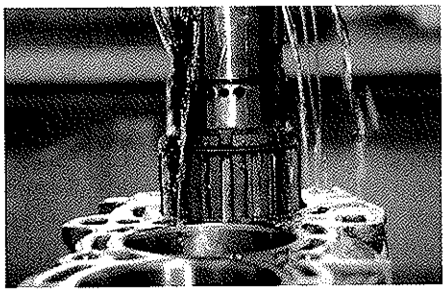
You will find the figures mentioned in this article in the German issue of MTZ 03I2007 beginning on page 180.

Funktionsgerechte Endbearbeitung von Zylinderbohrungen aus Gusseisen

Functionally Adapted Final Machining for Cylinder Bores Made of Cast Iron



The cylinder bore is of interest for functional and production development processes. The cylinder bore of the piston stroke engine is the place of the highest friction efficiency and its topographical design is decisive for the oil consumption and the emission of modern motor-vehicles, a challenge for engine development and production engineers. Gehring GmbH & Co.KG, Ostfildern, Germany, is an experienced partner for the realization of efficient cylinder bores. On the basis of the tribological requirements present honing variants are described.

Authors:
Gerhard Flores, Tobias Abeln and Ulrich Klink

1 Introduction

The honing process is concerned with engine specific development activities as production process for the cylinder bore. The realization of specific cylinder bore topographies is the task of the final machining development. In this manner new production variants like peak honing, plateau honing or laser structuring have been established which complement or replace other variants e.g. spiral slide honing. If it is not indicated differently this contribution refers to the application of cast iron.

2 Tribological Function

The most important application field of the cylinder bore made of cast iron with its different variants like GGG, GGL or GGV is the combustion engine. The main features are excellent sliding qualities, high structure resistance, high absorption properties, good machining conditions as well as attractive production costs. The following explanations relating to the cylinder bore tribology refer to cast iron materials as AlSi materials, thermal spray bores layers or nickel dispersion layers show different tribological conditions and require different machining technologies.

The tribological system is defined by the cylinder bore, the lubricant and the piston ring package. The respective friction conditions depend on factors like relative speed, lubricant parameters and normal force. They are given by design and by operation conditions. For this reason the macro as well as the micro geometry is of great importance for the cylinder bore. The micro geometry is defined by the functional values of the surface and their tolerances. Thus the topography is described by the profile shape and by the amount of profile changes within the measuring distance.

The tribological conditions are favourable if full hydrodynamic lubrication is given, **Figure 1**. Hydrodynamic pressure profiles are caused by local cross section narrowings under dynamical conditions which enable a stable formation of lubrication apertures. In this context superposed profile shapes are of importance. Profile sections of low roughness are responsible for the sliding functions. Other sections with deep scores serve as local lubricant storage [1]. During hydrodynamic lubrication conditions the oil film achieves just the minimum thickness in order to avoid solid contact. A possible design of the piston rings is a convex running surface. These counter shapes of the contact surfaces avoid mixed friction condition even at low piston speeds. The sinusoidal profile of the piston speed generates different local friction conditions. Especially at the top and bottom dead end arise mixed friction. In these sections the hydrodynamic lubricant film collapses. Partly solid contact is given. However due to the adhesion of the lubricant at the marginal surfaces seizing of components is prevented.

These tribological functions depend on the topography design and the herewith linked lubricant storage capacity of surface profile. The oil retention volume is defined by the profile depth and the distance of the profile peaks. In order to assure a sufficient lubrication on the complete running surface a scored structure is required which supports the distribution of the lubricant in the longitudinal and circumferential directions of the cylinder bore equally. The in contemporaneous oscillating stroke and rotational movement of the tooling result in the straight and crossed cutting traces of the honing stones, **Figure 2**. Thus the lubricant is omnipresent and it is stored sufficiently in the profile scores. The state of art shows cross hatches between 30° and 90°. The honing traces create a surface covering network of scores which form a communicating channel system by means of the points of intersections. The cross hatch is to be fixed so that the scores supply the vertical and the tangential directions of distribution equally.

The [2] investigated influences on the cross hatch show in case of decreasing cross hatch an increased lubricant film and a reduced friction. However it is also known that a small cross hatch (< 30°) gives a poor distribution of the lubricant in the longitudinal direction and that the engine tends to seizing. Increasing cross hatch (> 90°) dominates the distribution of the lubricant in axial direction. In this case it can happen that too much oil is transported towards the combustion chamber where it is burnt. In particular deep scores of the plateau profile with steep angle reduce moreover the gas density of the engine. The scores have a dominant axial direction and cause leakage towards the piston ring. The process variants like spiral slide honing [3] or glide honing can be considered as plateau honing processes. They lead to low oil consumption values [4] especially by the low values of core roughness depth R_k and reduced groove depth R_{vk}. A cross hatch of e. g. 160° has no advantageous influence on the oil consumption in the best case. But it is usually the contrary.

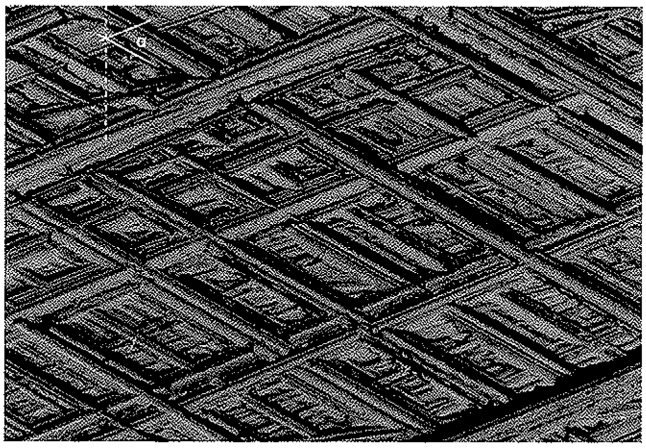


Figure 2: Cross hatch α of a surface honed with ceramic honing stones

Beside the micro geometry the macro geometry of the complete cylinder bore has great influence. The surface profile can only work under optimal conditions when complete form fitting between piston ring and bore surface is realized. This is largely given by the form filling capacity of the piston rings. The remaining form deviation has negative effects on the function regarding oil consumption and blow by.

3 Topography Development of Running Surface

At the beginning the development of the cylinder bore surface was determined by the requirements of fine surfaces with high bearing rate in low cutting depth which reduces the in-running phase and avoids an increased use [5]. This tribological comprehension is visualized in **Figure 3** and diagram point 1. However the rough surface succeeded [6] in being a tribologically safe solution but it had the consequence of high oil consumption. When the quality of the exhaust fumes and the oil consumption became more and more important then the oil retention volume of the running surface was reduced. A considerable reduction of the roughness was first realized by Japanese engine manufacturers (diagram point 2). All diagram points comprise surface specifications with cross hatches between approx. 40° to 60°. The reduction of the oil consumption was only achieved by the reduction of the surface roughness by preserving the cross hatch unchanged.

The respective replacement of single surface values can be explained by the increasing interest in the functional evaluation of the running surface relief and its single topographical elements. Furthermore new values have been developed in the field of surface measurement which allow a more functional evaluation of topographies. Apart from the cross hatch all other surface values have been developed or have been defined in a new manner and replaced by such values with a closer reference to the function. **Figure 4** shows the development of surface evaluation by different roughness parameters. At the beginning the RMS value was used which was common in USA. It corresponds with the root mean square R_q and delivers scarce information about the profile shape like the roughness average value R_a. The use of the roughness depth value R_t was always critical as in particular the actual roughness profile of the machining regarding cast iron material was highly influenced by material influences such as pipes or graphite accumulation. By the use of R_z these influences were reduced. The bearing roughness consists of the data of the plateau roughness A and the profile bearing part B as coordinates of the Abbott Curve and the complete profile depth C [7]. As for the determination manual evaluation was required the development of the bearing roughness can be considered as preparatory work of the nowadays used R_{vk}, R_k and R_{pk} values.

4 Present Definition of Running Face Topography

The low exhaust fumes and oil consumption values of modern combustion engines with very smooth surfaces are primarily based on the low oil retention volume V_o which is a surface parameter close to the function. The oil retention volume is a value for oil volume which still sticks to the roughness relief of the running surface after the slipping of the piston ring. It is calculated by means of the values R_{vk} and M_{r2} [8]. The optimized oil retention volume has to be laid out that neither a surplus of lubricant leading to high oil consumption nor a shortage of lubricant resulting in seizing of the piston are given. The consequence is a tribological system with low friction, low oil consumption and low emissions. For this reason the oil retention volume V_o should be tolerated two-sided for the production e.g. 0,010 to 0,040 mm³/cm². An oil retention volume of V_o = 0,1 mm³/cm² corresponds for instance to an average height of 1 µm of the lubricant film and to a smooth ideal surface of 1 cm².

Furthermore a theoretical oil retention V_{oil} [mm³/cm²] is known [9] which has a good correlation with the actual oil consumption at the beginning of use. This value is given by way of mathematical simulation of piston ring contact with running surface. With reference to the function it is also of importance if the oil retention volume V_{oil} is formed by a few wide or many small profile grooves. Therefore the given oil retention volume is related to the number of deep profile grooves within the measuring distance as V_{oilC} [mm³/cm²]. E. g. a plateaulike surface profile V_{oil} of 0,071 mm³/cm² leads to a V_{oilC} of 0,8 mm³/mm². Although the two-sided tolerance of V_o and V_{oil} as well as the measuring of V_{oilC} are not yet applied frequently it offers an interesting potential for a functional profile evaluation.

But it is a common practice to use the values of the reduced peak height R_{pk}, the core roughness depth R_k and reduced groove depth R_{vk}. They enable a differentiated evaluation of the roughness profile in different cutting depths of the roughness profile. The reduced peak height R_{pk} is of particular importance. The profile parts which are in contact with the piston ring are qualified herewith. A lowest possible R_{pk} value is advantageous in mixed friction condition. It is not to be achieved by the running-in phase of the engine but it is already to be realized by honing of the cylinder block. Due to this tribological function the R_{pk} is to be limited one-sided upward e.g. $R_{pk} \leq 0{,}30$ µm. The R_{vk} value is decisive for the oil retention volume. It is mainly formed by the deep groove structure as an element of the whole roughness profile. R_{vk} is to be also tolerated two-sided like V_o.

All roughness measuring values of the honing process show spreads which superpose the geometrical ideal groove formation by adhering micro particles, surface material deformations, shrinkholes or graphite accumulations. These deviations can be relatively influenced only during the honing process but not avoided. This is the reason for which statistical tolerance limitations for surface measuring cannot be used as they work with complete use of tolerance ranges.

Apart from the roughness parameters the deviations from the geometrical ideal surface profile and the condition of the edge zone are to be evaluated. They are material flake on the surface and material deformations which are designated as "Blechmantel". The deformation depth of the edge zone is evaluated by the grinding picture. There is no objective evaluation as no practicable value can be used. Fax films, optical representation processes or direct visual inspection of the surface by angle microscopes enable a subjective evaluation of the topographical condition. But it is to mention that the smoother surfaces show also less flakes, graphite lamella deformation and lower deformation depth of the edge zone.

5 Process Design

The functional running surface meeting the tribological requirements is the result of honing at the end of the surplus value chain. The different definitions of running surface topographies require an adaptable honing process with most reliable process stability. Honing is done on interlinked single machines or on honing transfer lines. Starting from the fine bored surface three honing operations are generally required for the correction of size precision, geometry and roughness. Diamond stones with high life times and short honing times are mostly used. Depending on the pre-machining condition and on the demanded topography the honing process is to be designed with different components and equipment.

5.1 Peak Honing

Peak honing generates a regular smooth surface profile, **Figure 5**. There are no defined particular profile shapes like plateau or closed micro pressure chambers. The main feature of peak honing is the complete removal of the preceding surface profile. The finished function profile is only the roughness profile of the last machining operation. The honing machine components like feeding system and tooling can be designed in a simple execution. The efforts for process control are low. Peak honing can be realized at a particularly attractive price. The requirements of most Otto engines for mass production are reliably fulfilled by peak honing.

5.2 Plateau Honing

Plateau Honing generates a well-aimed profile shape. It consists of regular smooth profile sections having excellent sliding properties as plateaus with low contact roughness. The deep grooves which serve mainly as lubricant storage are not regularly arranged. Therefore the finished function profile exists of a superposed surface profile, **Figure 6**. During the last honing operation only the profile peaks are removed so that the deep grooves of the semi-finishing operation remain partly as profile element.

Semi-finishing and finishing are carried out with one tool on one spindle. At the end of the semi-finishing operation the plateau honing stones are used. The passage to plateau honing is effected when the semi-finishing honing stones are still in operation. Thus the tool guidance is not interrupted at any time. Keeping up the stroke and rotation speed both profile elements get the identical groove direction and consequently the same honing angle. This combined final machining on one spindle requires double feeding systems and corresponding tools. The manufacturing technologies of plateau honing which sometimes is designated also as slide honing is proved and used all over the world for Diesel engines. The low oil consumption at the beginning due to the technically anticipated use is also a particular advantage for high stressed commercial vehicle.

5.3 Laser Structuring

The laser-structured and honed surface is a further optimization of the existing running faces. The communicating profile grooves of the surface form oil reservoirs. Now the laser structured pockets additionally work as micro pressure chambers in order to avoid largely the solid contact at the top and bottom dead end by hydrodynamic pressure, **Figure 7**.

The process consists of a combination of laser structuring and honing. Fine boring is followed by rough honing then by laser structuring and finally by finishing. Rough honing is done in one or two operations in order to improve the macro form and to create the basic surface for laser structuring. Hereby longitudinal pockets with a width of 40 to 80 µm and a depth of 5 to 25 µm are generated. Finishing removes the melted material accumulation caused by the laser operation and realizes a smooth running surface of approx. 1-2 µm Rz.

The evaluation of such a realized running surface results in aquaplaning of the piston ring, showing the increased distance between ring and cylinder surface. At conventionally honed engines this effect is not provable, **Figure 8** [10]. Friction research of structured surfaces shows that friction could be reduced by 60 %. Also the oil consumption of the same engine could be improved by approx. 70 % in comparison with former conventionally honed surfaces which leads to a reduced total particle emission of 25 %.

Laser structured surfaces lead not only to reduced oil consumption but also to reduced use of running surfaces and piston rings by up to 60 %. In the closed micro pressure chambers the hydrodynamic pressure can be better built up than by a plateau honed profile. This effect reduces considerably the solid contact at top dead end which results in a lower use of the reversal section.

6 Outlook

The realized surface structures are able to meet the requirements of the tribological systems of running surface and piston ring on a large scale. Depending on the material individual optimization can be necessary. However the effect of the structure is influenced by the macro form. Even it can be honed within microns the form deviations under operational conditions can be up to 0,040 µm. This is the reason for research of free forms honed as a preserved form which transforms into a cylindrical bore under stress condition.

References

[1] Abeln, T.: Reibungsminderung durch Laseroberflächenstrukturierung im Motorenbau. 3. VDI-Fachtagung „Zylinderlaufbahn, Kolben, Pleuel", 7.bis 8. März 2006, VDI-Berichte 1906

[2] Jocsak, J.; Li, Y.; Tian, T.; Wong, V.: Modeling and Optimizing Honing Texture for Reduced Friction in Internal Combustion Engines. In: SAE technical paper series 2006-01-0647

[3] Haasis, G.; Weigmann, U.: Neues Honverfahren für umweltfreundliche Verbrennungsmotoren. In: WB Werkstatt und Betrieb, Jahrgang 132 (1999) Nr. 3, S. 29 ff.

[4] Robota, A.; Zwein, F.: Einfluss der Zylindertopographie auf den Ölverbrauch und die Partikelemissionen eines DI-Dieselmotors. In: MTZ Motortechnische Zeitschrift 60 (1999) Nr. 4, S. 246 ff.

[5] Benz, W.: Oberflächengüte und Bearbeitungsverfahren. In: VDI-Zeitschrift Bd. 90, Nr. 10, Oktober 1948, S. 325-326

[6] Microhoning Automotive Cylinder Bores. In: Cross Hatch, Vol. 9, No. 4, Nov.-Dec-.1957, Schrift der Fa. Micromatic Hone Corporation, Detroit, Michigan

[7] Trautwein, R.: Bewertung der Oberfläche von Zylinderlaufbahnen. Firmenschrift, Fa. Mahle, Technische Information, Folge 13, September 1973

[8] DIN 4776, Ausgabe Mai 1990: Kenngrößen R_k, R_{pk}, R_{vk}, M_{r1}, M_{r2} zur Beschreibung des Materialanteils im Rauheitsprofil (Messbedingungen und Auswerteverfahren)

[9] MBN 31007-9: Theoretisches Ölhaltevolumen nach Kolbenringsimulation. Werksnorm Mercedes-Benz

[10] Golloch, R.: Downsizing bei Verbrennungsmotoren. Berlin, Heidelberg: Springer-Verlag, 2005

IMPRINT

MTZ WORLDWIDE

www.all4engineers.com

03|2007 · March 2007 · Volume 68
Vieweg Verlag | GWV Fachverlage GmbH
P.O. Box 15 46 · D-65173 Wiesbaden · Germany
Abraham-Lincoln-Straße 46 · D-65189 Wiesbaden · Germany

Managing Directors Andreas Kösters, Dr. Ralf Birkelbach, Albrecht Schirmacher
Senior Advertising Thomas Werner
Senior Production Ingo Eichel
Senior Sales Gabriel Göttlinger

EDITORS-IN-CHARGE
Dr.-Ing. E. h. Richard van Basshuysen
Wolfgang Siebenpfeiffer

EDITORIAL STAFF

Editor-in-Chief
Johannes Winterhagen (wih)
Tel. +49 611 7878-342 · Fax +49 611 7878-462
E-Mail: johannes.winterhagen@vieweg.de

Vice-Editor-in-Chief
Dipl.-Ing. Michael Reichenbach (rei)
Tel. +49 611 7878-341 · Fax +49 611 7878-462
E-Mail: michael.reichenbach@vieweg.de

Chief-on-Duty
Kirsten Beckmann M. A. (kb)
Tel. +49 611 7878-343 · Fax +49 611 7878-462
E-Mail: kirsten.beckmann@vieweg.de

Editors
Ruben Danisch (rd)
Tel. +49 611 7878-393 · Fax +49 611 7878-462
E-Mail: ruben.danisch@vieweg.de

Gernot Goppelt (gg)
Tel. +49 221 28056-91 · Fax +49 221 28056-92
E-Mail: gernot@goppelt.de

Dipl.-Ing. (FH) Moritz-York von Hohenthal (mvh)
Tel. +49 611 7878-278 · Fax +49 611 7878-462
E-Mail: moritz.von.hohenthal@vieweg.de

Dipl.-Ing. Ulrich Knorra (kno)
Tel. +49 611 78 78-314 · Fax +49 611 7878-462
E-Mail: ulrich.knorra@vieweg.de

Permanent Contributors
Christian Bartsch (cb), Rüdiger Baun (rb), Prof. Dr.-Ing. Peter Boy (bo), Prof. Dr.-Ing. Manfred Feiler (fe), Erich Hoepke (ho), Thomas Jungmann (tj), Prof. Dr.-Ing. Fred Schäfer (fs)

Assistants
Ellen-Susanne Klabunde, Martina Schraad
Tel. +49 611 7878-244 · Fax +49 611 7878-462
E-Mail: atz-mtz@vieweg.de

Address
Postfach 15 46, D-65173 Wiesbaden,
Tel. +49 611 7878-244 · Fax +49 611 7878-462

MARKETING | OFFPRINTS

Product Management Automedia
Melanie Engelhard-Gökalp M. A.
Tel. +49 611 7878-192 · Fax +49 611 7878-407
E-Mail: melanie.engelhard-goekalp@vieweg.de

Offprints
Martin Leopold
Tel. +49 228 6907-87 · Fax +49 228-6907-88
E-Mail: leopold@medien-kontor.de

ADVERTISING | GWV MEDIA

Ad Manager
Elisabeth Maßfeller
Tel. +49 611 7878-399 · Fax +49 611 7878-140
E-Mail: elisabeth.massfeller@gwv-media.de

Ad Sales
Frank Nagel
Tel. +49 611 7878-395 · Fax +49 611 7878-140
E-Mail: frank.nagel@gwv-media.de

Display Ad Manager
Susanne Bretschneider
Tel. +49 611 7878-153 · Fax +49 611 7878-443
E-Mail: susanne.bretschneider@gwv-media.de

Ad Prices
Price List No. 50

SUBSCRIPTIONS

Service
VVA-Zeitschriftenservice, Abt. D6 F6, MTZ
Postfach 77 77, 33310 Gütersloh
Tel. +49 5241 80-1968 · Fax +49 5241 80-9620
E-Mail: vieweg@abo-service.info

Management
Renate Vies
Tel. +49 5241 80-1692 · Fax +49 5241 80-61692
E-Mail: renate.vies@bertelsmann.de

PRODUCTION | LAYOUT
Kerstin Gollarz · Heiko Köllner
Tel. +49 611 7878-173 · Fax +49 611 7878-464
E-Mail: kerstin.gollarz@gwv-fachverlage.de
E-Mail: heiko.koellner@gwv-fachverlage.de

PRINT | PROCESSING
Imprimerie Centrale Luxemburg. Printed in Europe.

SUBSCRIPTION CONDITIONS
The journal MTZ appears 11 times a year (with at least 5 additional special editions) at an annual subscription rate of 209 €. The price for an annual subscription including the English text supplement MTZ Worldwide is 259 €. Special rate for students on proof of status in the form of current registration certificate 81 €. Special rate for students including the English text supplement MTZ Worldwide 120 €. Special rate for VDI/VKS members on proof of status in the form of current member certificate 153 €. Special rate for studying VDI/ÖVK members on proof of status in the form of current registration and member certificate 45 €. Price per copy 23 €. All prices exclude mailing (annual subscription: inland 21 €; foreign countries 35 €; AirMail 109 €; annual subscription including the English text supplement MTZ Worldwide: inland 22 €; foreign countries 44 €; AirMail 119 €. Cancellation of subscriptions in writing at least six weeks before the end of the subscription year.

The Vieweg Verlag is a company of Springer Science+Business Media.

HINTS FOR AUTHORS
All manuscripts should be sent directly to the editors. By submitting photographs and drawings the sender releases the publishers from claims by third parties. Only works not yet published in Germany or abroad can generally be accepted for publication. The manuscripts must not be offered for publication to other journals simultaneously. In accepting the manuscript the publisher acquires the right to produce royalty-free offprints. The journal and all articles and figures are protected by copyright. Any utilisation beyond the strict limits of the copyright law without permission of the publisher is illegal. This applies particularly to duplications, translations, microfilming and storage and processing in electronic systems.