Performance of a Surface Densified P/M Gear for a Passenger Car Gear Box

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Abstract

Selective surface densification is a tool for improving the mechanical properties of PM steels, such that the requirements for highly loaded gears can be matched. This paper describes the manufacturing and the properties of a helical P/M gear. The gear performance was evaluated on a 3-shaft back to back test rig, on a load bearing test rig and on a sound test bench. The results of these tests are presented and compared to data obtained from solid steel gear with identical geometry and surface quality. This comparison indicates that P/M gears have a load bearing capacity and noise level which are both well comparable to solid steel gears.

Key words : P/M gears, selective surface densification

1. Introduction

Powder Metallurgy (P/M) is a cost competitive technology for the series production of complex shaped components. Conventional P/M parts with residual porosity have lower strength and wear resistance when compared to solid steel, because all mechanical properties are primarily controlled by density. In the case of highly loaded gears two highly stressed areas must be considered [1]:

- The tooth root which is loaded by bending fatigue
- The gear flank which is loaded by rolling contact pressure and sliding.

In order to endure the stresses generated there, high fatigue and rolling contact fatigue strength is mandatory. A most attractive processing route to obtain such properties in P/M steels is selective surface densification (SSD). This method selectively densifies the areas which encounter local stress concentrations to nearly zero porosity.

Based on transverse rolling, a helical gear has been produced successfully under series conditions. Beside surface densification, the final dimensions and quality of the gear as well as its surface roughness and microstructure after case hardening also play a major role for strength and noise behavior. Back-to-back test bench trials, load bearing tests and sound tests have been carried out to compare the properties of P/M gear with a solid steel gear.

2. Experimental and Results

The gear under investigation is a 4^{th} fixed gear in a 5-speed front-wheel-drive manual transmission gear box. A solid steel gear with the composition 20MoCrS4 GN is actually under production at Getrag and employed in the above application. The gear (Fig. 1) has 39 teeth, a helix angle of 33° and a module of 1,8 mm. A section view of the gearbox in an assembly drawing is shown in Fig. 1 (right).

The selection of a P/M steel for this gear was based on previous processing experience and on rolling contact fatigue tests. From this information a high performance water atomized, Molybdenum prealloyed powder was chosen. The material with low carbon content shows good compactibility, good hardenability, high strength and good pressing properties.

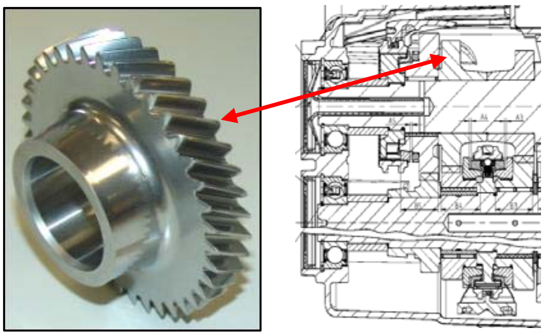

Fig. 1. Actual gear (left), assembly drawing with gear (right)

The following processing route was employed: (i) compaction with overmeasure to a density of 7.0 g/cm³, (ii) sintering in a N_2/H_2 atmosphere (1120°C, 30 min.), (iii) soft turning, (iv) SSD through transverse rolling, (v) case hardening, (vi) grinding of the inner and outer diameter and (vii) final surface finishing by honing. After case hardening, the final microstructure of the gear is martensitic at the surface with a case depth of about 0,4 mm at the flank and 0,3 mm at the tooth root. The core microstructure shows a homogeneous structure of bainite.

Through quantitative image analysis, it has been shown that the transverse rolling generates a densified layer at both flank sides and at the tooth root with nearly full density, i.e. a porosity < 2 %, up to a distance of 350 µm. Beyond this region the porosity gradually decreases to the core porosity level of 90 % at a depth of 1 mm. The surface quality, which is most pertinent to noise, generation was measured along the alignment direction. With an R_a-value of < 1.8 µm, the roughness after honing is comparable to the reference solid steel gear. After each processing step the typical dimensions and gear errors were measured on a 3D- and Mahr gear measuring machine. The evolution of the gear quality through the sequence of processing steps was described elsewhere [2].

Due to elastic deformation and spring back of the teeth after rolling, an significant amount of warping is generated which leads to profile and alignment errors in the front and rear section of the teeth. These deviations need to be removed by honing such that the final quality and tooth topography becomes similar to honed solid steel gears. The quality of the current P/M gear is DIN 7 or better.

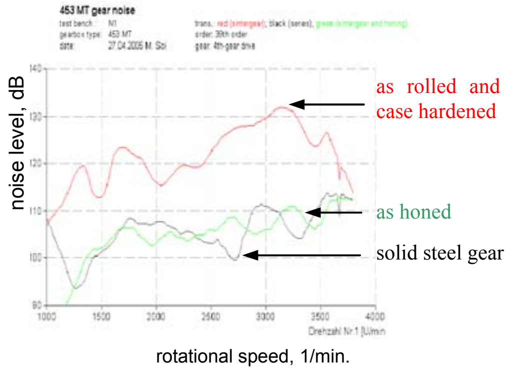

Fig. 2. Sound emission curve (drive condition). The noise in dB is plotted as a function of the number of revolutions.

The geometric deviation in the un-honed state, generates additional bending moments and deteriorates the sound emission and load carrying capacity as compared to honed gears (c.f. Fig. 2). Fig. 2 shows also, that the sound behavior of a honed P/M gear is nearly identical to the conventional gear. Fig. Furthermore, no significant difference was observed in noise behavior between the drive and the coast condition.

Fig. 3. 3-shaft back-to-back test rig

Investigations of the load carrying capacity of the P/M gears was performed using a 3-shaft back to back test rig at WZL (Fig. 3). The benefit of this test rig is the variable centre distance and a shorter testing time in comparison to conventional 2-shaft test rigs. The torque is applied via a torsion coupling with the aid of a loading lever. The drive torque is supplied to the middle shaft, to which the P/M gear is fixed. The oil temperature of the lubricant Castrol BOT 328 was held constant at 60°C. The test ends automatically when damage occurs by monitoring the noise level. After 50 million cycles (167 h at 2500 rpm) the tests were stopped.

The results of the testing are summarized in Fig.4. It is seen that the load bearing capacity of selective surface densified and honed P/M gears is in the range of conventional gears. For instance, at an applied torque of 338 Nm, which corresponds to a Hertzian contact stress of 1.300 MPa, the gear failed by *tooth fracture* between 10 to 50 million cycles (c.f. Fig. 2) while the flanks where *undamaged* with no signs of pitting, i.e. in this loading configuration the gears failed by fatigue crack growth at the tooth root rather than by pitting.

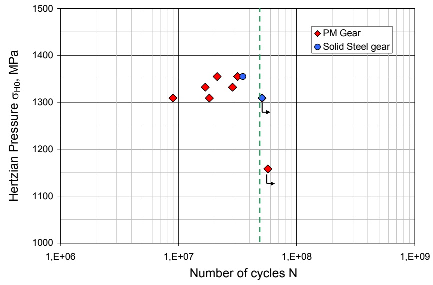

Fig. 4. S/N-data (Woehler-curve) obtained on the back-to-back gear tester from Fig. 3.

Further load bearing tests with a honed P/M and a conventional gear were conducted at Getrag, under the following conditions: input torsion 212 Nm at 2500/min, test duration 77h. The results of this load bearing test was positive, i.e. both the P/M and solid gear worked without failure.

3. Summary

This paper describes the manufacturing and the properties of a helical P/M gear. The P/M gear performance was evaluated on three different test rigs in comparison with solid steel gear:

- 3-shaft back to back test rig
- sound test bench at the customer and
- load bearing test also at the customer

This comparison indicates that the honed P/M gears have a load bearing capacity and low noise level which both are well comparable to solid steel gears. Thus it is demonstrated that P/M gears satisfy the demand of high fatigue and rolling contact fatigue strength and noise behaviour with respect to the proposed manufacturing process.

4. References

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