INCREASED PRODUCTIVITY BY HIGH SPEED DRILLING

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Resumo

Este trabalho faz uma revisão acerca das possibilidades e limitações existentes, hoje, quando se trabalha com o processo de furação em altíssima velocidade de corte. Diferentes tipos de materiais, tanto para ferramenta quanto para a peça usinada, foram pesquisados. Os resultados mostram que a técnica da usinagem em alta velocidade de corte é capaz de produzir peças com precisão e redução de tempo. Entretanto, a possibilidade do desenvolvimento de novas ferramentas é maior com utilização de métodos computacionais.

***Palavras-chave**: furação em alta velocidade de corte, desenvolvimento de novas ferramentas.*

Abstract

The paper gives a comprehensive overview of present possibilities and limitations in drilling and reaming with high cutting speeds. Different kinds of tools and material groups are investigated. The results of the research projects concerning high speed drilling (HSD) and reaming of the Institute of Production Engineering and Machine Tools (PTW) at the Darmstadt Technical University confirmed a high potential concerning production accuracy, reduced main times and effectiveness. Furthermore, new possibilities of tool development are presented which are stronger based upon computational methods.

***Keywords**: high speed drilling, tool development*

1 Introduction

Competition among the industrialized nations is characterized by an increasing toughness. The time and profit frame available for the company to gain profits from their products is decreasing steadily (BULLINGER, 1993). A transition between a seller market to a buyer market has already been taking place. For almost practically every product the customer has a good choice from different variants of products from different suppliers (BULLINGER, 1993). Since for several years almost all the attention was put onto an increase of productivity and the exploitation of new potentials of technical developments and improvements, now after a phase of orientation about the worker (job enlargement, job enrichment, job rotation, etc.) the attention is shifted again to the technology. This happens because of the possibilities and potentials, which can be found in high speed cutting (HSC), are recognized slowly but steadily by the users. To choose a new approach is very promising, because it does not make sense "... to search for the solution for the problems at the competitors, thus then one's force is concentrating upon the imitation of existing solutions and therefore only remain on second place." (WARNECKE, 1992)

2 Definitions

Figure 1 shows a number of suggestions of cutting parameters by different tool manufacturers. This is done for a solid carbide drill coated with TiN with a diameter of 6 mm for the cutting of 42CrMo4 steel. Even if the recommendations partially show strong variations, it can be seen, that values of over 90 m/min for cutting speed v_c and over 0.25 mm for the feed are an exception. Those values can be considered as usual and therefore conventional. If today's cutting parameters for e.g. aluminum cutting (v_c>>90 m/min) or titanium cutting (v_c << 90 m/min) are considered simultaneously, it is obvious, that high speed cutting cannot be set to specific fixed values for drilling and reaming. HSC has to be related to the used work piece material.

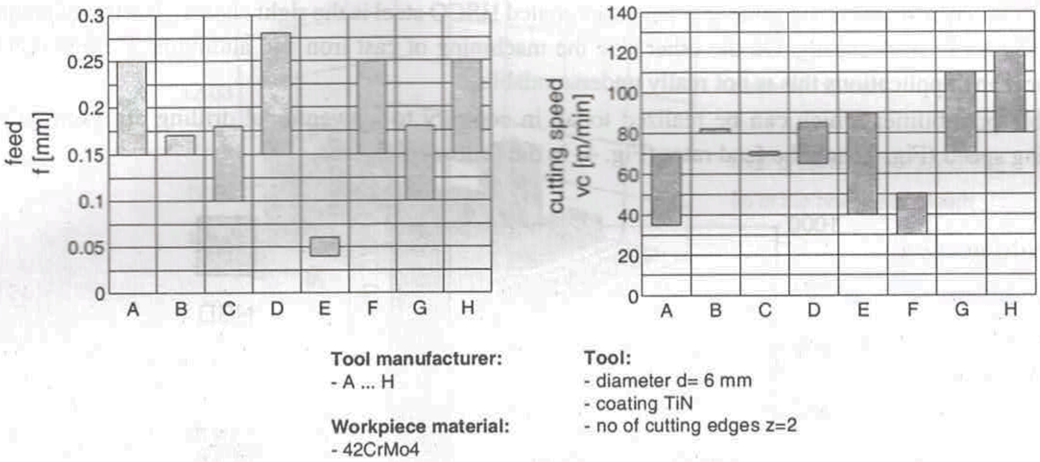

Figure 1 - Manufacturers suggestions for drilling in 42CrMo4 steel

Based on this preliminaries the high speed drilling has been set to (Eq.1):

$$HSD = D \times 3 \quad (1)$$

this means, that the conventional parameters have first been increased by a factor of 2 (EMRICH, 1996), but now have been risen to a minimum of factor 3 (EMRICH, 2000). This has been done in different research projects "HSD - High speed drilling and reaming with high precision" (HSD: 08/1993-07/1996; HSD II: 01/1997- 08/1999; HSD III: 11/1999-12/2001). The latest developments in cutting technology are aiming, besides the obvious reduction of nonproductive time, exactly for the increase of cutting speed and feed to reduce production time. Because of the short chips related to the cutting technology, especially milling is suitable for the application of high speed cutting (SCHULZ, 1989; SCHULZ, 1996 and EMRICH, 1996). Drilling with high cutting speeds leads to significant difficulties, because of the limited transport capabilities to remove the occurring chips out of the bore hole through the chip flute of the tool. Furthermore the generated heat cannot be dissipated into the chip as fast as in milling or turning. But the heat will be dissipated into the walls of the drilled hole and the shaft of the drill. The use of internal cooling, in which the coolant is transported directly to the application point on the ground of the bore hole through the tool can in most cases yield several improvements. Additionally to this the chip removal is supported very good by the flushing. Because of this reasons, dry cutting high speed machining is not state of the art for drilling (GÜHRING and CSELLE, 1995). But because of the estimation of drilling taking the biggest share of the overall machining times (HOFF, 1986), there is a high potential for new developments, especially regarding the machining on transfer lines. This is also shown by the distribution of the tools in production of a crank case of the 900 series of the Mercedes Benz AG, Mannheim, Germany (Fig. 2).

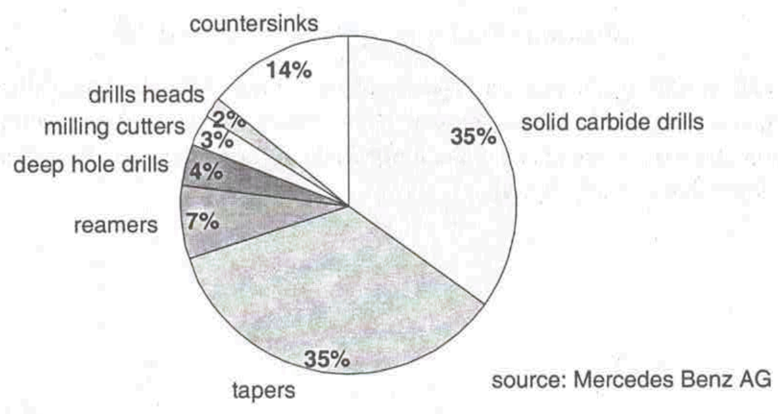

Figure 2 - Tool distribution for the machining of a crank case

3 Technology of high speed drilling

Besides of the rather rare cutting materials CBN, cermet and ceramics, coated tools or PCD also are used in an increasing number for drilling and reaming. Coated carbides are applied, if the boundary conditions are suitable (rigidity of the machine tool and clamping, rotational speed, etc.), in the other cases coated HSCO steel is the right choice. The use of coated drilling tools is state of the art in steel cutting. On the other side the machining of cast iron and aluminum is often done with not coated tools. For many applications this is not really understandable.

The available possibilities which can be realized today in contrary to conventional drilling are exemplified by the achievable cutting speed (Fig. 3) and the feed rates (Fig. 4) in the following figures.

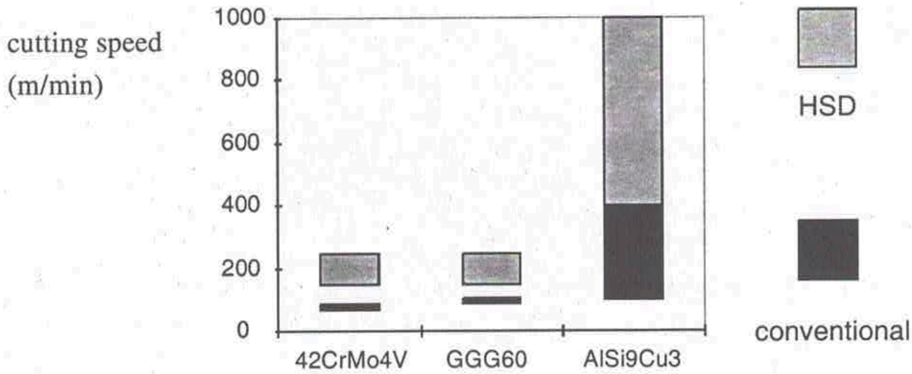

Figure 3 - Cutting speeds – conventional vs. HSD

These examples are related to the application of high class HSD suitable cutting materials, like coated carbide for the use in steel and spherical cast iron and polycrystalline diamond (PCD) for aluminum alloys.

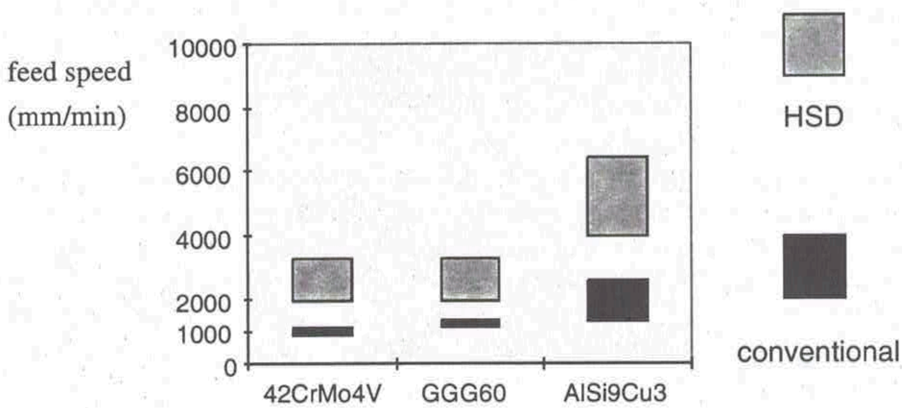

Figure 4 - Feed speeds – conventional vs. HSD

Especially in the fields of milling, the positive effects realized for high speed cutting on the quality are well known. In the framework of the above mentioned projects, besides others theses influences have been proven also for high speed drilling. Following figures show this without any doubt for the field of form tolerances (Fig. 5) as well as for the achievable surface qualities at the drilled hole's wall (Fig. 6).

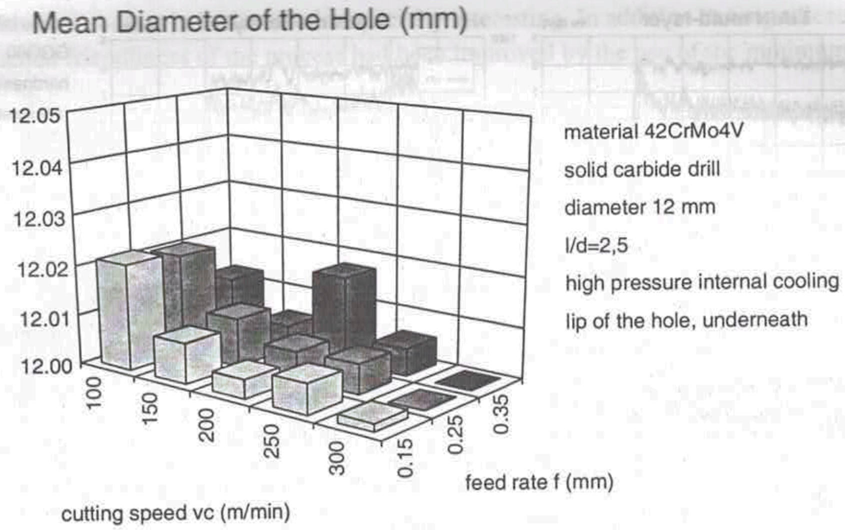

Figure 5 - Reachable quality using HSD I

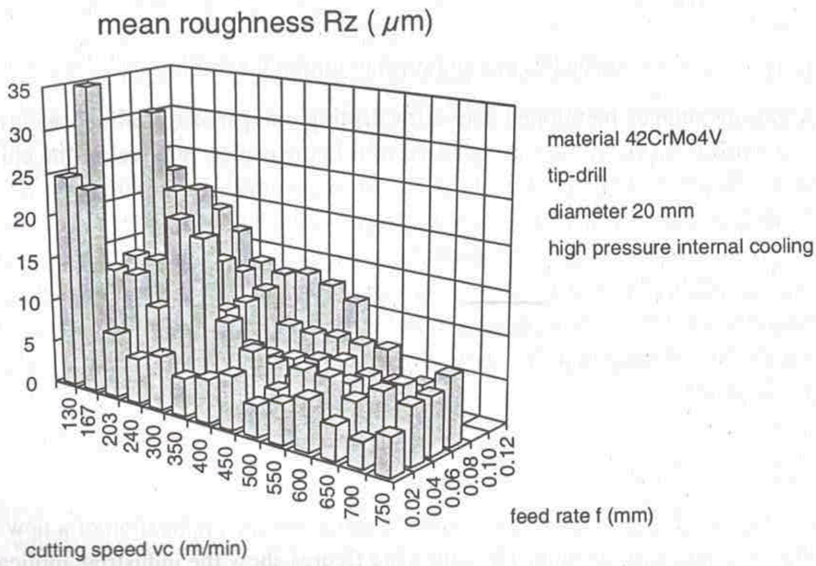

Figure 6 - Reachable quality using HSD II

4 Cutter material and coatings

In this relation figure 7 displays the influence of different coatings upon the process stability, for the drilling of GGG60 using solid carbide tools. The visualization is done by using the feed forces and drilling torque (SCHULZ et al., 1999).

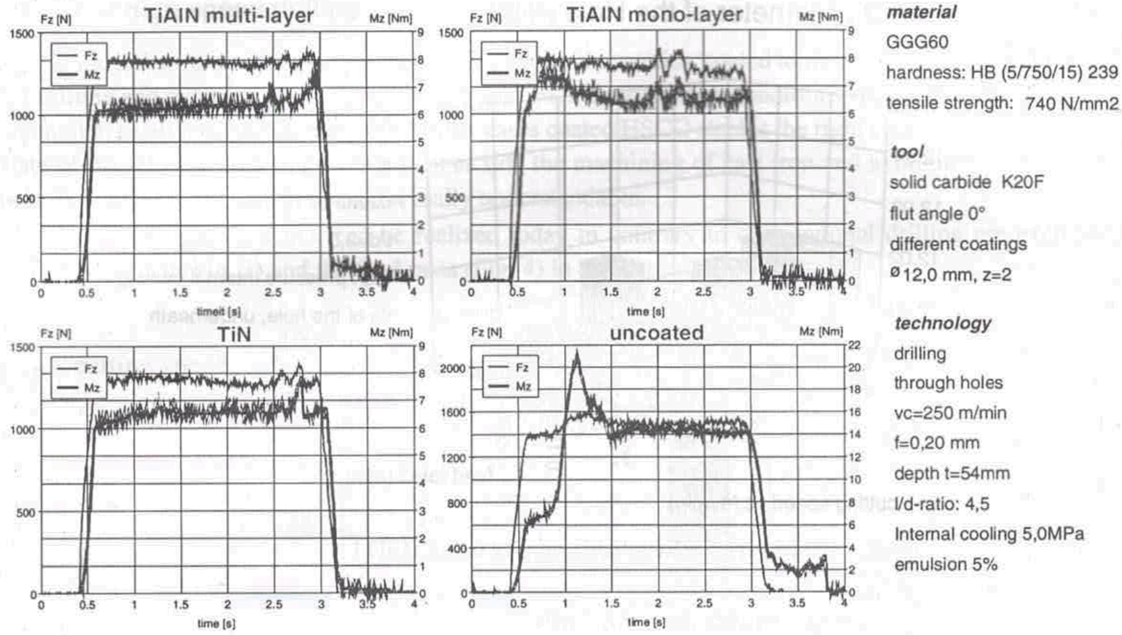

Figure 7 - Curves for feed forces and drilling torque for drilling into solid material

Out of the principal disadvantages mentioned above for drilling compared to milling or turning (a linear increasing cutting speed on the main cutting edges with a cutting speed of 0 in the center, removal of the chips from the hole ground through the flutes which are always to small, continuos cut and so on), results high requirements onto the coating technology and the tool substrate. Especially the varying cutting speed along the main cutting edge requires cutting materials and layers, which besides the standard requests for i.e. good adhesion, also require a combination of high toughness and compression resistance in the center and a high hardness and scuff resistance at the edges. For the cutting materials there have been some very interesting developments in the latest past (duo carbides) and also the field of solid carbide (KOHLBERG, 1997) has seen some advances. But also the coating industry shows some very interesting new results, like combined hard and glide layers of multiple Al_2O_3/TiN layers.

5 Machining examples

Besides the results achieved basically in research projects, the industrial application of a new technology is of special interest. This is also valid for high speed drilling. The following figures show the industrial applications.

Figure 8 - Example I - drilling sheet metal packages (wrought aluminum alloy)

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The renunciation of classical coolant in both cases is especially interesting. In addition to a significant reduction of the machining time, environmental friendliness of the process had been improved by the use of the minimum lubrication.

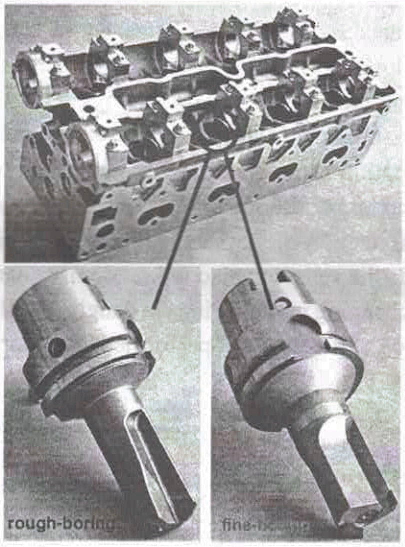

Figure 9 - Example II - rough- and fine-boring in a cylinder-head

6 Tool development

Many tools used in today's cutting production are the result of year long practical experiences. In the best case a combination of the know how of the research groups and of the laboratories of the universities combined with the practical experience of the customers lead to new products. This classical way is long and expensive because for example it takes EDM or grinding to produce a solid carbide tool. Long production time in combination with needed high class CNC-machines, which require costly programs, yield an expensive tool development and expensive prototypes (SCHULZ and EMRICH, 1999).

Still expensive carbide tools are used for example in drilling (which takes a 35% share of all the cutting operation (THIERFELDER,1988) instead of HSCO drills to increase the productivity (ADAMS, 1996). These are often very sensitive to bad cutting conditions, which makes it had to realize a process safety needed for the automated application. On the other side this safety is very important especially for drilling because of being at the end of the value added chain for most of the time (SPINTIG, 1995).

6.1 Problems in the development of drills

The development of drilling tools has to deal with special difficulties because of the often contradicting and differing requirements. The cutting speed being zero in the center of the drill would require a very ductile cutting material. In opposite to this, the cutting speed is maximal at the corners of the cutting edges, which asks for a highly wear resistant material. New developments like duplex carbides consider this fact. Another example of the totally contradicting interests is the chip flute design. For the optimal chip removal, flutes as big as possible are needed, for the best case an "unsupported cutting edge without a shaft". This has not (yet) been realized. To decrease the deviation or the breakage due to overload of the shaft material of the tool, a complete cylinder would be the optimal choice as cutting edge body. But this does not leave any room for chip removal. Therefore here is a classical conflict of targets: big chip flutes or high rigidity.

6.2 Genetic - biological basics

The method of genetic algorithms provide a great deal of advantages for those cases: On the one hand an optimization of several parameters at the same time is possible and on the other hand good convergence behavior is yielded which leads seldomly to sub optimas. Furthermore only little information about the system to optimize are needed. The disadvantages are a quite slow convergence and that a final convergence cannot be reached (see GOLDBERG (1989), for example). For the genetic algorithm the parameters defining the problem are first coded binary. All binary numbers (genes) are added to a so called (bit-) strings.

In the first step of this method some variants are produced by a random number generator, which build the so called generation (in this case the ancestor generation of the following optimization). All parameters are occupied by random values. After this all variants are evaluated. For the application described here, this is done in a finite element system. It's outputs are the maximum reduced stress as well as the maximum local displacement of a point on the tool contour to improve. At the same time another target function for the optimization is defined (here the minimization of the remaining diameter of the drill). Both values are combined to the actual target, the so called fitness.

With the aid of this fitness a new generation of a cross-section of variants is "grown". Variants with high fitness are preferred. The production of the generations includes beside the selection also the randomly change of the bit string coded parameters using crossover ("mating" of two parent tools exchanging partial strings to daughter tools) and mutation (randomly change of a gene in a bit string). The method of the calculation of the fitness is performed again for this new generation. Until a fitness of sufficient highness is reached the program loops (Fig. 10).

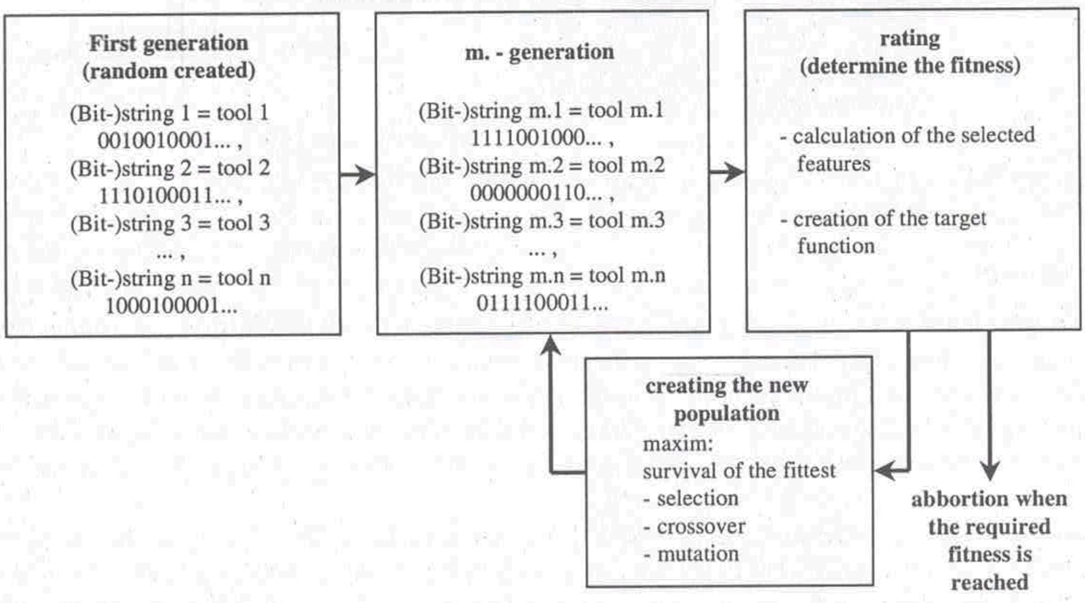

Figure 10 - Procedure of the generic algorithm

The procedure of the generic algorithm is closely related to the theory of biological evolution. It portrays the principle of the survival of the fittest. This system developed and tested for millions of years will be applied in the following to the above mentioned problem of the chip flute optimization.

6.3 Chip flute optimization

The stability of a twisted drill cannot be calculated by simple analytical methods, because of it's geometrical shape and the extraordinary complex load cases in the application. Besides a purely experimental evaluation of the drill geometry however a numerical calculation with finite element methods FEM is also well suited to determine the strength of a tool, at least as an approximation. Unfortunately the results of the FEM calculation cannot be set equal to those of the tests: it is only possible to make statements concerning one specific specimen, but no tendencies can be derived out of this. The influence of the different factors are only visible by a comparison of different variants (WEBB, 1993; ZIENKIEWICZ, 1977).

To optimize the geometry of a solid carbide drill regarding the chip flutes, the FEM system will be linked to an implemented optimization algorithm programmed in the C language. This realizes the optimization with the aid of the generic algorithm using a drill cross-section similar to DIN 1412, 1414 and 1836 for the drill shaft. The outer diameter of the tool is used as the input, whereas all the remaining contour parameter are automatically evaluated by the optimization algorithm. This parameterization guarantees, that the generated tool can be produced at least close to the calculated geometry. Forces and torque which occur during machining will be applied to this cross-section, which is additionally twisted around the vertical axis by the radial rake γF. The forces consist out of the cutting torque, the centrifugal load and a radial force, which represents the practical problems like radial deviation or the deflection of the tool.

Using the output of the FEM system the maximum reduced stress or the maximum local displacement and another target, the remaining cross-section of the drill (to be optimized), will be linked mathematically to evaluate the fitness. Goal of the analysis is to achieve a high utilization or a small deflection, while at the same time reducing the remaining cross-section of the drill. Especially a high bending force (like for drilling on sloped planes) leads to total failure of the tested solid carbide drills because of breakage.

Figure 11 exemplifies two "tool" cross-sections of a randomly generated ancestor generations of an optimization process. These have been obviously a bad evaluation and could not survive into the next process.

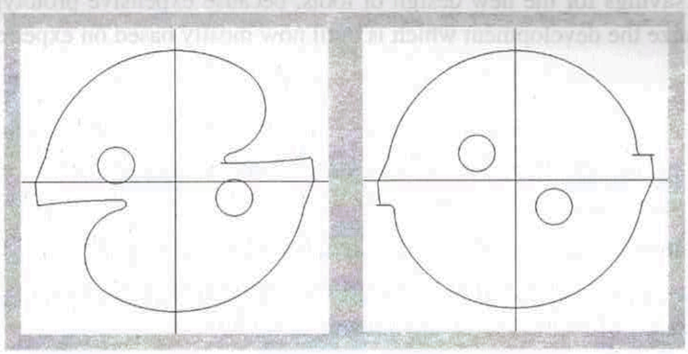

Figure 11 - "Tools" of an ancestor generation

Furthermore displays figure 12 a tool not designed by the classical approach, but it is rather the result of a successful optimization.

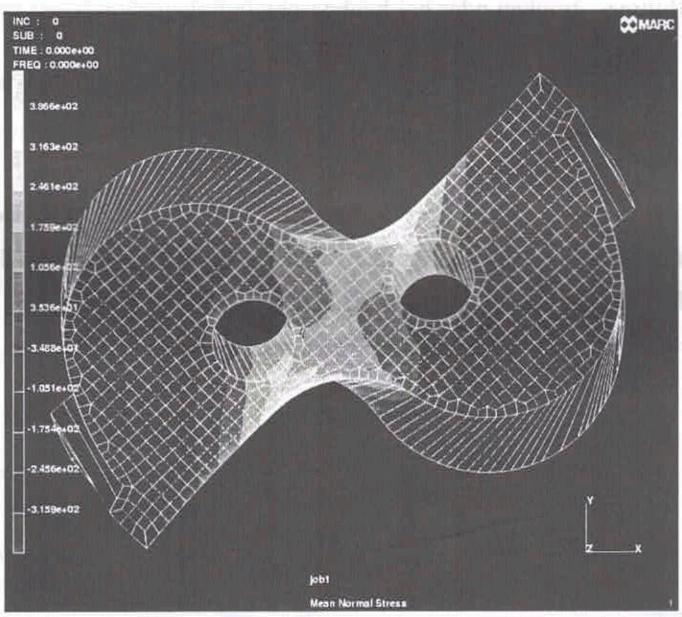

Figure 12 - Optimized Tool

The displayed tool is the result as the best assessed individual in the 19th generation of the optimization. In this it is important to consider, that there is no "optimal drill cross-section". This depends substantially on the characteristics of the tool material, the applied loads, which represent the planned application and also the resistance against breaking (to name only some parameters).

Now drill cross-sections for different applications can be generated by a variation of inputs (loads, shaft material properties, coolant channel size, etc.). This should simplify the development of user application specific tools, at least for the shaft and flute area in the future.

7 Conclusions

The technology of high speed drilling and reaming has left the laboratory stage at least for some applications. In the presented results it can be clearly seen, that this technology has a comparable potential like high speed milling, which has been accepted for a long time. But it's dissemination did not proceed as far as it would be desirable or possible. Especially in combination with the environmentally friendly technology of nearly dry cutting it has big potential. Besides this it could be shown, that new ways of tool development and design are possible. The presented method of optimization using generic algorithms yields significant savings for the new design of tools, because expensive prototypes can be omitted partially. Furthermore this can systematize the development which is until now mostly based on experience.

Reference

ADAMS, F. J. *Einsatzverhalten von symmetrischen, hartmetallbestückten kurzlochbohrern.* Essen: Universität Dortmund, Institut für spanende Fertigung. Vulkan-Verlag. 1996. 16p.

BULLINGER, H. J. Werkstattsteuerung mit leiständen. *Technika.* Darmstadt, v. 13, Oct. 1993.

BULLINGER, H. J. Wege aus der krise. In: GESCHÄFTSPROZEBOPTIMIERUNG UND INFORMATIONSLOGISTIK, 12., 1993, München. *Verfahren...* München: IAO - Arbeitstagung. 1993.

EMRICH, A. K. *Hochgeschwindigkeitsbohren und - reiben.* Wien: Hanser, 1996. 123p.

EMRICH, A. K. *HSD III - unveröffentlichtes projekthandbuch.* Darmstadt: PTW - Technische Universität Darmstadt, 2000. 4p.

GOLDBERG, D. E. Genetic algorithms in search. *Optimization e Machine Learning,* Reading, v. 124, Oct. 1989.

GÜHRING, J.; CSELLE, T. Bohren - trocken oder bei hochgeschwindigkeit. *Werkstatt und Betrieb,* Heft, v.127, p. 538-542, Mar. 1995.

HOFF, M. *Analyse und optimierung des bohrprozesses.* 1986. 143f. Dissertation an der RWTH Aachen.

KOHLBERG, G. Erfolgreiche präzisionswerkzeughersteller. *Werkstatt und Betrieb,* München, v. 130, p. 1147-1155, Sept. 1997.

KÜMMEL, D. *Mechanismen beim hochgeschwindigkeitsfräsen von Gubeisen.* Wien: Hanser, 1991. 211p.

SCHULZ, H. *Hochgeschwindigkeitsfräsen metallischer und nichtmetallischer werkstoffe.* München: Hanser, 1989. 67p.

SCHULZ, H. *Hochgeschwindigkeitsbearbeitung high-speed machining.* München: Hanser, 1996. 76p.

SCHULZ, H. et al. Dicker schutz durck dünne schichten. *Werkstatt und Betrieb,* München, v. 139, Apr. 1999.

SCHULZ, H.; EMRICH, A. K. Neue wege in der werkzeugkonstruktion. *Werkstatt und Betrieb,* München, v. 133, Mai 1999.

SPINTIG, H. *Prozebführung und werkstoffbeeinflussung beim bohren gehärteter stähle.* Düsseldorf: Fortschritt - Berichte VDI-Verlag, 1995. 123p.

THIERFELDER, A. *Beitrag zur auslegung des werkzeug-spindel-lager-systems für asymmetrisch bestückte hartmetall-wendeschneidplatten-bohrwerkzeuge.* 1988. 234p. These - Fakultät Fertigungstechnik, Universität Stuttgart, Stuttgart.

WARNECKE, H. J. *Die fraktale fabrik.* Berlin: Springer Verlag, 1992. 145p.

WEBB, P. The three: dimensional problem of twist drilling. *International Journal of Production Research,* München, v. 22, n. 5, p. 1247-1254, May 1993.

ZIENKIEWICZ, O. C. *The finite element method.* London: McGraw Hill, 1977. 213p.

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