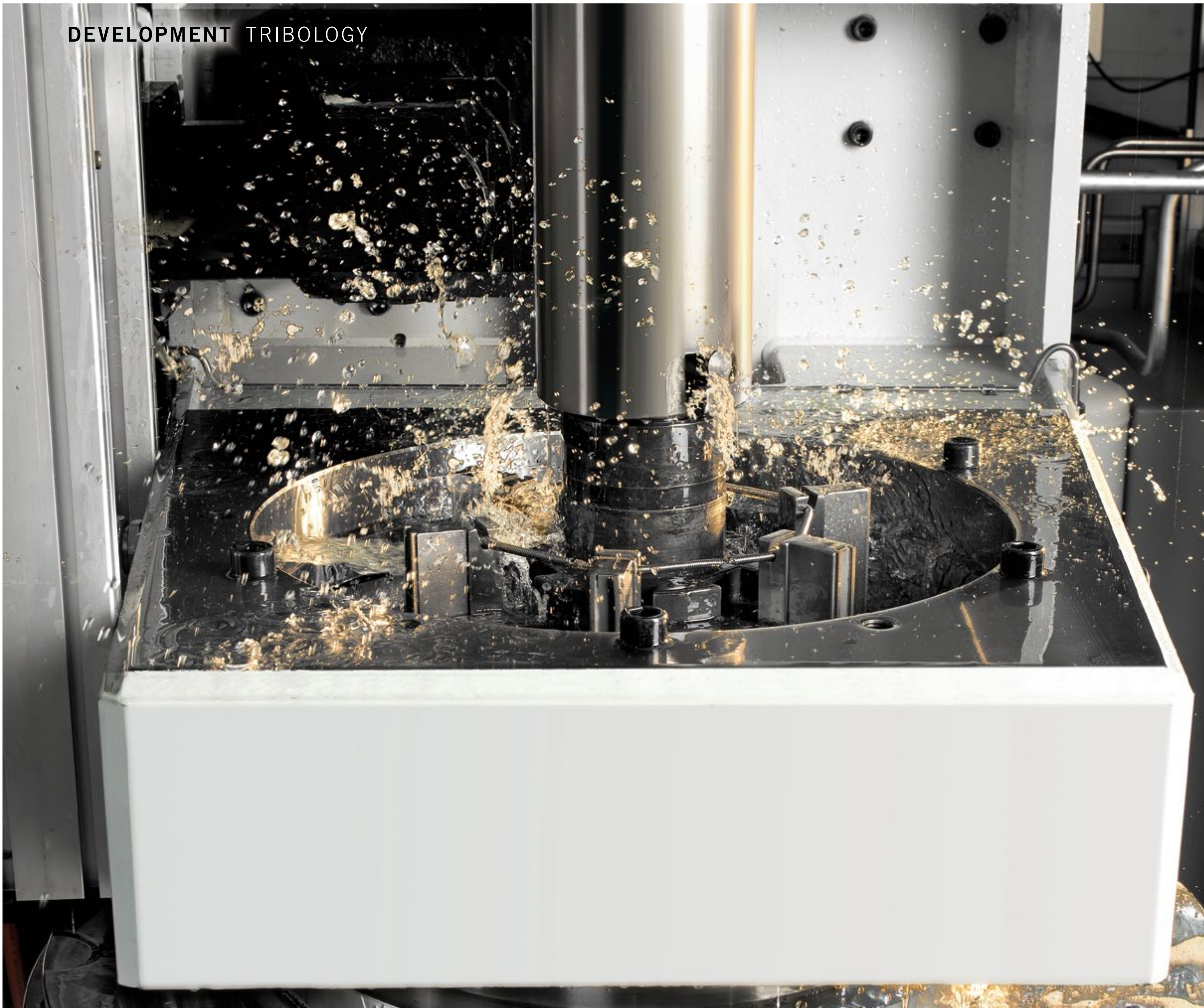

LARGE ENGINE CYLINDER HONING AS A CONTRIBUTION TO EMISSIONS REDUCTION

As well as new combustion processes and aftertreatment, increasingly rigorous environmental protection regulations are also promoting advances in engine manufacturing techniques. These measures include optimised surfaces made possible using the most modern honing technologies, such as those already in widespread use in the manufacture of automotive engines. The transfer of these honing technologies to large high and medium speed engines is best achieved using new machining concepts.

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EMISSIONS BENEFITS OF MODERN MACHINING METHODS

Engines for marine propulsion, rail traction and stationary generator and compressor sets are subject to tightening emissions regulations. A strong focus in marine applications is the 80 % reduction in NO_x emissions in Emissions Control Areas under IMO Tier III, but equally urgent is the need to reduce (and maintain), for example, particulate emissions in ECAs from 1 % m/m from July 2010 to 0.10 % from January 2015 and 4.5 % to 0.5 % outside ECAs.

Hence, as well as emissions from the basic engine function of burning fuel in air, emissions related to factors like lubricating oil consumption and cylinder blow-by must also be addressed. These are closely dependent on the wear characteristics of paired materials, and so influenced by the machining of their surfaces. With regard to piston rings and cylinder surfaces, precise honing of the cylinder liner, to create plateaux and cross-hatch patterns with narrow but deep honing striations, are state-of-the-art methods of ensuring good lubricant retention and optimised friction, especially at the piston's upper reversal point. Hence precise honing promotes low wear, optimised specific fuel consumption and, via reduced lubricant consumption, avoidance of particulate emissions in diesels and combustion knock in gas engines. In recent years, refined honing techniques have been widely applied on automotive engines which could be usefully transferred to larger high and medium speed engines.

Moreover, special coatings with wear inhibiting characteristics, already in wide use, are set to play a growing role on future large engines and only honing techniques can be considered for machining coatings to a residual thickness as thin as 0,1 to 0,2 mm. Machining technologies with geometrically defined cutting edges are ruled out for reasons of both their useful life and the quality of the finished surface.

As a result, there is a perceived need for new honing machines specifically designed for processing large engine cylinder liners. To meet this demand, Nagel Maschinen- und Werkzeugfabrik GmbH has developed the new VLM18 honing machine.

❶ Stratum honing to achieve a steeper, wear-reducing honing structure in around the piston reversal points

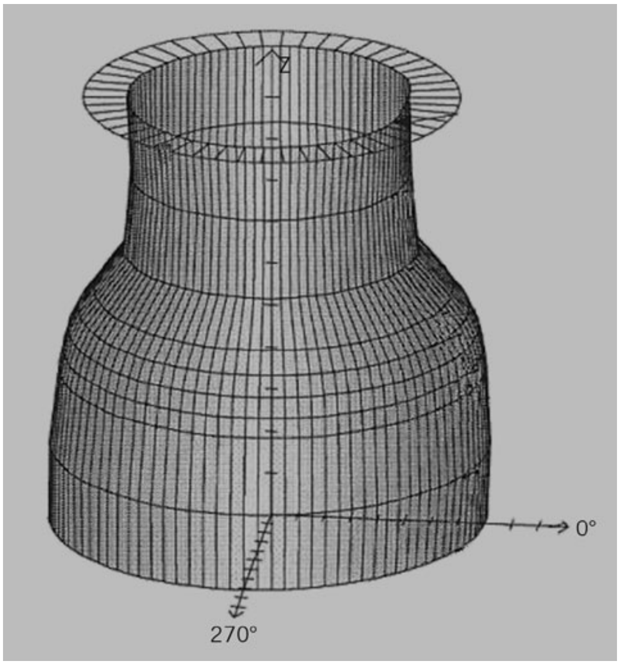
TARGETED HONING PATTERNS, TARGETED CYLINDER GEOMETRY

As the final machining step, honing plays an important role in determining the wear characteristics of pistons, piston rings and cylinders. It thus represents a decisive technology for maximising the useful life of large engines while minimising their emissions. Contributory factors include friction reduction from optimised surfaces with favourable lubricant retention and improved piston-to-liner sealing. These derive from the capability to produce targeted liner geometries in defined zones as a means of reducing lubricating oil combustion by controlling ingress into the combustion chamber during the compression stroke. Similarly, blow-by of products of combustion into the crankcase during the power stroke is better controlled.

A problem zone is, in particular, the upper reversal point of the piston in the cylinder liner. When a certain stage of wear is reached at this position, the piston rings are no longer able to prevent lubricating oil from entering the combustion chamber. One potential way of minimising wear is to match the typical rhombic pattern of piston movement to piston speed. During the rising piston stroke this varies from its maximum at the midpoint of the cylinder to zero at the top dead centre piston reversal points.

FORM HONING AND HELICAL SLIDE HONING

Engine developers therefore specify surface conditions matched to piston speeds, referred to by specialists "stratum honing". As shown in ❶, stratum



❷ Exaggerated representation of form honing and bottleneck honing techniques, resulting in a smaller cylinder diameter around the upper reversal point

honing enables the production of variable honing structures in the axial direction of the cylinder liner, comprising a wear-reducing pattern in the vicinity of the piston reversal points, based on a "steeper" cross hatch angle.

Requirements for finished cylinder liners are defined in terms of roundness and cylindricity as well as the shape the surface profile. In combustion engines the specifications take account of distortion of the cylinders during both engine assembly and engine operation. Critical is distortion in the cylinder's combustion zone, adjacent to the combustion chamber, where firing pressure around the upper reversal on the power stroke expands the cylinder and increases the piston ring gap.

Clearly, such distortion compromises the piston ring's ability to reliably seal the combustion chamber, hence decreasing engine efficiency and increasing oil consumption. The larger ring gap also favours the blow-by of combustion residues past the piston and into areas of the engine where they are detrimental. Specifically, blow-by contaminates lubricating oil to the detriment of wear in the whole engine, as well as contributing to crankcase oil mist and crankcase emissions (breathings). In addition, piston slap can occur due to the expanded cylinder dimension, further contributing to wear and noise, vibration and harshness during engine operation. Due to their very high firing pressures this effect is particularly pronounced in modern large engines.

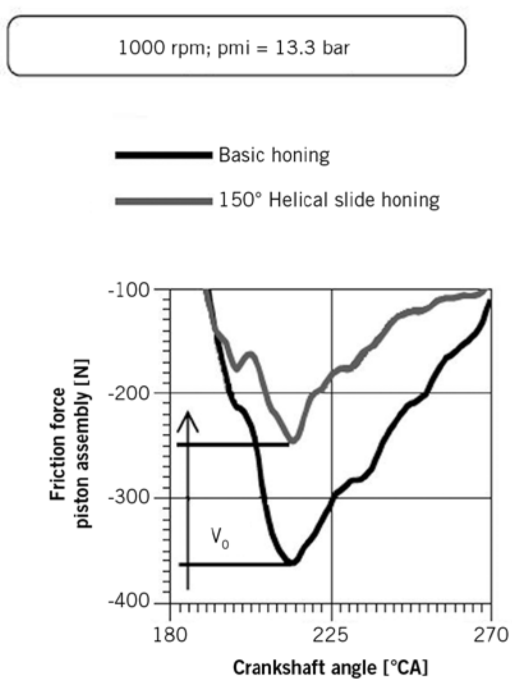
To counter the distortion, Nagel Maschinen- und Werkzeugfabrik GmbH developed a "form honing process". An example is depicted in ❷. Form honing allows distortion to be compensated during the production process by targeted shaping of the cylinder, so that an almost perfect cylindrical form results in the running engine. Much exaggerated, the form achieved in the cylinder combustion zone is reminiscent of a bottleneck

A further Nagel development is the "helical slide honing process" which leads to considerably reduced friction and oil consumption in comparison to conventional plateau honing. These benefits been verified in long-term tests over operating times up to 3000 hours.

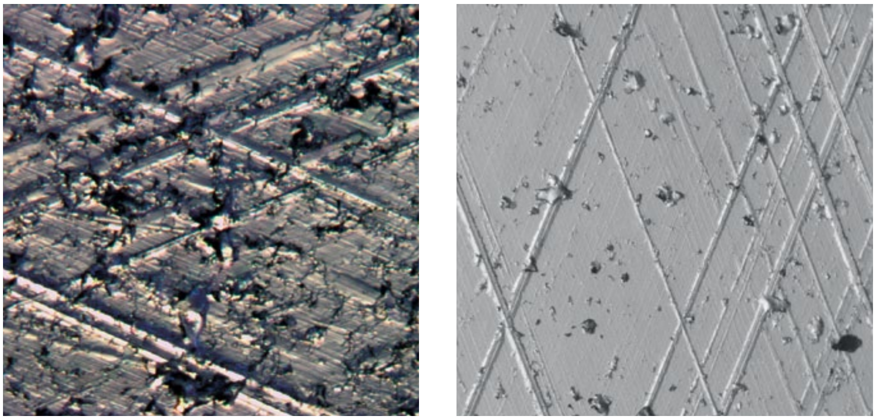
ADVANCED HONING BENEFITS ON LARGE ENGINES

In mass produced high speed engines for cars and commercial vehicles, form and helical slide honing have proven their value in terms of a substantial reduction of wear and mitigation of the other negative effects described above. However, to date form and helical slide honing have played virtually no part in the manufacture of large high and medium speed engines. Yet it is precisely large engines for rail traction, marine propulsion and stationary power systems, with life expectancies up to 30 years and more, that would benefit from the long term improvements these techniques confer by minimising wear dependent emissions year-on-year.

To achieve this technology transfer, Nagel has developed the VLM18 honing



❸ The friction measurement shows that helical slide honing with a steep honing angle of 150° brings about a significant reduction of friction compared with basic honing at a 45° honing angle

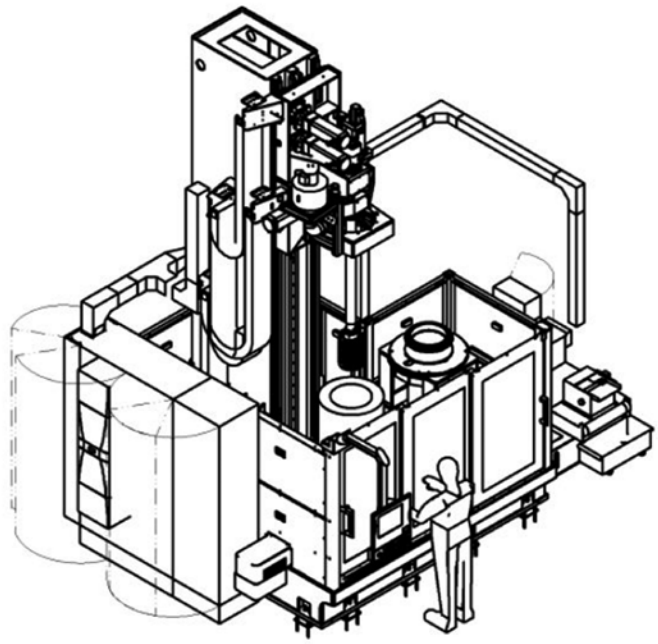


❹ Conventional honing pattern (left) and helical slide honing with a steep honing angle (right)

machine for large cylinder liners, As shown in ❸, friction measurements made during the development of the VLM18 machine demonstrated that helical slide honing with a steep, 150° cross hatch pattern angle together with suitable surface parameters brought about a significant reduction in friction compared with classic honing based on a 45 ° cross hatch. The result is reduced wear and therefore longer effective life. It was demonstrated that even very narrow piston rings slide more easily to their reversal points over the steep 150° honing structure. In addition, as shown in ❹, stick-slip effects, which contribute to wear, are eliminated. As a result of the high flexibility the new honing machine, combinations of various honing strategies are possible, like helical slide honing with stratum honing and/or bottleneck honing.

MACHINE DESIGN AND DEVELOPMENT

The scale of the VLM18 machine for large cylinder liners is shown in ❺. It is designed to apply the advanced honing techniques described to cylinder liners for large engines with diameters up to 380 mm. The new machine employs advanced control technology and an inno-



❺ The vertical axis type VLM18 honing machine for large cylinder linings up to a diameter of 380 mm

vative electro-mechanical honing spindle to achieve the precise and rapid variations in cylinder surface and geometry required to produce the honing patterns and geometries described. As well as the maximum machining diameter of 380 mm, the VLM 18 machine can be applied to workpieces weighing up to 300 kg and offers a maximum honing length of 1000 mm and maximum lifting speed of 50 m/min.

For the task of honing of large cylinder liners it did not prove feasible to simply scale-up a proven concept for smaller engines. In order to achieve the same honing result in a cylinder with a diameter of more than 300mm as in a cylinder of 80 mm diameter, new designs were called for.

Following an extensive development programme, a combination of the new electro-mechanical spindle and a control system featuring lift position dependent speed reduction was adopted. Importantly, it proved fully capable of executing complex honing patterns around the upper and lower piston reversal points. As the name implies, the control system allows the rotational speed of the honing spindle and the lifting stroke of the honing head to be exactly synchronised and the direction of spindle rotation to be rapidly changed at the piston reversal point.

In addition, the new solution is designed to offer higher honing speeds and hence shorter working cycles. A high precision but rugged gear rack guide design is used to achieve the required accuracy for the control of the heavy honing tools needed for large engine liners. These characteristics did not prove achievable using an hydraulic drive system, also initially considered. The reaction time of the hydraulic system proved too slow, given the large masses of the moving parts and resulted in a curvilinear surface structure. Likewise, ball-screw spindle drives, as used in the production of car and commercial vehicle engines, did not prove satisfactory when tested. In the trials undertaken, the new machine has proven more economical in terms of electrical power consumption and working cycle times, as well as

❻ The type VLM18 honing machine showing vertical axis design

more process-secure than honing machines featuring traditional drive and positioning concepts.

In a further departure from traditional large engine honing equipment, as seen in ❻ the VLM18 honing machine for large cylinder liners also features a vertical axis. In the large engine sector, horizontal honing machines have hitherto predominated. In addition to offering lower dynamic control, material removed may fall onto the workpiece due to gravity and interfere with the precisely defined removal of material. This is particularly the case when honing coatings at typically high rates of stock removal. The vertical design adopted for the VLM 18, by contrast, allows removed material to fall downwards, clear of the workpiece.

CONCLUSION

The targeted features of the new Nagel VLM 18 honing machine allow the application on large high and medium speed engines with bore diameters up to 380 mm, of cylinder honing techniques already widely applied on smaller engines for automotive and truck applications. Application of the new techniques is expected to be a factor in achieving and maintaining over long term engine operation, strict emissions legislation, by ensuring low cylinder wear and hence good piston sealing, especially in engines logging high total operating hours. The honing techniques made possible directly reduce both blow-by of combustion products into the crankcase and ingress of lubricating oil into the combustion chamber. Techniques like form honing and helical slide honing will enhance large engines' tribological characteristics, to the benefit of mechanical efficiency and hence specific fuel consumption (SFC), leading in turn to the abatement of emissions directly related to fuel consumption like oxides of sulphur (SO_x) and the greenhouse gas carbon dioxide (CO_2).

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