Publik rapport

En ny lösning för ökad prestanda och låg vikt för transmissionskugghjul till elfordon

Författare: Ignacio Victoria/ Linus Everlid/ Luiz Pereira
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Projekt inom Delprogrammets namn alt strategisk satsning exempelvis Trafiksäkerhet och automatiserade fordon

FFI Fordonsstrategisk Forskning och Innovation
VINNOVA Energimyndigheten TRAFIKVERKET
FKG VOLVO SCANIA VOLVO

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Instruktioner

- *Instruktioner är skrivna med brun kursiv text – all sådan text tas bort innan redovisning sker.*
- *Ingen begräsning finns för antalet sidor*
- *Infoga inte dokument eller objekt som måste öppnas för att läsas eller ses. Det fungerar inte då slutrapporten omvandlas till en PDF-fil när den laddas upp i portalen.*
- *Denna rapport är publik vilket innebär att rapporten är tillgänglig för alla utan att någon sekretessgranskning kommer att göras. Rapporten läggs ut på FFI:s hemsida.*

1 Sammanfattning

Din text här…

Kort sammanfattning, max 5 000 tecken.

2 Executive summary in English

This Project aimed at evaluating the potential power loss reduction of different mechano-chemical surface treatments applied to Powder Metal Gear at different loads and speeds on a controlled environment through a standardized FZG rig with type C gear types.
The samples' surface roughness was measured as a way to characterize the differences between different treatments in comparison to the reference, an untreated gear pair.
As an extension of the project, a pitting test was conducted with the same samples used in the mechanical losses characterization, aiming to verify potential durability improvements.

3 Bakgrund

The gross majority of vehicle powertrains rely on lubricated gear pairs to a given extent. Gear pairs despite their inherent high efficiency still experience mechanical losses upon teeth contact. With the advent of Battery Electric Vehicles, facing of charging time challenges as well as availability and limited infrastructure, infra-structure, a long driving ranges are key. Although the most direct solution is a larger battery packthis comes at a steep cost and weight increase.
Thus, loss reduction, of any sort, will offset the need for greater battery capacity.
Furthermore, there is a large push from both OEMs and Governing Bodies to reduce material waste and the environmental impact of Battery Electic Vehicles.
Powder Metal Gears have an increased material utilization rate yielding a net positive environmental impact reducing material waste whilst surface treatments methods, improve efficiency and therefore reduce the vehicle's environmental impact
Alas, any and all improvements in this area would represent a leap forward on Electric Mobility and electrification.

4 Syfte, forskningsfrågor och metod

All experiments were completed at Kungliga Tekniska högskolan (KTH) encased in the Master Thesis (Kalathil, 2023) funded through this project.

The objective of the Project was quantify the impact of Triboconditioning® CG (TCG), a mechanochemical surface treatment developed by Tribonex AB, on the power losses of powder metal gears. The effect from the surface treatment is threefold: the surface roughness is optimized, compressive residual stress is generated, and tribologically favorable chemistries react with the surface. Two variants of the TCG surface treatment were chosen for evaluation in a rig test, where the surface treatments were compared to a ground powder metal gear pair.

It is worth noting none of the Powder Metal Gears in this study underwent surface densification.

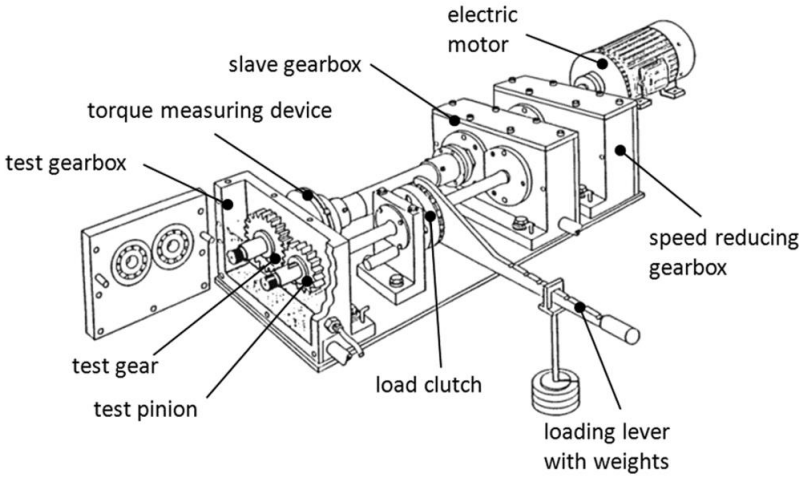


Figure 1 FZG test rig sample configuration (Kalathil, 2023)

The tests were conducted on an FZG test rig (see Figure 1). Said test rig configuration recirculates power through 2 gearboxes (each with a single 1-to-1 ratio spur gear pair) with a statically applied constant torque applied through a preload with weights and a given lever arm. The power intake during the test at any given constant speed, corresponds to the power loss of the closed-loop gearboxes.

Through a zero-torque run all load-independent losses can be estimated. These load-independent losses can thus be subtracted from subsequent loaded tests, yielding load-dependent losses. These load-dependent losses were computed following the procedure detailed in the reference (Kalathil, 2023).

Additionally, FZG tests have a standardized operation points which can be seen below in Table 1:

Table 1 FZG Load Stage parameters (Kalathil, 2023)

Load Stage	Torque on Pinion (Nm)	Hertzian Contact Pressure (MPa)
5	94.1	773
7	183.4	1080
9	302	1386

The test speeds are also standardized and can be seen below in Table 2:

Table 2 Test speed & pitch line velocity (Kalathil, 2023)

Pinion speed (rpm)	Pitch Line Velocity (m/s)
87	0.5
174	1
348	2
550	3.2
1444	8.3
1740	10
2609	15
3479	20

The lubricant used for the test was a DCT 10 and the test cases were run at 60°C.

The extension of the project which was decided after Volvo has replaced on the activity has used the same samples coming from the above described efficiency testing method. Due to the less structurally demanding nature of the Efficiency tests, compared to the Pitting, eventually some appropriate measures relevant to the Pitting have been overlooked at samples manufacturing and preparation stage.

To test those samples for Pitting it was used the modified DGMK procedure, proposed by KTH and defined at the Doctoral Thesis by Edwin Bergstedt.
[1] E. Bergstedt, online: https://www.diva-portal.org/smash/get/diva2:1548346/FULLTEXT01.pdf
[2] D. W. Gesellschaft, “Short Test Procedure for the investigation of the micropitting load capacity of gear lubricants,” DGMK Information sheet, vol. 2002, no. August 2002.

5 Mål

As described at the original agreement, the initial purpose of the project was: *“Huvudsyftet med projektet är att studera en ny lösning för att förbättra elfordons transmissionsprestanda när det gäller hållbarhet, effektivitet, buller och vibrationer samtidigt som vikten minskas. Vidare är syftet att utvärdera hur lösningen fungerar tillsammans med olika smörjmedel, för att undersöka påverkan på de olika ytbehandlingarna. Projektets mål är att demonstrera en transmission med pulvermetallkugghjul, förstärkt med ANS nya ytbehandlingsmetod i en fullskalig transmission. Delmål är att ta fram vilken inverkan den nya lösningen har med avseende på tillverkningskostnad, resursutnyttjande och miljöpåverkan, energieffektivitet, buller samt kompatibiliteten med moderna växellådssmörjmedel. Det övergripande målet är att utveckla lösningen från teknikutvecklingsnivån (Technology readness level) TRL5 till TRL7.”*

The initial goals has to be reviewed, since implementing it in a full-scale transmission was demanded a significant extension of the Project’s original timeframe. Additionally, it also presented challenges related to testing, requiring an ad-hoc test rig with a matching lead time and increased budget.

Alas, the efficiency tests were completed on a standard FZG test rig, the industry’s benchmark test rig. This in turn lured the Project towards KTH due to their FZG test rig availability. FZG-based efficiency tests require a specific gear pair, FZG-type C gears.

The weight and cost optimization goals were met through the usage of Powder Metal Gears maintaining the geometry of FZG-Type C standard.

The assessment & study of the different surface treatments was carried out as planned. The same gears that went through efficiency testing were later used for durability testing.

6 Resultat och måluppfyllelse

In an initial study, several different variants of the TCG surface treatment were evaluated based on surface topography, compressive residual stress, and performance in a ramped-speed friction test. Two variants of the surface treatment exhibited a particularly interesting combination of increased residual stress and low friction, an indication that both efficiency and durability could be improved. Pictures are extracted from the CIRP proceedings referred in the publications section.

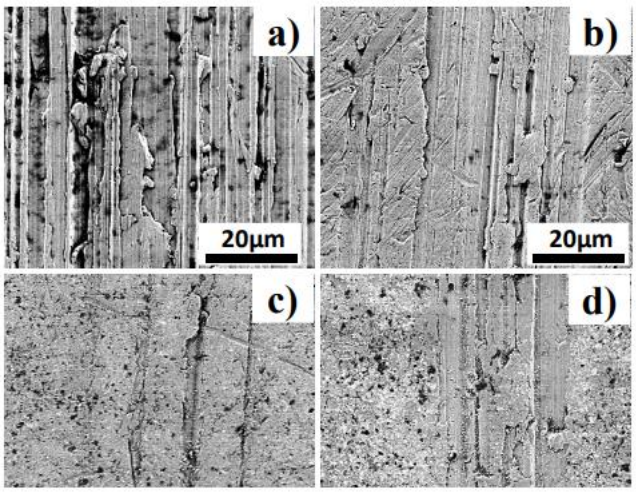


Fig. 4. Surface topography after (a) grinding (b) V-A1 (c) CC-A2NA2 and (d) CV-A2NA2 triboconditioning.

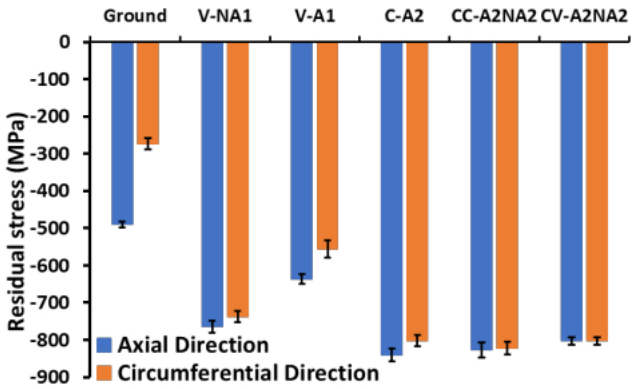


Fig. 5. Surface residual stresses of ground and triboconditioned samples in both circumferential and axial directions.

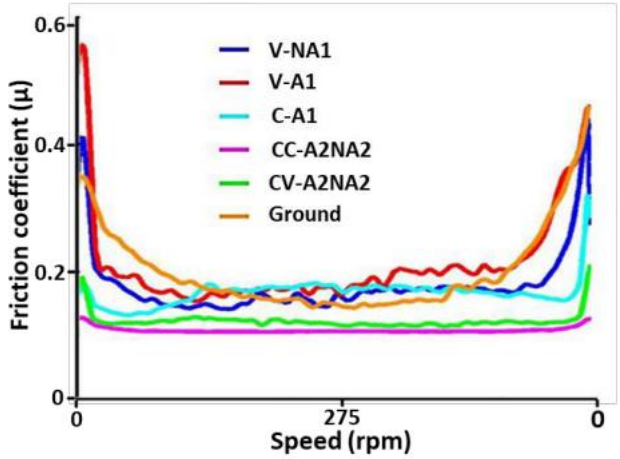
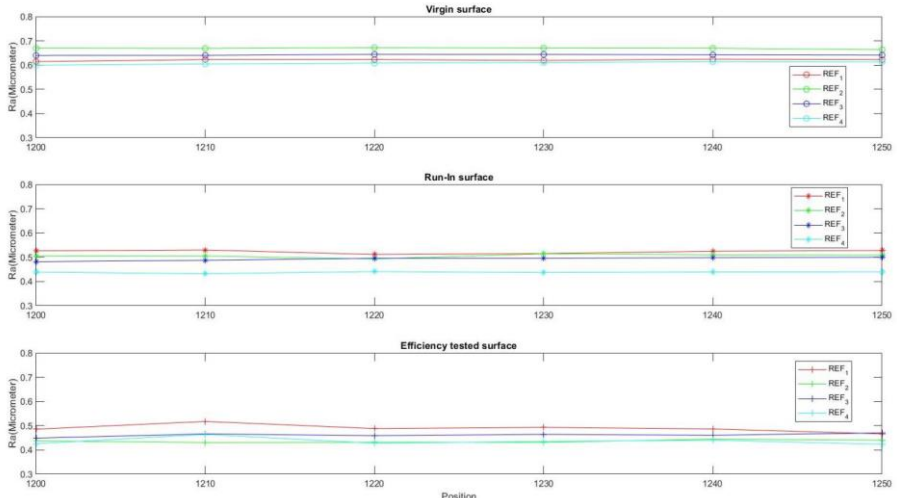


Fig. 7. Friction coefficient as a function of speed for speed acceleration friction test.

Based on the results from the initial study, two TCG variants were applied on powder metal gears: TCGv1 (one-step process) and TCGv2 (two-step process).

- **Reference Gears [REF]**



- **Triboconditioned® Version 1 [TCG-V1]**

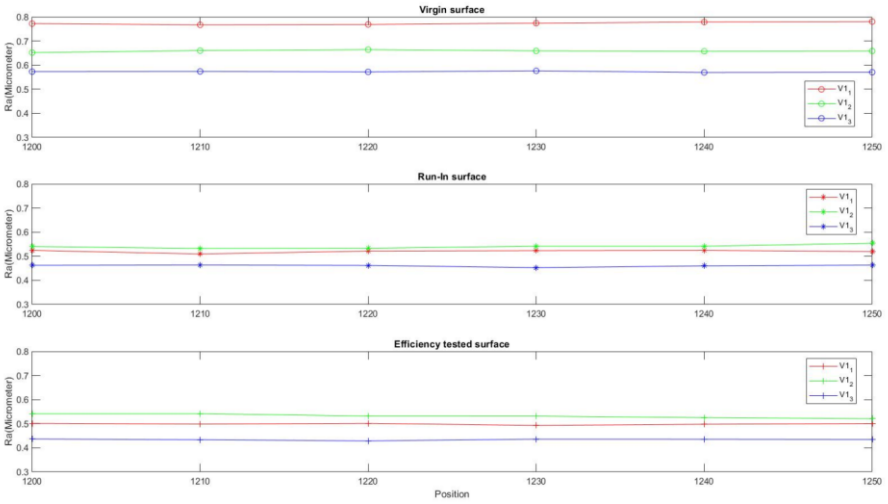


Figure 37. Surface roughness measurement on TCG-V1 gears.

The surface roughness under metric R_a was measured prior to testing, after run-in and after testing. The pictures are extracted from the KTH Master Thesis referred at the publications section:

- **Triboconditioned® Version 2 [TCG-V2]**

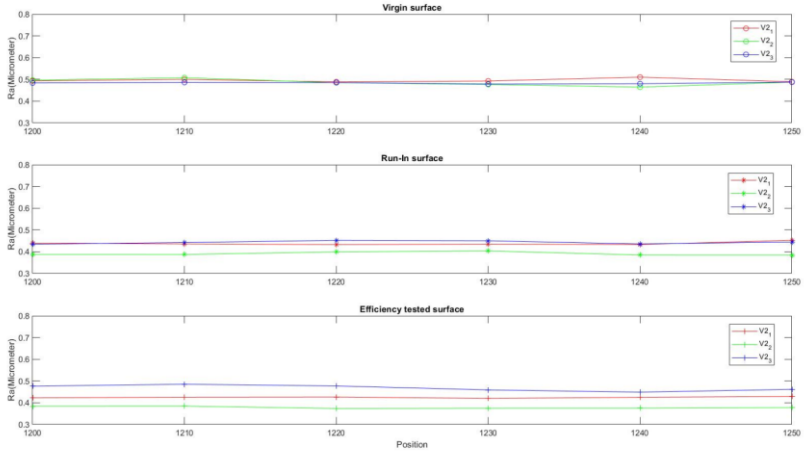
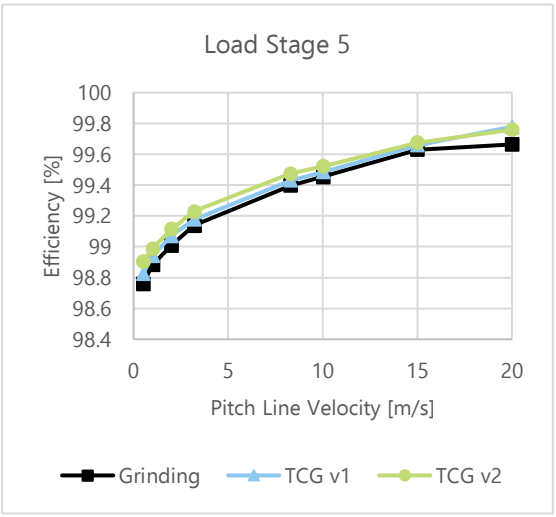
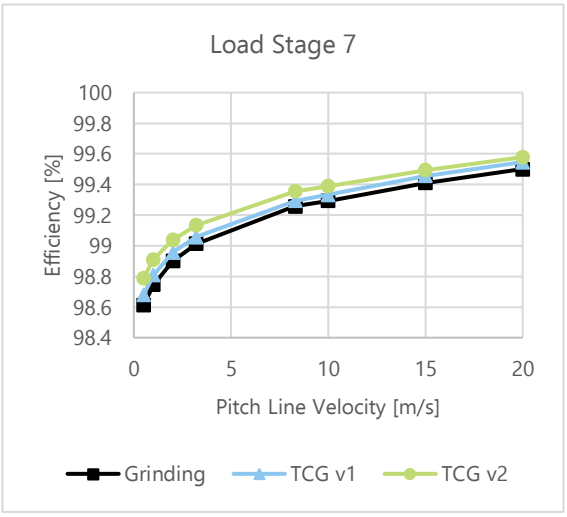
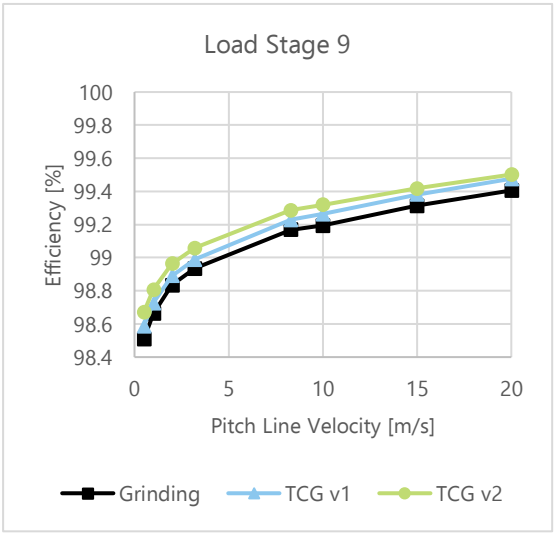


Figure 38. Surface roughness measurement on TCG-V2 gears.

The below graphics show the efficiency of the gear pairs with the reference surface, compared to the 2 surface treatments for the 3 load stages:







The results depicted above consist of the average of 3 measurements and suggest that TCGv2 has a better efficiency than TCGv1, additionally, both treated samples show an efficiency improvement with regards to the reference sample across all load stages. The difference is more pronounced as the load increases.

The results from the Pitting tests were incoherent with the theory, expectations and prior work done by Tribonex. Further analysis is being carried out, but the results will exceed the due date of the report. Due to the public nature of this report, it was chosen not to disclose partial details, before a deeper root cause analysis has been carried out.

7 Spridning och publicering

7.1 Kunskaps- och resultatspridning

Hur har/planeras projektresultatet att användas och spridas?	Markera med X	Kommentar
Öka kunskapen inom området	X	
Föras vidare till andra avancerade tekniska utvecklingsprojekt	X	
Föras vidare till produktutvecklingsprojekt	X	Considered, despite requires more in depth and application related testing
Introduceras på marknaden	-	
Användas i utredningar/regelverk/ tillståndsärenden/ politiska beslut	NA	

7.2 Publikationer

Kalathil, V. M. (2023). *Efficiency and Roughness Characteristics of Surface Treated Powder Metal Electric Vehicle Gears.* KTH, Skolan för industriell teknik och management (ITM). Stockholm: KTH. Hämtat från https://urn.kb.se/resolve?urn=urn%3Anbn%3Ase%3Akth%3Adiva-340060 den 13 06 2024

Mallipedi, Dinesh et al., 2022 Investigation of the surface integrity of mechano-chemically finished powder metallurgy gear, *Procedia CIRP 115 pp. 142-147*

8 Slutsatser och fortsatt forskning

The original hypotheses were that the surface treatment Triboconditioning® CG reduces power loss in the gear meshes. The improvement is consistent across all load stages and more prominent as load increases. Based on that the results fulfilled the original intent of the project.

In order to have a formal and more consistent hypothesis confirmation an extended study with a larger number of samples needs to be carried out and preferably with application-like gears (helical

pairs and appropriate module). That is due to the small magnitude of the differences expected in results, it needs to be analyzed along with their variances.

Regarding pitting and lifetime effects further investigations is required to explain the inconsistency of the results and also extended test scope dedicated for the Pitting purpose.

Regarding the roughness, R_a showed a positive trend related to the efficiency, but no numerical calculation could be confidently described. Further research is required to define the correct metric correlating surface finish and efficiency. The surface treatment affects not only the surface roughness, but also introduces tribologically favorable chemistries, contributing to reduced friction losses.

9 Deltagande parter och kontaktpersoner

Volvo Cars Company: Ignacio Victoria Rodriguez (ignacio.victoria.rodriguez@volvocars.com), Luiz Filipe Silva Pereira (luiz.filipe.silva.pereira@volvocars.com)
Tribonex: Christian Kolar (christian.kolar@tribonex.com), Linus Everlid (linus.everlid@tribonex.com), Elias Nyrot (Elias.nyrot@tribonex.com)
Chalmers: Philip Hoier (hoierp@chalmers.se)
Höganäs: Mattias Rehn (Mattias.Rehn@hoganas.com)