Wear Investigation of Finish Rolled Powder Metal Gears

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When manufacturing powder metal (PM) gears lead crowning is not achievable in the compaction process. This has to be accomplished either by shaving, grinding or honing. Each of these processes has their merits and draw backs. When employing rolling using a roll burnishing machine lead crowning can be accomplished but due to errors in profile a hard finishing operation such as grinding is used by the industry (Ref. 1). In this paper a helical PM gear that has sufficient tolerance class after rolling has been tested in a test rig for durability and the wear has been studied.

Introduction

Powder metal gears for automotive transmissions are becoming a reality and GKN is the first company to deliver PM gears for car transmissions (Ref. 2). However, these gears are surface rolled and likely to be hard finished. Adding both processes will take away some cost advantage. It would be preferable to have only hard-finishing or surface rolling. So far, the rolling technology cannot meet the tolerances obtained by hard-finishing and hard-finishing cannot give the high-dens layer on the gear teeth that boosts mechanical properties to solid gear steel levels. Rolling can still deliver tolerances compared to shaved gears, but with a surface that is smoother and more comparable to superfinishing technology than traditional gear grinding or honing. In a joint-development effort, a finish-rolled gear replaced the original 6:th driven gear in a 6-speed manual transmission (Fig. 1). The entire transmission was put in a test rig and the gears were tested for durability and vibration. The findings are presented in this paper.

Figure 1 **Top: two views of 6:th output gear; Bottom: gearbox before case is bolted together; 6:th output gear is clearly seen (see arrow).**

Testing

The test sequence used was an OEM test cycle for a European premium car and equivalent to 300,000 km service life of the drivetrain. For the 6th gear the cycle was set as follows: 230 Nm input torque, which is maximum engine torque, for 21.6 million cycles at 3,000 rpm. This corresponds to a contact pressure of 1,285MPa and root bending stress of 677MPa.

The gears were measured before and after running on a Wenzel GearTec gear inspector for comparison. The output from the gear inspector was filtered both mechanically and in the software, but it still gives an understanding of the amount of wear that has taken place throughout the testing (Figs. 2–3).

Results

Wear results were recorded by measurement of profile and eyeball inspection. Figure 2 demonstrates that a high degree of accuracy is obtainable with the finish rolling process. There is good convex curvature on top of the involute, with tip relief visible on the driven flank; very little to no waviness. What cannot be seen on these measurements is the mirror-like surface finish (Fig. 4).

Figure 3 shows some wear of approximately 5–8 microns, and the convex crowning of the involute has worn away. So now the tooth shape is closer to the perfect involute. Some waviness can be seen, and around the pitch point there is a hump in the involute curve indicating the no sliding zone or rolling point. This is in line with what can be found in the literature (Refs. 3–6). Figure 4 displays photos of the gear teeth — before and after running.

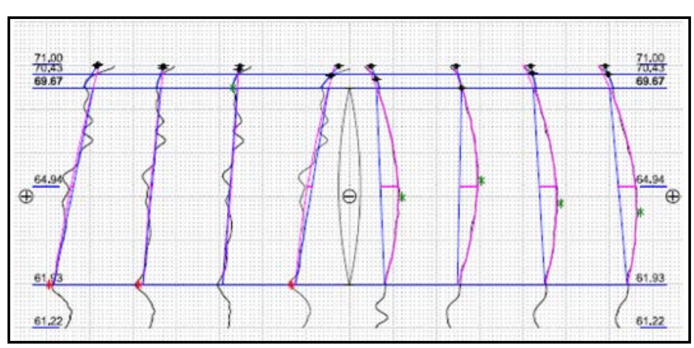

Figure 2 **Left and right flank of four gear teeth on tested gear before testing.**

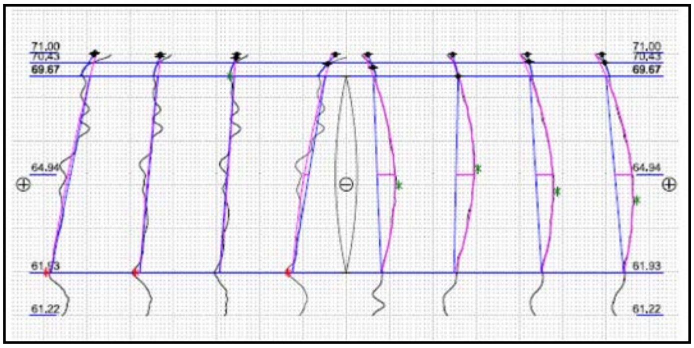

Figure 3 **Gear flanks after testing; left flank is driven flank and right flank is the coast flank that has not seen any contact.**

In Figure 4 the left column photo reveals some wear marks with the pitch line and some gray areas that are micropitted. Since this is end of life for this gear and equivalent to 300, 000Km driving, there seems to be more life left in the tooth, with no macro-pits and no noticeable NVH increase occurring during testing — a very good result. Vibration was also tested for this gear and was found to be considerably lower than for the reference gear, i.e. — OEM ground steel gears (Fig. 5).

Figure 5 shows a very significant difference between PM and the reference steel gears to the advantage of PM. The test was done at several different torques and speeds, with the same advantage for PM in all tests. The interested reader can go to the Höganäs Youtube channel and listen to the PM gears versus the original steel gears; it (is more informative) than the graph in Figure 5.

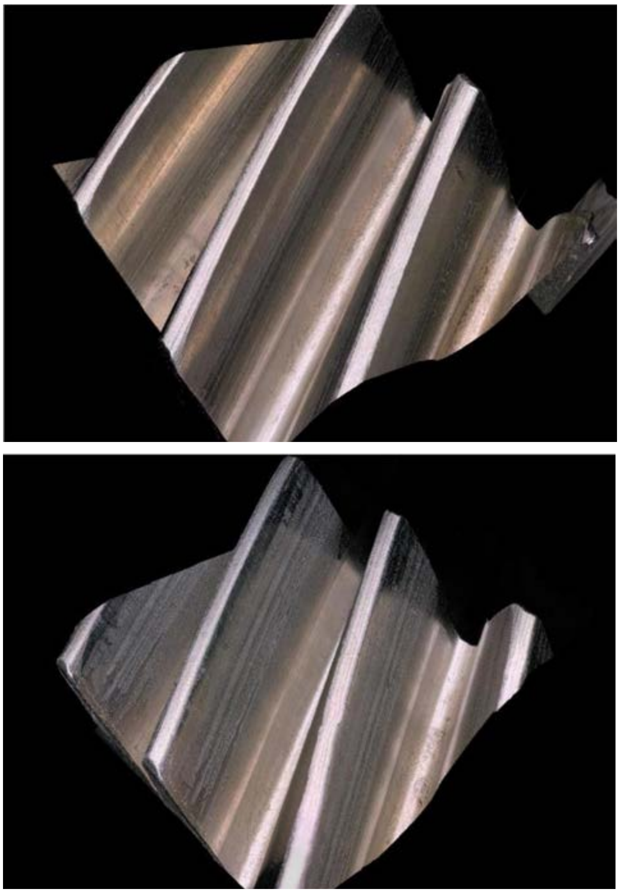

Figure 4 **Top: non-worn gear; Bottom: worn gear after completed durability cycle.**

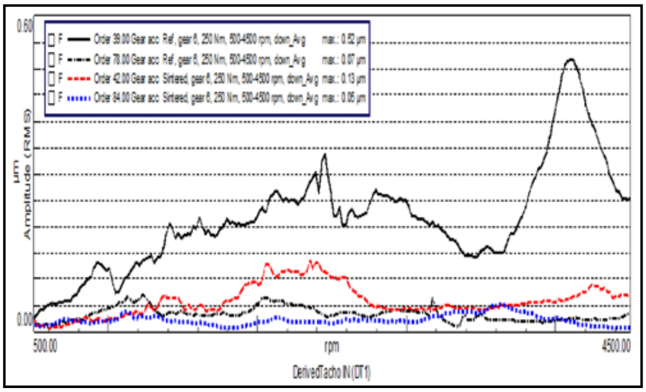

Figure 5 **Acceleration amplitude from pick-up on gearbox housing: black lines are reference steel; red and blue lines are PM gears.**

Summary

The 6:th output gear has been finish rolled and hardened, with no further machining on the teeth and bench-tested in a 6-speed manual transmission. The gear showed, after a full durability cycle, some mild wear of around 5–8 microns — but no significant failures such as pitting or tooth root breakage were observed. The gear mated with another hard finished gear pair in PM and displayed a significant reduction in vibration levels for all torques and speeds.

Conclusion

In this paper a finish rolled gear in a commercial automotive 6-speed manual transmission has been tested in test rigs for durability, wear and vibrations. The results were very promising and show that finish rolling to a high degree of accuracy is possible with results that meet and exceed OEM standards for durability, vibration and wear.

References

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