 Dortmund
Phone: 00 49 (0) 231 755 4859
E-Mail: kessler@isf.de

Abstract:
Deep hole drilling methods such as BTA-deep hole drilling are machining processes to produce boreholes with high length to diameter ratio as well as boreholes with high quality. Nevertheless, if prism-shaped workpieces or workpieces with eccentrically placed boreholes have to be machined the product attribute hole straightness deviation can lead to a main problem. The non-compliance of the tolerances of hole straightness deviation can cause a rectification of rejects or the loss of functionality of the workpiece. These kinds of workpieces can only be produced by an exclusive tool rotation with a non rotating workpiece. Within this paper a new method, developed at the Institute of Machining Technology, is described to reduce the hole straightness deviation. This method bases on a thermally influencing, in particular on induction heating at the workpiece. Furthermore, the essentially variables for an effective influencing of the orientation of the tool are analysed.

Keywords:
BTA-Deep Hole Drilling, Hole Straightness Deviation, Thermally Influencing by Induction Heating

1 Introduction

If boreholes with a high length to diameter ratio and with a high accuracy regarding to the compliance of the tolerance of the bore diameter, the roundness or the surface roughness deep hole drilling methods are applied. State-of-the-art are three different deep hole drilling methods such as single lip deep hole drilling, BTA (Boring and Trepanning Association) deep hole drilling and the ejector drilling. Lately, new twist drills with a special geometry and relieved flutes are used for deep boreholes. For diameter $d \geq 20$ mm and above and a high length to diameter ratio the BTA deep hole drilling is to be used for example to machine hydraulic cylinders.

The BTA deep hole drilling tool is characterized by an asymmetric cutting edge arrangement. The working principle of a BTA deep hole drilling process is furthermore characterized by an external cooling lubricant supply through the annular space between the boring bar and the produced borehole. For a deep hole drilling process the coolant lubricant supply is essential on the one hand for the lubrication of the guide pads and on the other hand for the reliable removal of the chips. During the drilling process the resultant radial force composed by the cutting force F_c and the passive force F_p are achieved by the guide pads which results into a self guide effect of the deep drilling tool. The working principle is shown in **figure 1**.

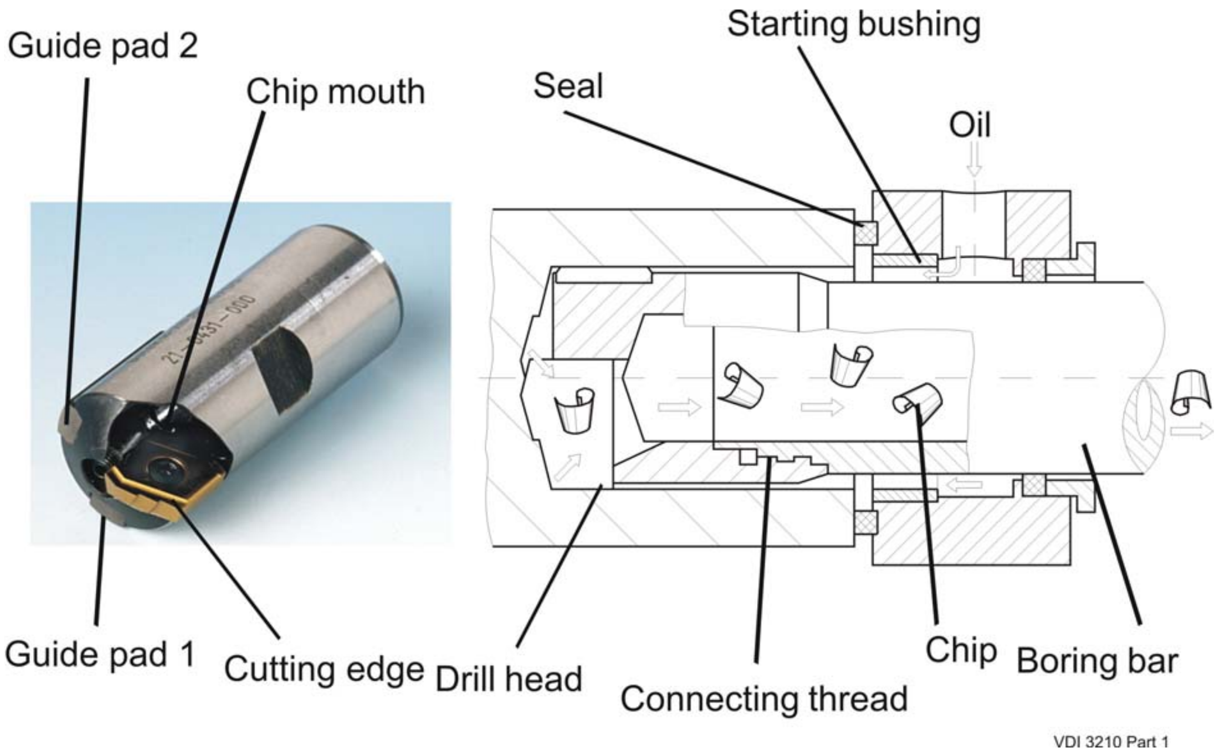

Figure 1: Working principle of BTA deep hole drilling [1]

If workpieces have to be machined which feature a prism-shaped contour or which have eccentrically placed boreholes, the mode of operation for this processing is an exclusive rotating tool with a non rotating workpiece. This kind of mode of operation increases the hole straightness deviation. It is also well known in the literature and in the industrial praxis [2], [4]. Therefore several devices are developed to reduce the hole straightness deviation These devices are often based on mechanical load and influence the deep hole drilling tool [3]. A new method developed at the Institute of Machining Technology bases on a thermally influencing by using an external inductive converter.

2 Experimental setup

The experimental investigations were carried out on a CNC BTA deep hole drilling machine, type Giana GGB 560. For the thermally influencing during the BTA deep hole drilling process a special device was necessary. The special device is designed as an external feed unit with a push rod connected at the headstock of the tool spindle. Therefore, the external feed unit exists of two ball-bearing longitudinal guides, guiding wagons and a linear positioning system. With the hand wheel the radial position between the inductor and the workpiece is adjustable. In preliminary tests the position of the inductor was investigated [6]. The best distance between the inductor and the workpiece is $a_I = 2$ mm. A commercial available drill head with a nominal diameter of 26 mm, equipped with one TiN coated cemented carbide (P25) cutting insert and two cemented carbide (P20) guide pads were applied. The workpiece material was steel C60 with a special shape to produce eccentrically placed boreholes. The process parameters for the BTA process were constant: cutting speed $v_c = 90$ m/min, feed $f = 0.13$ mm and the oil flow rate $\dot{V}_{oil} = 105$ l/min. The process parameters for the induction heating were verified. Furthermore, two different strategies of the heating were carried out. In **figure 2** the feed unit for the inductor is shown.

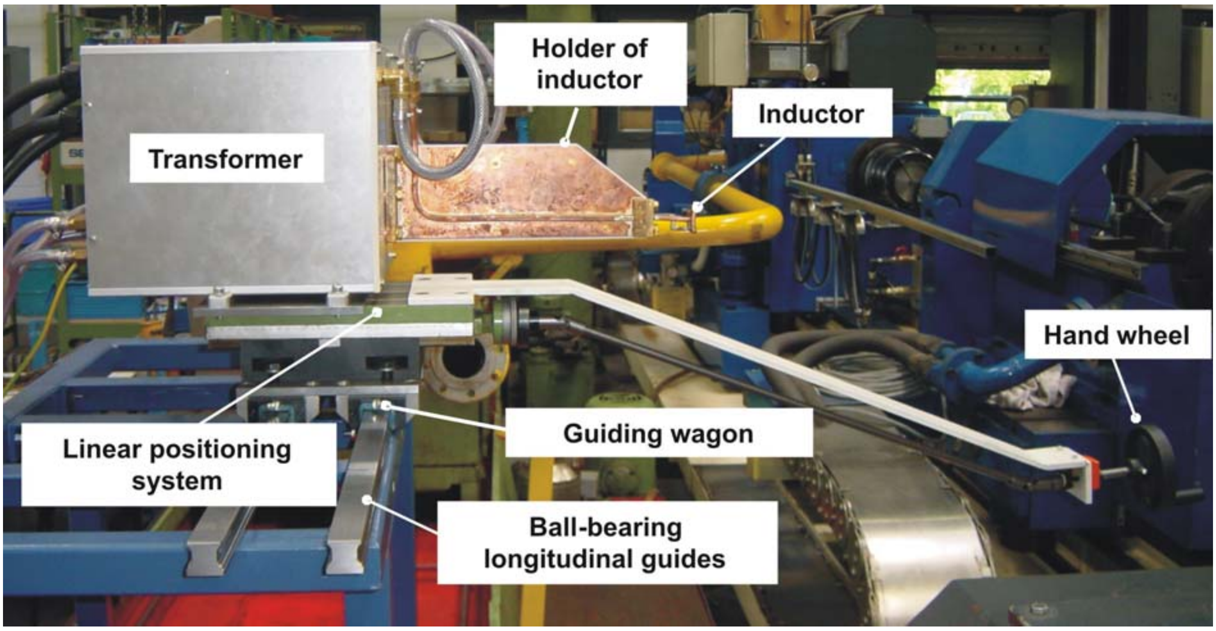

Figure 2: Developed feed unit for the induction heating during the deep hole drilling process

3 Strategies of the induction heating

The experimental investigations were designed by using two different strategies to analyze the main effects of the thermal influencing during the drilling process. One of the heating strategies is the heating at the thick-walled side of the workpiece. The other strategy is the heating at the thin-walled side of the workpiece. The aim was to verify the working hypothesis that the asymmetrically temperature gradient inside the workpiece can be composited by the external induction heating (see **figure 3**).

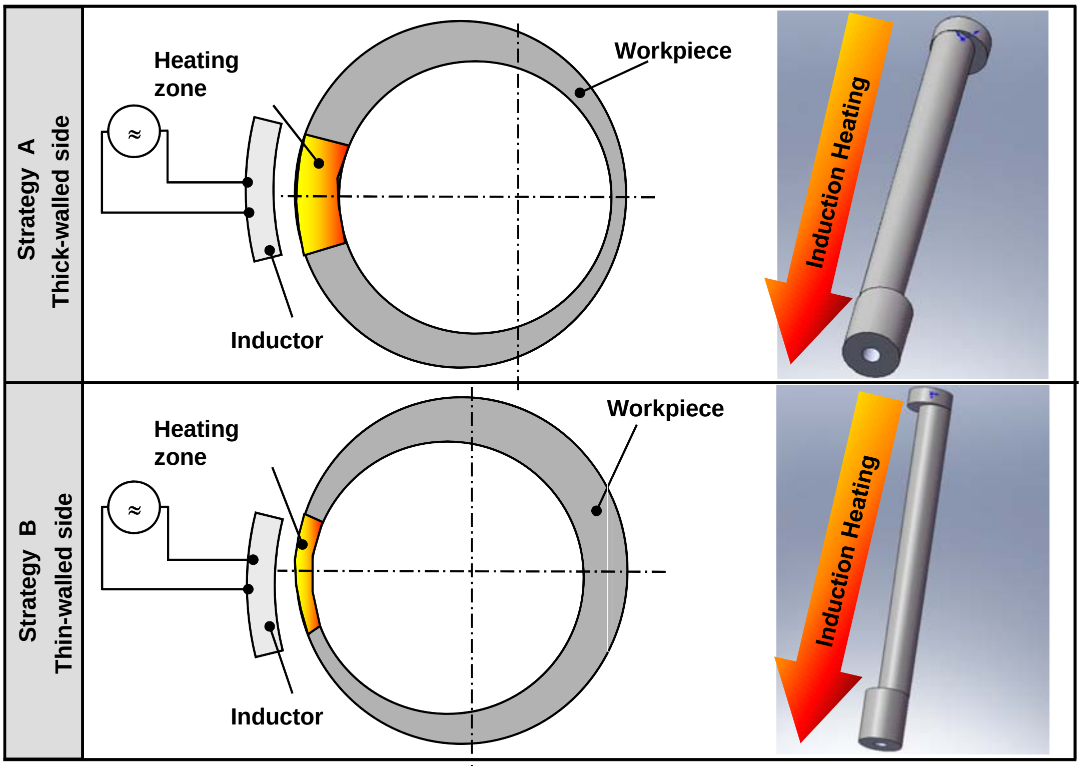

Figure 3: Explanation of the two strategies of induction heating [7]

Previous experimental investigations were carried out to analyze the orientation of the BTA drill head. Therefore several experiments were carried out on the CNC BTA deep hole drilling machine, type Giana GGB 560. In order to machine eccentrically placed boreholes on the horizontal BTA deep drilling machine a special shape of the workpiece was necessary. By using a statistical experiment design the main variables cutting speed v_c and feed f were varied. According to all experiments the orientation of the BTA drill head is ever towards the thin-walled side of the modified workpiece. Furthermore, the influence of the process parameters was analyzed. Thereby, the influence of the chosen feed is more significant than the influence of the chosen cutting speed. The reason are the higher cutting forces which causes higher elastically deformation of the thin-walled side. Because of this deformation the hole straightness deviation increases by the option of the feed f [4]. Nevertheless, the influence of the workpiece geometry and the measured asymmetrical temperature field have the highest effects in order to the value of the hole straightness deviation.

4 Results of the induction heating

The results of the interdependences induction heating are important for the understanding of the thermal and mechanical sequences inside the eccentric workpiece. The bases of operations are two separate processes, on the one hand an asymmetrical temperature gradient inside the workpiece during the BTA deep hole drilling process and on the other hand an external contribution of heat by the induction heating with own adapted parameters. For the analyze of the induction heating parameters, the process parameter of the BTA deep hole drilling process are constant. Only the rated power of the frequency-converter for induction heating was changed to analyze the influence of the generated heat, in particular the amount of heat and the heat flux, according to the orientation of the BTA drill head during the deep hole drilling process.

Exemplarily, the results of the investigations are demonstrated for the strategy of induction heating B. For the results of the different settings of the rated power of the converter the experiments were repeated two times. The orientation of a not influenced experiment shows that the drill head tend towards the thin-walled side of the eccentric workpiece. The results of the experiments with $p_u = 2.5$ kW and 5 kW show that the influence is low. The orientation of the drill head after a feed travel $L_f = 700$ mm is nearby the orientation of the not induction heating influenced workpiece. If the rated power of the frequency-converter arises the orientation of the drill head tend more towards the zero point of the x-axis (see **figure 4**). With an increasing rated power of the frequency-converter more generated heat flows through the eccentric workpiece. Because of the strategy B the heat is generated at the thin-walled side. That means that a heat accumulation arises by the deep hole drilling process and the external induction heating. The material at the thin-walled side was very quickly heated through. Metallographic preparation of the workpiece microstructure was done. The structure of the thin-walled side which was thermally influenced by a high rated power shows a structural change in the form of grain refinement and a rise of hardness. That could be the reason for the orientation of the drill head against the inductor during the deep hole drilling.

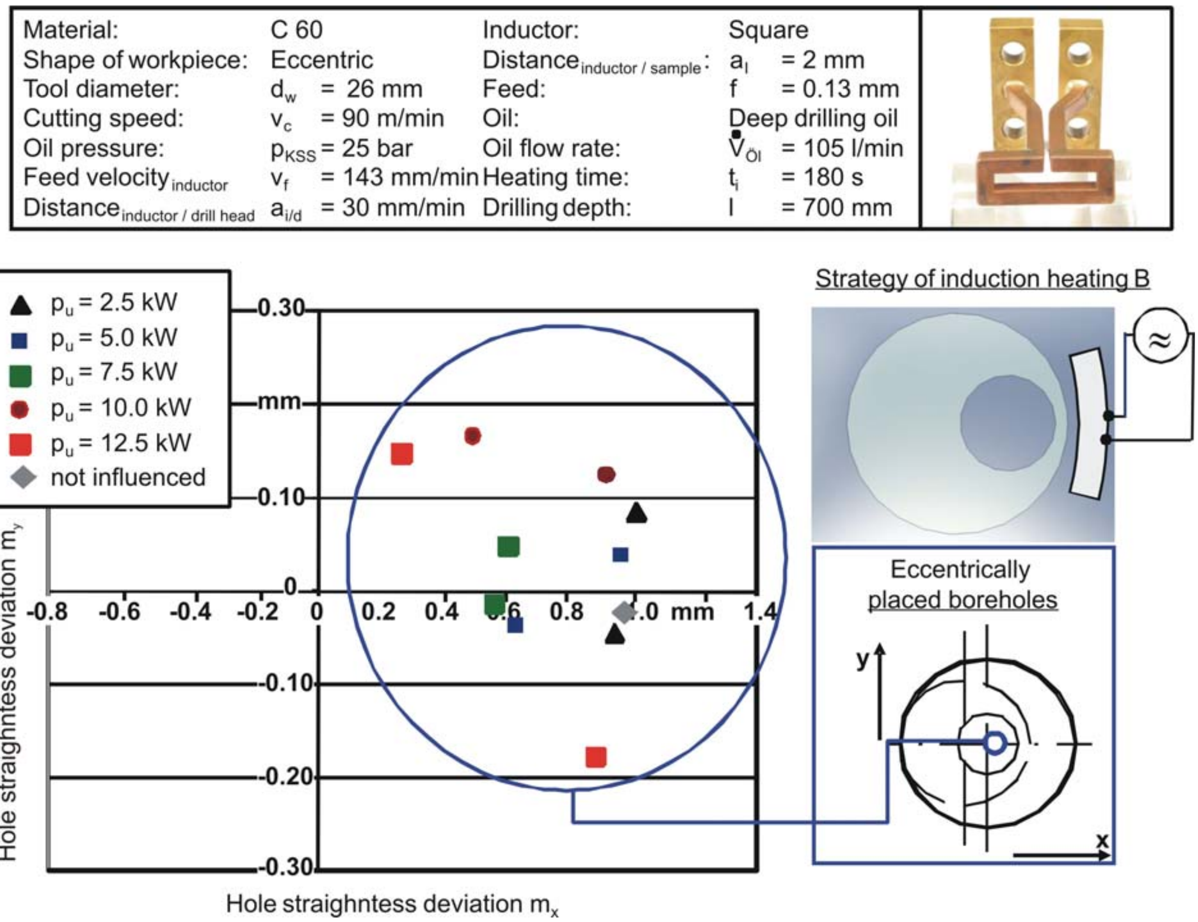

Figure 4: Orientation of the hole straightness deviation towards the axis of a Cartesian coordinates system

In **figure 5** the hole straightness deviation depending on the feed travel for two experiments are exemplary pointed out. On the left hand side the result of an influenced workpiece by using a frequency-converter with a setting of variables such as distance between inductor and workpiece a_I = 2 mm, distance between inductor and drill head $a_{i/d}$= 30 mm and rated power p_u = 12.5 kW is demonstrated. On the right hand side the result of a not influenced workpiece is compared with the influenced workpiece.

As expected, the measured data of the hole straightness deviation increase with an increasing feed travel. The first phase of drilling is the most important phase for the hole straightness deviation because the drill head will be guided by using a boring bush. In this phase the drill head with its guide pads is not complete in the borehole, so a deviation of the drill head from its intended path is possible. After this phase the quasi-stationary drilling process starts in which the deviation increases. On the left hand side are the results of the absolute hole straightness deviation depending on the feed travel of the thermally influenced workpiece are pointed out. After each 100 mm a measurement was carried out to analyze the absolute hole straightness deviation according to the thermally influenced with the not influenced workpiece. Within these investigations the induction heating with a variable rated power of frequency-converter p_u = 12.5 kW lead to a significantly reduced hole straightness deviation over the complete feed travel. The measured data from the not influenced workpiece are about the factor three higher as the measured data from the thermally influenced workpiece. All measured data of the hole straightness deviation from the thermally influenced workpiece are under the preassigned value of m = 0.4 mm.

Material:	C 60	Inductor:	Square
Shape of workpiece:	Eccentric	Distance$_{inductor / sample}$:	a_I = 2 mm
Tool diameter:	d_w = 26 mm	Feed:	f = 0.13 mm
Cutting speed:	v_c = 90 m/min	Oil:	Deep drilling oil
Oil pressure:	p_{KSS} = 25 bar	Oil flow rate:	$\dot{V}_{Öl}$ = 105 l/min
Feed velocity$_{inductor}$	v_f = 143 mm/min	Heating time:	t_i = 180 s
Distance$_{inductor / drill head}$	$a_{i/d}$ = 30 mm/min	Drilling depth:	l = 700 mm

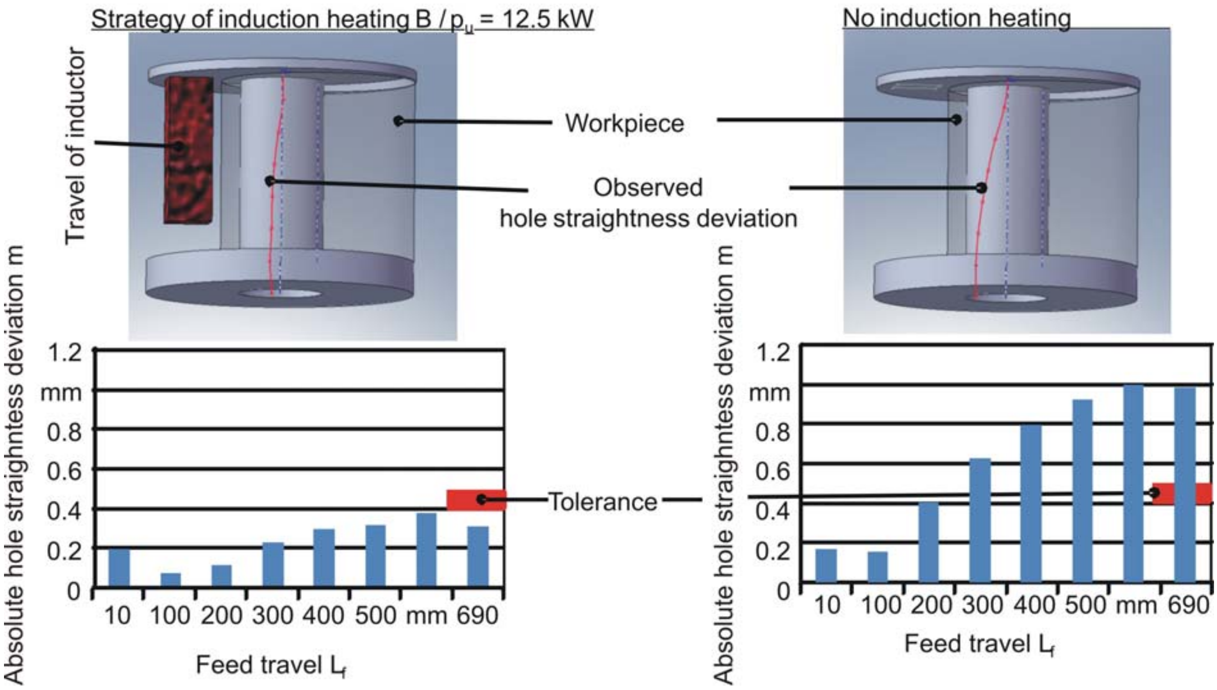

Figure 5: Measurement data of the absolute hole straightness deviation about the feed travel

5 Conclusion

In this paper the influence of the induction heating with an external feed unit is pointed out to achieve an advanced understanding of the BTA deep hole drilling process. Based on the major influencing factors such as the cutting parameters, the shape of the workpiece and particularly the temperature the new method of a thermally influencing by using inductive heating is investigated.
Within the presented investigations the potential of thermally influencing in BTA deep-hole drilling by using a frequency-converter is pointed out. Therefore, the layout of the process parameters for the frequency-converter is an important factor for the success of the method. In this context a short overview of the influence of the generated heat with a frequency-converter is given. With the choice of the right strategy of induction heating such as the strategy B and the accordingly rated power of the frequency-converter the increasing hole straightness deviation can be significantly reduced.

Acknowledgments

This work has been supported by the German Research Foundation (DFG).

References

[1] VDI-Richtlinie 3210, Blatt 1 / Part 1 *"Tiefbohrverfahren / Deep-hole drilling"*. VDI-Richtlinie published in German and English, Beuth Verlag GmbH, pp 1-26, March 2006.

[2] Katsuki, A.; Sakuma, K.; Tabuchi, K.; Onikura, H.; Akiyoshi, H.; Nakamuta, Y. *"The influence of tool geometry on axial hole deviation in deep drilling: Comparison of single- and multi-edge tools*." JSME International Journal, Vol. 30, No. 265, pp 1167-1174, 1987.

[3] Katsuki-A; Onikura-H; Sajima-T; Mohri-A; Moriyama-T; Hamano-Y. "*Development of a practical high-performance laser-guided deep-hole boring tool – improvement of guiding strategy"*. Euspen Topical Conference on Fabrication and Metrology in Engineering and Nanotechnology 2003, pp 97-100, 2003.

[4] Weinert, K.; Hagedorn, M.; Kessler, N. *"Mittenverlauf beim BTA-Tiefbohren – Untersuchungen zeigen Einflussfaktoren auf die Bohrungsqualität"*. VDI-Z, 147, Vol. 11/12, pp 35 - 38, 2005.

[5] Weinert, K.; Kessler, N.; Wittkop, S. *"Tiefbohren zwischen Forschung und Praxis"*. VDI-Berichte Nr. 1897, ISBN 3-18-091897-7, pp 1-30, 2006.

[6] Biermann, D.; Kessler, N.: *"Mechanism and Potentials for Reducing of Hole Straightness Deviation in Deep-Hole Drilling."* Proceedings of the 2nd Manufacturing Engineering Society International Conference, CISIF-MESIC 2007, 9.-11. July 2007, Madrid, Spain, digitally published on CD (ISBN 978-84-611-8001-1), 8 pages

[7] Biermann, D.; Felderhoff, F.; Heilmann, M.; Kersting, M.; Kessler, N.; Sacharow, A.: *„Aktuelle Entwicklungen der Werkzeug- und Prozessgestaltung beim Tiefbohren"*. VDI-Berichte Nr. 2054, ISBN 978-3-18-092054-2, pp 141-154, 2008.

ZPĚT