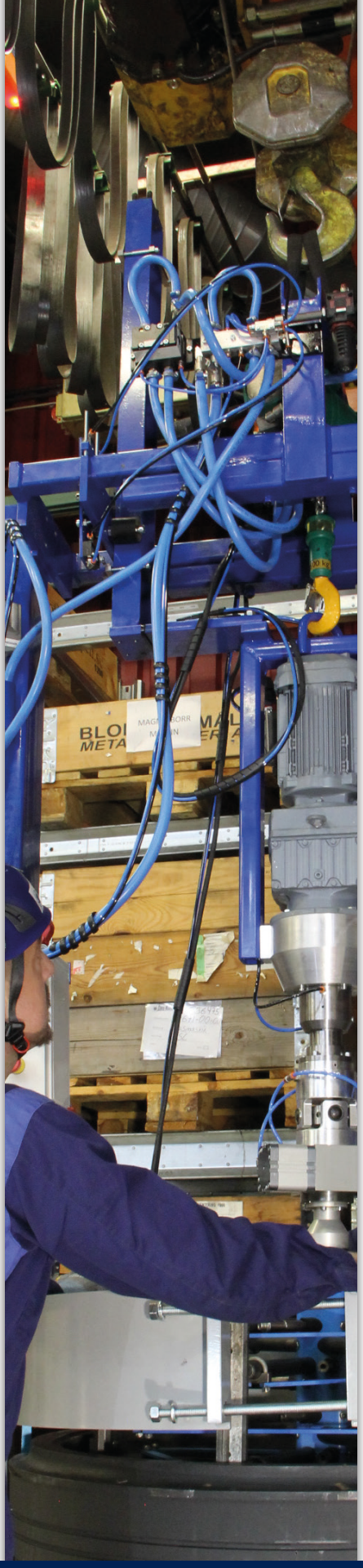


Cylinder condition monitoring and reconditioning

2-stroke engines

Innovative engineering since 1962

CHRIS-MARINE®



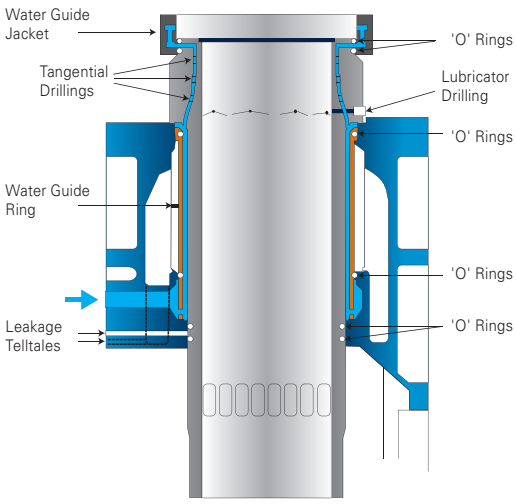
Why prioritise cylinder condition monitoring & reconditioning of 2-stroke engines

The cylinder lube oil is fed separately in a marine 2-stroke engine, which is different from 4-stroke engines. This allows for minimizing the cylinder lube oil consumption, but it also makes the 2-stroke engine more sensitive to disturbance caused by inaccurate lube oil feed or lube oil type. For economical operation, the alkali content of the lube oil, the so called Base Number (BN), and the oil feed rate should be balanced against the fuel oil Sulphur content to avoid cylinder condition issues without excessive spending of lube oil.

Too little lube oil or too low lube oil BN will cause an abnormal condition called cold corrosion, where Sulphuric acid from combustion is not fully neutralized, thereby leading to increased wear rate through corrosion.

Too much lube oil or too high BN can cause an abnormal cylinder condition called bore polish. This condition occurs when the absence of corrosion leads to glazing of the cylinder liner, preventing the liner wall from acting as an oil reservoir. In rare cases calcium deposits can also lead to hard contact between piston crown and cylinder liner thereby scratching the cylinder liner.

Cold corrosion and bore polish can both lead to a high cylinder wear rate and cylinder scuffing.

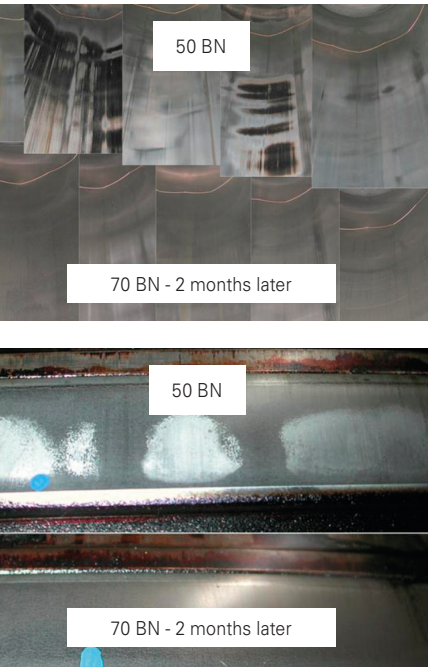


Schematic of 2-stroke cylinder liner with high lube oil quills. Source: www.marinediesels.co.uk

How to identify cold corrosion

Cold corrosion is probably the most common reason for increased cylinder liner and piston ring wear rates seen in modern engines. Corrosion patterns can be visually observed in the cylinder liner as well as on Chromium-coated piston ring types. Higher lube oil feed rate and / or higher BN lube oil will stop the corrosion attack and thereby reduce the wear rate.

Cold corrosion can be identified through visual inspection of cylinder liner and piston rings with aid of the Chris-Marine Liner Condition Camera (LCC). Wear on cylinder liners and piston rings can be measured with the Chris-Marine Liner Diameter Measuring instrument (LDM) and the Coating Thickness Measurement tool (CTM). All these tools can be used without immobilizing the engine more than 15 mins. There are test kits available in the market for checking the iron content and remaining BN number in scrape-down lube oil. Such kits can be used in combination with the Chris-Marine tools when tuning the lube oil feed rate to an economically favourable level.



Cold corrosion shown as black lacquer in cylinder liner (above) and oxidized chromium on piston rings (lower). After introduction of higher BN lube oil during two months of operation, the surfaces have normalized. Source: Castrol (CIMAC 2013).

The 2020 low-S fuel legislation

Chris-Marine has found that several 2-stroke engines found in the modern world fleet have not been set to balance lube oil type and feed rate against fuel type in an economical way. The main reason for this is that modern engine types are more susceptible to cold corrosion because they have:

- Longer stroke length -> more difficult to distribute fresh oil -> higher wear rate
- Lower engine speed -> more time for sulphuric acid condensation -> cold corrosion
- Miller cycling -> a colder combustion chamber -> more sulphuric acid condensation -> cold corrosion
- Higher cylinder pressure -> more sulphuric acid condensation -> cold corrosion

Multiple-fuel technology adds further complexity regarding oil type and feed rate minimization.

The 2020 low-S fuel legislation is likely to further increase the number of cylinder condition issues in the world fleet. In practise, 2020 low-Sulphur fuel oils will push the cylinder condition toward bore polish, meaning for instance that it will be important to have a honing cross-pattern structure acting as oil reservoir for the engines to work well in absence of corrosive wear.

Life time expectancy for cylinder liners found in modern 2-stroke engines

In recent years, Chris-Marine has been collecting cylinder wear rate data from the market during equipment training sessions. A theoretical cylinder liner life time can then be computed from wear data, assuming that no actions are taken to change the cylinder wear rate. A summary is shown below. The data indicates that 10% of the vessels are going to wear out all cylinder liners before the vessel reaches an age of 5 years, i.e. a common interval for the first dry-docking. Another 14% of the vessels will wear out all cylinder liners before the second dry-docking. So 24% of the modern fleet of 2-stroke engines will have a life expectancy for cylinder liners of 10 years or less.

At the same time, 47% of the vessels have cylinder liners that will last 20 years or more. The data indicates that some operators have already implemented economical combinations of technology and lube oil strategy, whereas others are going to suffer, or have already suffered, from cylinder liners getting worn out very quickly. The reason for the shorter life expectancy is the current engine development trend as explained before.

Liner lifetime	<5 years	5-10 years	10-20 years	>20 years
#vessels	13	19	39	62
Share	10%	14%	29%	47%
Current age	1.5	2.4	5.9	10

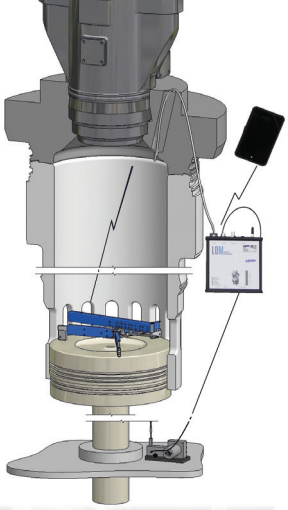
Cylinder liner lifetime expectancy for 133 vessels measured with Chris-Marine equipment.

Average age of fleet:
6.9 years @ 6,000Rh/year

The table above indicates that at least 10% of new vessels entering the market are going to experience urgent replacement of cylinder liners before the first dry-docking if cylinder condition monitoring is not appropriately practised. So what is the financial consequence of such urgent replacement or refurbishment of cylinder liners? Firstly, there is an apparent risk for off-hire, especially if vessels are not allowed to immobilize engine during port stays. Secondly, overhauling costs will increase dramatically due to freight costs and poor negotiation position when new cylinder liners or flying service squads are sourced. The Chris-Marine condition monitoring tools are therefore very useful when minimizing the lube oil feed rate of modern engines or consequences can be very costly.

The Chris-Marine cylinder condition monitoring portfolio for 2-stroke engines

The Chris-Marine cylinder condition monitoring portfolio allows for time-effective collection of cylinder liner and piston ring data. All tools can be used without removing the cylinder cover.



CHRIS-MARINE®
LDM

LINER DIAMETER MEASURING INSTRUMENT

Measures cylinder liner wear / remaining life time, ovality and clover leafing. Liner time scale: ~1000 Rh. Measurement time: ~1 h/liner.



CHRIS-MARINE®
CTM

COATING THICKNESS MEASUREMENT TOOL

Measures the wear rate / remaining life time for coated piston rings. Liner time scale: ~1000 Rh. Measurement time: ~15 mins /liner.

CHRIS-MARINE®
LCC

LINER CONDITION CAMERA

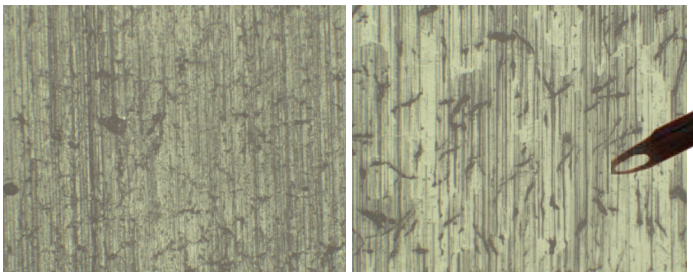
Scans / documents the condition of cylinder liner surface, exhaust valve, piston rings and piston crown.
Liner time scale: ~100 Rh. Measurement time: ~15 mins /liner.



CHRIS-MARINE®
RAM

REPLICA ANALYSIS & MICROSCOPY

Takes an imprint of the liner that is later analysed in microscope in Chris-Marine's laboratory.
Liner time scale: ~100 Rh. Measurement time: ~15 mins /liner.





Microscopic pictures of the cylinder surface from replicas from a liner on the onset of scuffing (left) and a normal liner (right) from the same engine taken during the same inspection, prior to dry-docking.

The Chris-Marine cylinder condition monitoring reporting service

We know that time is limited for the crew members operating today's vessels. This is why we have made a great effort in making our tools as user-friendly as possible. So data collection is straight-forward, but interpreting the data can be more difficult. Therefore, Chris-Marine has introduced a cost-effective reporting service allowing customers to collect data cost-efficiently on their own and send it to Chris-Marine for processing. Chris-Marine will then revert with a report summarizing the findings and comparing the results to other engines of similar type.

A report can include:

- Cylinder liner wear, life expectancy and clover data collected with the LDM, with recommended cylinder maintenance actions based on findings.
- Cylinder liner and piston ring pictures taken with the LCC and analysis of the cylinder condition (under-lubricated / over-lubricated / critical).
- Piston ring wear and life expectancy from data collected with the CTM.
- Cylinder condition and cat fine analysis though microscopic images from replica imprints collected through scavenge air port. This method is especially useful when changing from high-S fuel oil to low-S fuel oil after 2020.

Why and when do cylinder honing?

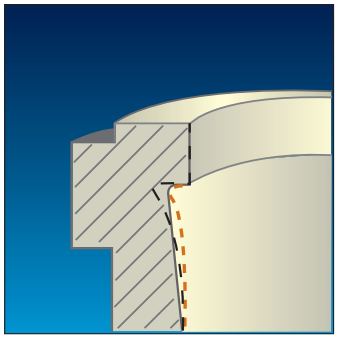
The main reason for re-conditioning a cylinder liner is to rectify its longitudinal and circumferential geometry and to restore its oil-retaining surface properties. Engine makers define a maximum recommended wear level for each engine type. This limit is approx. 0.7%-0.8% of the nominal bore size, i.e. 3.5-4.0 mm for a 500 mm liner. The cylinder wear rate is often considered normal by makers when it is lower than 0.1 mm/1000hrs. Such a wear rate will offer a life expectancy of 35,000-40,000 hrs for a 500 mm bore liner, corresponding to 5-7 years in service. Under those conditions, it is normally more economical to replace the cylinder liners during the first docking instead of reconditioning them. However, when the lube oil feed rate and type are matched appropriately; the average wear rate is often as low as 0.01-0.02 mm/1000hrs. This means for the same bore size that cylinder liners could last longer than the vessel itself.

Cylinder honing during dry-docking is therefore an excellent alternative for prolonging the life expectancy of the liners so that the official wear limits defined by makers can be achieved without issues. As a rule of thumb, a remaining liner life expectancy of 50% at the time of docking will normally make cylinder honing more economically favourable compared to replacement. The larger the bore size, the larger is the economical saving from honing compared to replacement.

If honing is not practised then there is a risk that the maximum wear limit given by makers will not be reached before cylinder condition issues appear. Common cylinder condition issues are then broken piston rings and cylinder scuffing.

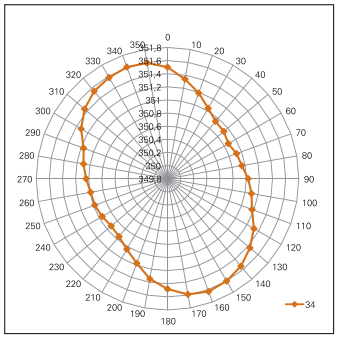
How modern 2-stroke cylinder liners are worn

A so called trumpet-shape will always appear at the top of the liner after some time in service. A similar trumpet can sometimes appear at the lower end of the liner. A too steep trumpet shape in the liner will eventually prevent the piston rings from functioning properly.



Trumpet-shape

The cylinder liner will also become non-circular after some time in service. Modern cylinder liners often attain a harmless oval shape due to thermal and mechanical deformation. The ovality direction will then typically shift along the stroke of the liner. Under corrosive conditions, the liner shape is eroded by the fuel plumes to attain a 2-clover or 3-clover shape in the upper part of the liner which can disturb the piston ring function. When the circumferential lube oil distribution is insufficient, the cylinder liner can attain a multi-clover shape following the pattern of the lube oil quill distribution, which will disturb piston ring function even more. Clover leafing can therefore become critical long before the official wear limit has been reached so general recommendations for cylinder liners are quite difficult to establish for engine designers. Chris-Marine has long experience from interpreting cylinder geometry data and correcting it through honing. We can therefore assist customers by recommending appropriate cylinder liner maintenance actions based on LDM measurement data and microscopy analysis of replica imprints.



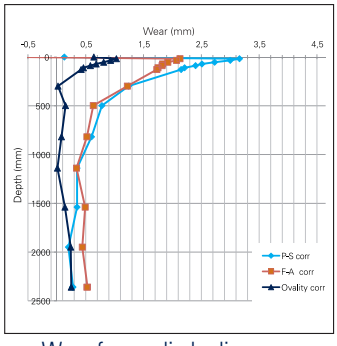
Clover shape

How can honing prolong the life expectancy of a cylinder liner?

As mentioned above, the economical wear limit for cylinder honing is approx. 0.4% of the cylinder bore size. However, cylinder condition issues can appear prior to 0.4% x bore for several reasons.

During cylinder honing, the wear edges will be removed and the trumpet shape smoothened out in the upper and lower ends of the liner. Clover pattern and ovality will also be removed before the surface structure is normalized to new condition. If there are micro-cracks in the liner surface then these will be removed too, to prevent liner material from breaking loose later. If the cylinder liner has suffered from bore polish or micro-seizures then any such damages will be removed so that the cylinder liner surface is restored to new condition.

As a rule of thumb, a wear level of 2 mm or more will often mean that honing is required, but reduction of clover leafing and trumpet gradient will have an impact as described previously. All these actions will improve the piston ring function, thereby increasing the life expectancy for honed liners.



Wear for a cylinder liner

Chris-Marine honing equipment

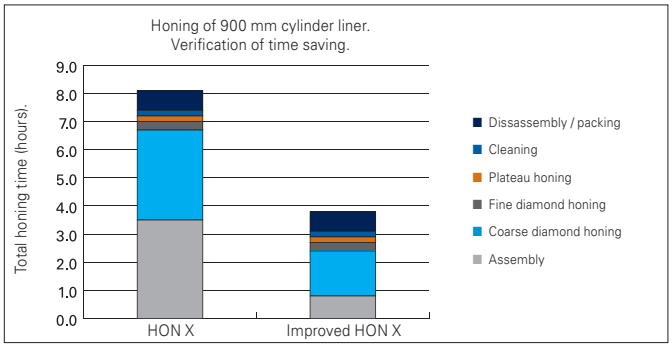
Cylinder honing for 2-stroke engines is normally carried out using the Chris-Marine HON X machine.

The HON X machine is portable making it suitable for in-situ honing. The basic machine has recently been updated and now has the following advantages compared to the previous version:

- Stronger pneumatic hoist -> faster honing
- More rigid structure -> faster
- Rougher diamond stones -> faster
- Honing head vibration dampers -> faster
- Transported fully configured -> faster & safer
- Controls easy to reach -> safer
- Technology / spares compatible with previous HON X machines

Previous HON X machines are upgradable through kits.

In a back-to-back test comparison with the previous HON X version, Chris-Marine has verified significant time savings for in-situ honing jobs. Below example shows the time consumption during honing of a 900 mm cylinder liner.





Honing process time for previous HON X (left) and updated HON X (right). Both assembly and material removal capacity have been improved.

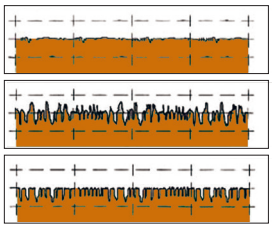
Monitoring and controlling the honing process

An ideal honing process generates a surface with deep sharp valleys providing excellent oil-retaining properties, without sharp peaks that can otherwise harm piston rings or break-out of hard particles from the liner.

Several parameters describe the end result after the honing process:

- Maximum diameter and ovality. These dimensions are normally verified through micrometer measurement before and after honing in a series of measurement levels. Chris-Marine provides micrometer kits well suited for this purpose.

- Surface roughness parameters describing the peakiness and the oil retaining property of the resulting surface. Common parameters here are Rz, Ra, Rpk, Rk, Rvk, Mr1 and Mr2. Chris-Marine provides a Surface Roughness Measurement tool (SRM) intended for verifying surface characteristics.



Surface profile of the running surface from glazed surface (top) through coarse honing (middle) and fine honing (bottom) stages.



Chris-Marine Surface Roughness Measuring device (SRM).

Chris-Marine Honing App

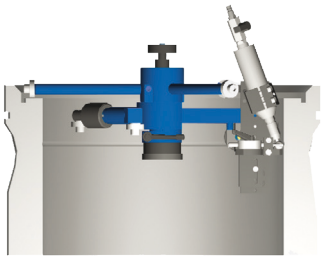
The honing result depends on a number of process parameters such as honing speed, stone pressure and number of strokes for each stage. Different types of stone are used throughout the process and up to five surface roughness parameters and several more geometrical parameters should be within a pre-specified range at the end of the honing process. This means that monitoring and controlling the process is challenging also for quite experienced users. Chris-Marine has therefore developed the Chris-Marine Honing App, a tool intended to make it easier to monitor and control the honing process, thereby improving quality while also saving time.

The Honing App collects geometrical dimensions measured with the micrometer kit and surface roughness values logged with the SRM and guides the user through the honing process step by step.

At the end of the process, data collected is summarized in a final measurement report.

The Honing App has a set of pre-defined recipes and measurement report formats making it easy to save time and improve quality at the same time.

It normally takes 3-10 hours per liner to carry out honing / deglazing, measurement and reporting when using HON X together with the Chris-Marine Honing App. Time increases with bore size and wear condition of the liner. Best practice, report formats and honing recipes can be updated remotely by Chris-Marine as long as the Honing App has internet access.



CHRIS-MARINE®
VKS

WEAR EDGE MILLING MACHINE

The Chris-Marine wear-edge grinder, VKS, is available as multi-bore version (for workshop use) and single-bore version (for on-board use). The VKS is an essential tool during piston overhauls when the wear edge has not been removed through honing. The wear-edge grinder removes some liner material thereby preventing hard contact between top piston ring and cylinder liner wear edge. Removing the wear edge by other means can damage the top piston ring and generate severe cylinder condition issues during running in of a new piston ring pack.





CHRIS-MARINE®
WGM

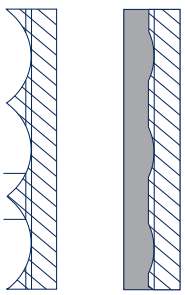
WAVECUT GRINDING MACHINE

For MAN cylinder liners, wave-cut grinding is sometimes used after honing. Wave-cut is a spiral pattern in the liner surface that acts as an oil reservoir and oil distributor in the liner surface.

The wave-cut grinding process is particularly suitable for workshops, but it is possible to do wave-cut grinding also during in-situ jobs.

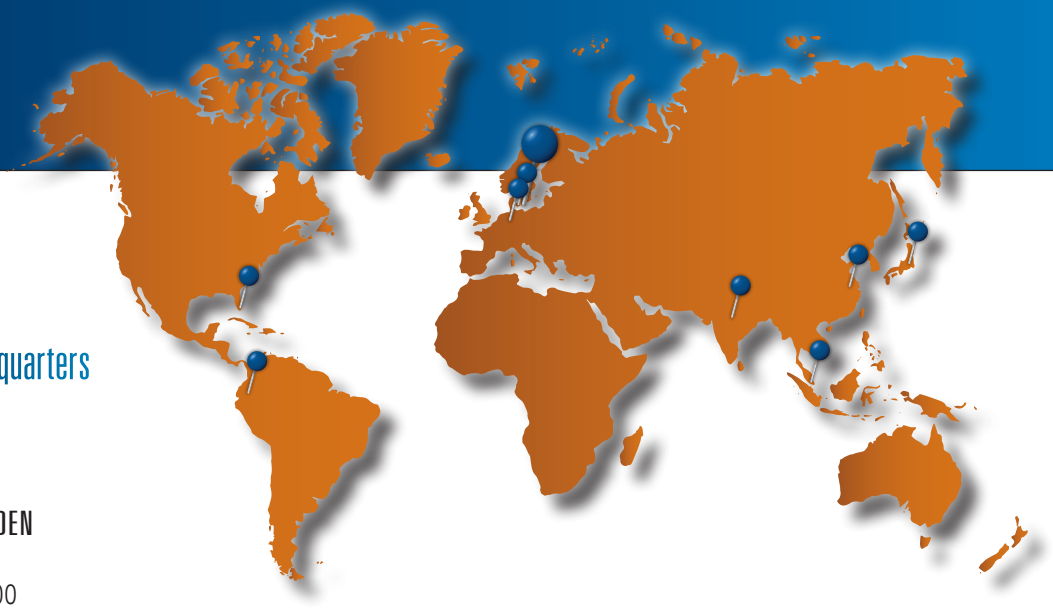
The WGM is used after rough diamond honing and will create a wave pattern as shown above. Following wave-cut grinding, the cylinder liner needs to be finished through honing with fine ceramic stones. The total process time for WGM and fine honing is comparable to honing, i.e. 3-10 hours.

The wave-cut grinding depth can be fine-tuned with the remote control. The wave-cut pattern can be extended from the top of the liner down to the upper scavenge port level, but not in level with the scavenge air ports.



Liner surface after WGM (left) and after fine honing (right).

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