Research in competitive manufacturing of low friction components

Project within: Hållbar produktionsteknik

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FFI

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FFI in short

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1. Executive summary

Scania and Volvo cam follower rollers and rocker arms have been treated with the ANS Triboconditioning process and the results evaluated with very good performance in terms of low friction and reduced wear.

In order to evaluate whether the ANS process meet the stringent demands of cycle times in production while maintaining performance, new mechanical tool heads were designed and manufactured. These were used in a honing machine which was hired from Sunnen and placed in Gnuttis factory in Alvesta. During the three months that the machine was rented, eight tests were done during which ANS was on site in Alvesta to treat components. In total, over 1000 cam follower rollers have been treated with ANS Triboconditioning including a larger series of about 700 rollers which completed the tests. This test was run with production like cycle times to evaluate the stability of the results over time. Between each treatment trial in Alvesta, Halmstad University has made friction tests on treated rollers in their Cam-follower-roller test rig. Treatment parameters at the next trials in Alvesta has been adjusted based on the results from prior friction tests. Treated components have finally been evaluated at Scania in their Start-Stop test rig and at Gnutti in their VT-test rig (Valve Train test rig) with good results.

Rocker arms that are currently used by Volvo has a bushing which protects the contacting surfaces against abrasion. A bushing less rocker arm would result in a reduced cost and an elimination of the assembly stage in production. Rocker arms have been treated with Triboconditioning at Nagel in Germany in a horizontal honing machine with a modified mechanical honing tool. Friction tests haave been used to optimize the process parameters that eventually was selected for production of prototype components for rig and engine tests.

ANS and Gnutti have jointly developed and manufactured a mechanical prototype tool head for the treatment of rocker arms in a standard machine. This tool head enables Gnutti to use existing production mahines in their own factory to treat rocker arms with Triboconditioning. The tool head function have been verified at three different trials in Gnuttis factory in Kungsör and treated Volvo rocker arms will be evaluated in future trials in Gnuttis VT-test rig.

In order to optimize the process it is important to understand in detail what happens during the treatment of components. This knowledge has been improved by simulations and practical evaluation of the treatment process in a tribological test rig with respect to the change of surface parameters and friction results at Halmstad University. Experiments in test rigs have been the basis in order to simulate the ANS Triboconditioning process. The results from the simulations have been presented at a national conference and also sent to an international tribology conference. Extensive work has also been done to find suitable measurement and quality assurance tools for the ANS process, where among other optical methods, Eddy Current, Barkhausen and various chemical analysis methods were examined and evaluated. Work with QA tools have resulted in that ANS has

invested in an optical measurement equipment, Optosurf, to be able to do fast, non-contact measurements of the change in surface roughness as well as a handheld XRF which can measure the chemical composition of the surface that is created with the Triboconditioning process.

2. Background

Two of the world's leading and most reputable manufacturers of heavy duty vehicles are Swedish: Volvo and Scania. Together, they account for a significant share of the world market, and they are both in the forefront when it comes to producing effective and affordable trucks, buses and engines. One of Sweden's well regarded subcontractors who develops advanced subsystems and components is Gnutti Carlo Sweden, former Finnveden Powertrain. Gnutti is a global leader in valve train mechanism systems for medium and heavy duty diesel engines, and currently supplies components and subsystems for both Volvo and Scania. Through its mother company Gnutti Carlo, Gnutti also delivers components for other international diesel engine manufacturers. Applied Nano Surfaces (ANS) is a company with cutting-edge technology in the field of tribology and friction minimization that has its roots in the Ångström Laboratory at Uppsala University. ANS has developed a technology to cost-effectively treat surfaces for low friction. This technique is called Triboconditioning and has extremely high potential since it involves the formation of a durable low friction surface that can be created at low cost. This has thus an impact both from an environmental and competition point of view. Halmstad University (HU) is a leading part within tribology research in Sweden, and especially in surface characterization, where HU is considered as one of the best in its field.

ANS began collaborating with Gnutti in 2009, when ANS technology was tested with very promising results on Gnuttis products. The tests showed that a surface treated with Triboconditioning has lower friction than both bronze and PVD coatings, and the price is much lower. This preliminary study with Gnutti built the case for this project whose objective was to lay the foundation for industrialization of Triboconditioning of valve train components for a future introduction of treated components at Volvo and Scania.

3. Objective

The objectives of this project has been to do research on how the ANS Triboconditioning could be applied on an industrial scale with optimal results and how the process should be controlled. Through well-planned experiments in a real production machine, the knowledge of how various process parameters affect the outcome of the treatment has increased and by using new quality assurance methods, process stability and component quality could be monitored. The results have been verified in advanced rig and engine tests.

4. Project realization

The project has largely followed the original project plan with the activities scheduled and specified in the project application. Only minor adjustments have been necessary during the project and these have not been of significant impact for the outcome of the project.

4.1 Treatment and evaluation of cam follower rollers

A Sunnen ML-5000 honing machine has been rented for three months and placed in Gnuttis factory in Alvesta. The machine is basically identical to the production machines Gnutti uses for internal honing of cam follower rollers. Customized mechanical tools have been designed and manufactured for the treatment of cam follower rollers and the honing oil has been replaced with the ANS process fluid. Surface roughness- and shape measurements of the components have been made before and after treatment in the metrology room at Gnutti.

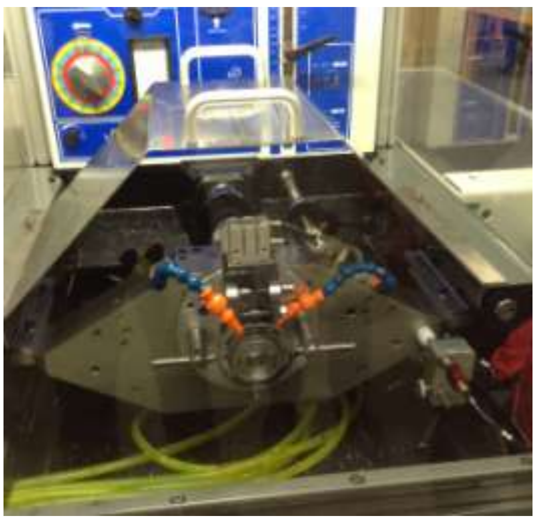

Fig 1. Treatment of Volvo cam follower rollers in Alvesta

In parallel with treatment trials at Gnutti, friction tests with treated components have been made in a test rig at Halmstad University. The rig has been rebuilt and developed during the project in order to simulate the contact between the cam follower roller and pin. Among other things, a new control software, new automation solution and a new evaluation tools have been developed during the project. In the cam follower roller test rig the same operating conditions as in a truck engine are simulated and tests are therefore very close to reality at a very low cost compared to more advanced rig and engine tests. The test rig at Halmstad University has been used to evaluate a large amount of treated components produced in Alvesta.

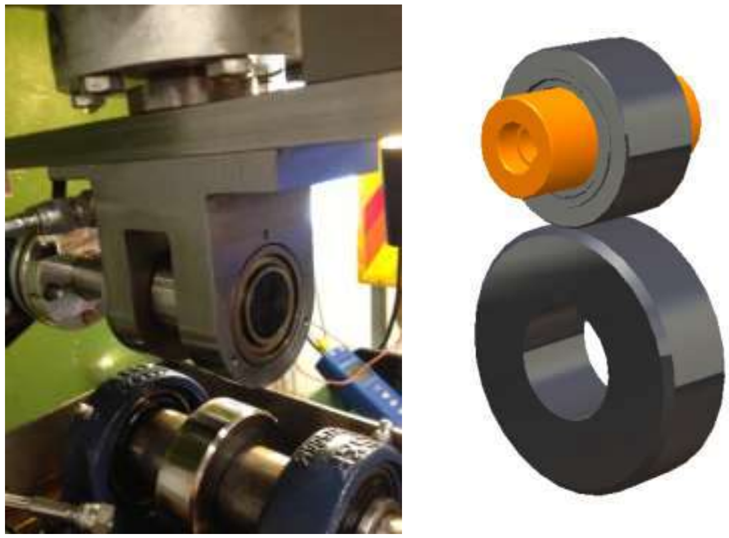

Fig 2. Pin/roller contact in test rig at Halmstad University

Results from prior friction tests made it possible to optimize the process parameters for the next treatment session for the specific component. Both Scania and Volvo rollers have been treated with Triboconditioning and the parameters that have been investigated are:

1. Initial surface roughness of roller
2. ANS ledge material
3. Treatment force
4. Rotational speed
5. Oscillation speed
6. Treatment time

This iteration between treatment trials and friction tests have led to that the process parameters could be optimized and that parameters not affecting the outcome has thus been ruled out. In this way, the test matrix decreased between each iteration. Finally a larger series including about 700 cam follower rollers were produced with production-like cycle times. In total, eight visits were made by ANS to Gnutti and a total of over 1000 rollers were treated during these trials. Based on results from the friction test rig at Halmstad, a set of process parameters were chosen for the next step in the test procedure.

Valve train mechanism tests have been performed at Gnutti in two rounds with treated rollers and one test with treated rocker arms. Valve train mechanism rig is used to perform service life tests on components in an accelerated manner with real components. At Scania a start/stop test has been performed in a similar valve mechanism rig. Treated rollers have passed 80,000 cycles, which corresponds to 1/10 of engine service life and treated rocker arms have passed 100,000 cycles. After the start/stop test, Scania has performed a 2200 hours engine test with treated rollers scheduled for completion in March 2015. A partial visual inspection was made after approximately 1000 hours.

4.2 Treatment and evaluation of rocker arms

Scania and Volvo rocker arms have been treated with Triboconditioning at Nagel in Germany using a horizontal honing machine. Three visits were made at Nagel to produce prototype components for subsequent tests. At the first visit, a screening test was made with a variety of process parameters in order to evaluate their impact on the result. The parameters that were used in this first experiment were:

1. Treatment time
2. Rotational speed
3. Treatment force

After the first visit, an evaluation of the treated rocker arms in terms of friction was done in a reciprocating test rig at ANS. The process parameters that gave the lowest friction was then used at the next treatment session at Nagel.

A mechanical prototype tool head for Triboconditioning of Volvo rocker arms in a standard machine has been designed and produced by ANS/Gnutti. The function of the tool head has been verified at three different experiments in Gnuttis factory in Kungsör. The same process parameters as in the previous attempts at Nagel were used. In one of the experiments in Kunsör, Optosurf GmbH was on site to evaluate the surfaces before and after they were treated.

Fig 3. ANS Triboconditioning of Volvo rocker arm in standard machine with prototype tool head

4.3 Research on surfaces and simulations

A new block-on-ring module has been bought and used to simulate Triboconditioning in a CETR-test rig at Halmstad University. A tool made of the same material as used in the treatment of rollers is mounted in the module and pressed against the outer surface of a sample ring and rotated. ANS process fluid has been used in the contact between the tool and the ring. A large number of tests with different process parameters and different initial surfaces on the sample ring have been performed in the rig. One parameter that cannot be simulated is the oscillating motion of the tool in the Triboconditioning process. The results from the rig tests have then been used to try to simulate the process.

4.4 Quality Management

To find methods that would be suitable for evaluation of the quality and reproducibility of the surfaces treated with Triboconditioning a pilot study was carried out. In the study possible techniques were identified, which are listed below:

Optics	**Electricity**	**Chemical analysis**
- OptoSurf	- Eddy Current	- Handheld XRF-equipment
- Color coordinates	- Barkhausen noise	- AES
- Luminance	- Surface resistivity	- WDS

Test rods were made to evaluate whether these techniques were suitable for quality control of treated surfaces, each rod was treated with five standardized treatments (with different degree of Triboconditioning). These test rods were analyzed with the listed techniques and evaluated after the ability to distinguish the different degrees of Triboconditioning.

After a first round of testing four techniques were sorted out for a more comprehensive evaluation (OptoSurf, Eddy Current, XRF and AES). These techniques were evaluated on a larger set of test rods and components treated within the FFI-project.

5. Results and deliverables

5.1 Treated cam follower rollers

Friction results from treated cam follower rollers have shown that the ANS Triboconditioning is an excellent option for replacing both PVD and bronze in the contact between the roller and the pin. When the speed decreases, the friction between the surfaces increases but with rollers treated with ANS Triboconditioning, friction is keep at a lower level than for a PVD coated pin (Volvo) and a bronze pin (Scania). High friction at low speeds will cause the roller to stop and slide (skidding) on the camshaft, which eventually will lead to failure.

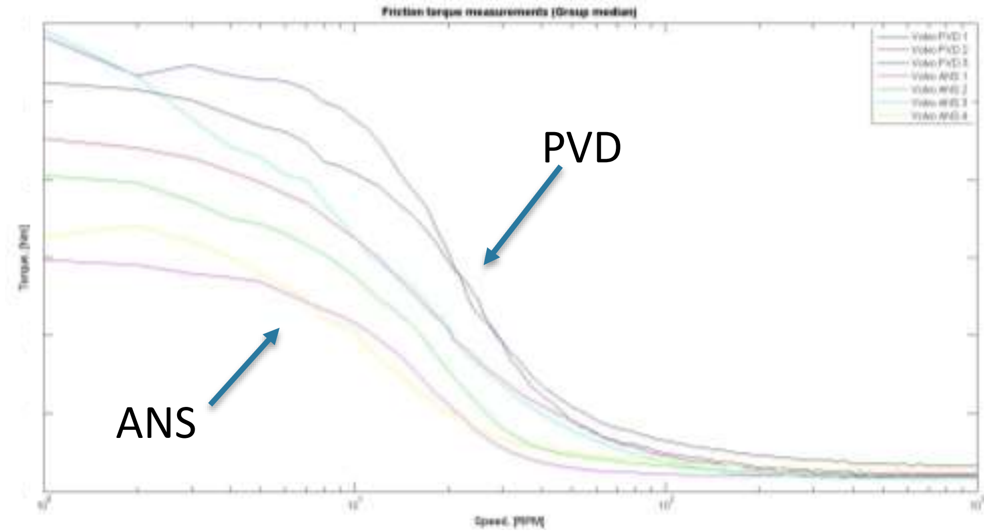

Fig 4. Friction results of treated Volvo rollers compared to PVD-coated pins (ref)

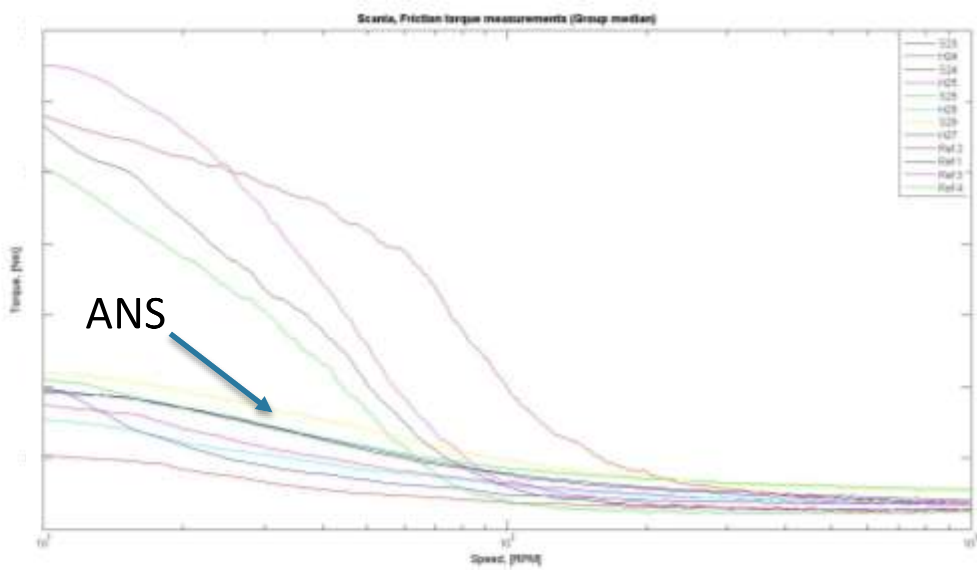

Fig 5. Friction results of treated Scania rollers compared to bronze pin (ref)

The results of Scania's start-stop tests in the rig shows no damage or visible wear on the treated rollers and rocker arms, indicating that a treated roller can replace bronze pin in the pin/roll contact. The subsequent engine test is ongoing and the visual half time inspection after about 1000 hours have not revealed any damage or other problems. Tests made at Gnutti in VT-test rig on rollers have given slightly divergent results. The first round of tests showed good results for treated rollers while the results of the second round showed slightly worse results. The poorer results from the second VT-test rig test is believed to be explained by geometric differences on the incoming components. Therefore, another VT-rig test will be performed at Gnutti in 2015 with treated components.

5.2 Treated rocker arms

Results from tests with treated rocker arms have shown that it is possible to use the bushing-less rocker arm in heavy duty diesel engines. No signs of increased wear or friction problems have been observed.

5.2 Research on surfaces and simulations

The results of the research in Halmstad has been presented at a national Tribology Conference (Tribology Days 2014) in Gothenburg, where a large part of the Sweden’s tribologists were present. Another article will be presented at an International Tribology Conference in the spring of 2015 (Metrology and Properties of Engineering Surfaces). Two students have completed their Master thesis within the project. The results of the research produced during the project will be used as the basis for further work to fully understand how the different parameters affect the outcome of the ANS Triboconditioning.

5.4 Quality Management

Many of the techniques that have been evaluated had the capacity to distinguish between treatments with different degree of Triboconditioning. Those who showed the most potential was OptoSurf, XRF and Eddy Current. OptoSurf that measures the Aq-value of surfaces (which is a measurement of the surface roughness) could easily separate a treated from an untreated surface, and distinguish between the different grades of Triboconditioning. The measurements reflected information that was consistent with supplementary profilometer measurements and visual inspection. It was also possible to distinguish the different degrees of treatment with Eddy Current, but to achieve satisfactory results the measuring frequency needed to be at a level that is not suitable for industrial environments. The XRF equipment was able to consistently distinguish between the different degrees of Triboconditioning when the amount of tungsten in the tribofilm was used as a marker for the degree of treatment. The measurements were repeatable and the distribution between the readings was relatively small. The AES analyses proved to be a great addition to the XRF measurements.

Fig 6. Optosurf and hand held XRF-instrument

Since Triboconditioning both affects the surface roughness and deposits a thin tribological film on the surface, it is desirable to have a quality control system that can analyze both surface roughness and chemistry of the surface. The conclusion and recommendation is therefore to use a combination of OptoSurf and XRF to be able to monitor the quality of treated pats after Triboconditioning.

5.5 Delivery to FFI-goals

This project's goal has been to strengthen Sweden’s international competitiveness by enabling the production of new vehicle solutions using Triboconditioning and to do this in such a way that the environmental impact is minimized. The results from the project shows that the ANS treatment reduces friction on the investigated components and that it also can replace the environmentally hazardous bronze, which both lead to reduced environmental impact. The ANS treatment also results in less transports as all the process steps are made in the same production line as compared to the current situation where components must be sent to external suppliers for the PVD coating. In addition, the production tests show good production efficiency and a great potential for cost reduction as compared to both PVD coatings as well as solutions that use bronze.

Knowledge-based production in Sweden
The Triboconditioning technology has been developed at the Ångström Laboratory in Uppsala. The technology is complex to understand and to fully describe, but is easy to apply, which also has been shown in this project. The potential for this technology is therefore huge. However, further research and development is required before it can be fully implemented on an industrial scale. A follow-up project is therefore planned with the target of enabling introduction of the process in full scale in Gnutti’s factory in Alvesta.

Contribution to the competitiveness of Sweden’s automotive industry
The results of the project have shown that the ANS Triboconditioning can be used to replace the PVD coating as well as the bronze material in the pin and roller contact. Thus, by pursuing with the final implementation of the technology, both Gnutti and ANS will strengthen its competitiveness on the international market and thus increase the Swedish subcontractors' competitiveness globally. Volvo and Scania will have a competitive advantage in the global market as well, if they can manage to offer the Start-Stop technology (and thus lower fuel consumption). With the Triboconditioning process they can also replace the bronze material, thus increasing their environmental and technological image by replacing a hazardous substance and introducing a modern technology.

Development of industrial technology and skills
The project has increased the understanding of the Triboconditioning process as well as how it can be implemented in production on an industrial scale for parts such as the cam

follower roller and the rocker arm. The results will be used for the future implementation of the process both for these applications, but also for other engine components and parts.

Future employment, growth and strengthening of R & D activities
Advanced research in tribology at the Uppsala University can now become a new industrial production method for surface finishing of parts in Alvesta at Gnutti’s production plant. Volvo and Scania can get an environmentally friendly and cost-efficient low friction solution, thereby enabling the introduction of Start-Stop technology in its products at the lowest cost in the world. The project's results have shown the potential of the ANS Triboconditioning process, but further development of the process needs to be done in order to roll out the technology on a full scale. The project has also led to the strengthening of knowledge and research capability both at ANS, in the field of tribology and production, but also at the University of Halmstad within the valve train mechanism area.

Concrete production improvements at participating companies
Volvo pins are in the current solution coated with a PVD process. The process is sensitive with respect to the purity of the components. Furthermore, the process is batch-based, which requires much manual handling. The pins are made of steel, and a series of production steps are carried out in Alvesta (cutting, drilling, hardening, grinding, and honing). They are then packed and sent to Germany for PVD coating. They will then return to Alvesta after 3 to 4 weeks, inspected and assembled into the complete rocker arm that is then delivered to Volvo. With Triboconditioning, the inside of the roller is treated in the same factory and treatment tests in Alvesta shows that the processing time does not exceed the current cycle times for rollers. The roller is then ready to be installed directly and the whole process takes only a few seconds instead of 3 weeks.

Strengthen research in production
The project has led to the results and information exchange between Halmstad University and international research centers such as the Ecole Central de Lyon, Enise in Saint Etienne, ENSAM in Chalons Champagne and the University of Huddersfield and Fraunhofer Laser and Production Institute IPT ILT in Aachen, Germany.

Research at Halmstad University has also been strengthened by enabling the development of tribological test methods, test rig improvement and increased skills in the valve train mechanism applications. In addition, two Master students graduated during the project.

Strengthen the collaboration between automotive industry and Universities
We see this project as a model example of how OEM:s, suppliers in the automotive industry and small knowledge-intensive companies as ANS can interact with leading Universities.

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6. Dissemination and publications

6.1 Knowledge and results dissemination

Halmstad University has helped to disseminate the results of the project to its partners Ecole Central de Lyon, Enise in Saint Etienne, ENSAM in Chalons Champagne, the University of Huddersfield and Fraunhofer Laser and Production Institute IPT ILT in Aachen, Germany. The articles and conference papers produced by Halmstad University has also reached out to large sections of the International Tribology world. ANS has in recent years published research in a variety of publications (STLE, TLT, TLE, Lube Magazine, VDI, etc.), and will also continue to disseminate knowledge about this area.

The results of the research in Halmstad has also been presented at the national Tribology Conference (Tribology Days 2014) in Gothenburg, where a large part of Sweden's tribologists were gathered. Another article will be presented at an International Tribology Conference during the spring of 2015 (Metrology and Properties of Engineering Surfaces).

6.2 Publications

"Optimization of the Triboconditioning Process on External Cylindrical Surfaces", Z Dimkovski, F Guilbert, J Lundmark, J Mohlin, B-G Rosén, Metrology and properties of engineering surfaces, 2-5 mars 2015

"Process Optimization of Low Friction Surfaces in Pin-Roller Contacts", Z Dimkovski, Tribology days, 15-16 oktober 2014

"Characterization of a tribofilm in valvetrain applications", Franck Guilbert, 2014, Master thesis, Halmstad University

"Tribometer improvement and friction testing for ANS coating", Guillaume Algarra, 2014, Master thesis, Halmstad University

7. Conclusions and future research

The results from the project shows that the ANS Triboconditioning process has a great potential to replace PVD-coated pins as well as bronze pins in the valve train mechanism of heavy duty diesel engines.

The production tests made have given positive results with short cycle times and stable treatment results. Tests with the newly designed mechanical prototype tool have shown that the ANS Triboconditioning could be used in standard machines and would therefore reduce the need for investments in the form of special honing machines. This would strengthen the competitiveness of the method further as compared to other solutions.

However, the production concept needs to be further developed in order to be ready for implementation on a larger scale. Further research will therefore be needed to develop new and better tool systems that are less dependent on incoming component geometry, where a more flexible system can provide a consistent quality treatment.

The quality assurance tools that singled out as the most promising ones during the project, in order to ensure a smooth and even treatment, will additionally need to be verified on a larger scale in an industrial environment.

8. Participating parties and contact person

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Gnutti Carlo Sweden AB, Johan Mohlin

Scania, Lars Hammerström

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