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Runtime Testing of Casehardened Gears

K. Petr[1, a]

[1]Czech Technical University in Prague, Faculty of Mechanical Engineering, Technicka 4, 166 07 Prague 6, Czech Republic

[a]karel.petr@fs.cvut.cz

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Introduction

Experimental testing of gearing (gears) [1] can be done in several ways, e.g. by pulsating [2] or runtime. This article describes the runtime tests of carburized gears with different thickness of casehardened depth (CHD) and casehardening technologies, i.e. addition or removal of certain steps during the casehardening process of the tooth flank and tooth root. Results of tests were compared with respect of results of metallographic structure.

Description of the Tests and Parameters

Runtime test was based on the following principle: gears-mesh of two gears with described parameters (torque preload, rpm…). For these tests were used test equipment with mechanical closed loop (Fig. 1) – M_k=4500 Nm, n=1500min^{-1}. Testing parameters are shown in Table 1.

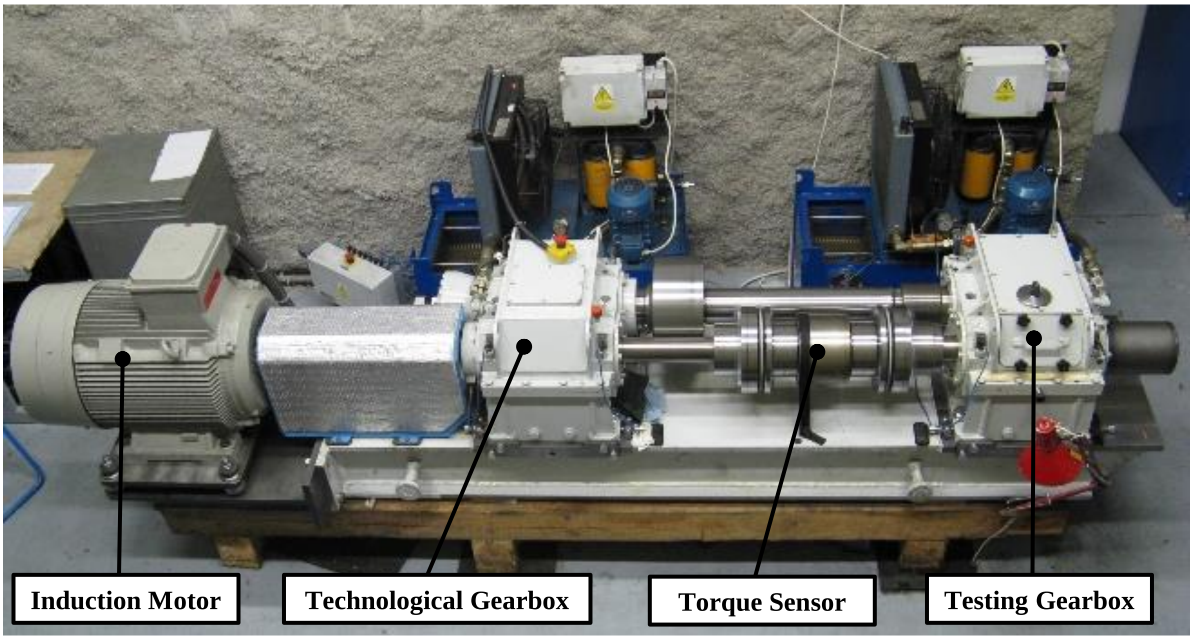


Fig. 1. Testing device for runtime test with variable load spectrum.

In this type of test may be tested by contact failures of gears, such as pitting, micropitting, wear and scuffing, fractures of teeth, etc. The test cycle consists of the process running, which is necessary for elimination of damage of teeth (scuffing from test cycle). Running-in cycle has been chosen so that have minimal impact on fatigue gearing during operational tests.

Table 1. Parameters of runtime tests.

Testing phase	*Rpm [min^{-1}]*	*Torque [N·m]*	*Time [min]*
Running-in	*500*	*500*	*60*
	1 000	*500*	*60*
	1 500	*1 000*	*60*
	1 000	*2 000*	*90*
Test	*750*	*3 475*	*Acc. to lifetime*

During runtime test were tested four types (see Table 2) of gear set (three gearing in the set). These experiments were aimed at the comparison between sets of gears in terms of the growth of pitting (see Table 3) and flank breakage (see Table 4). Semi-product was the same for all gear set (forged bar). Within four sets of gear set were compared different CHD and within the same CHD were realized different parameters of casehardening process.

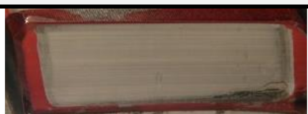
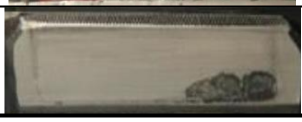
Table 2. Pressure angel (α = 20° and α = 25°).

Indication	*Semi-product*	*Casehardening technology*	*CHD [mm]*
CHD04-St	*Forged bar*	*Standard*	*0.4 ÷ 0.6*
CHD07-St		*Standard*	*0.7 ÷ 0.9*
CHD07-WA		*Without annealing*	*0.7 ÷ 0.9*
CHD07-C		*More % of carbon (C)*	*0.7 ÷ 0.9*

Comparison of Gears with Different CHD and Casehardening Technologies

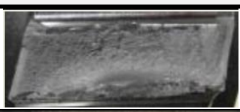
From a comparison of results of runtime tests (α = 20°) can be concluded, that worst was gearing with lower hardened layer. There was pitting almost immediately, and there was flank breakage very soon too.

Table 3. Example of growth pitting on gears (α = 20° and α = 25°).

Indication	*Origin of pitting*	*Growth of pitting*	*Final pitting*
CHD07-C-20°			
CHD07-C-25°			

For gearing with the same CHD was achieved best results for gearing with higher percent of carbon (C). For the geometry of gearing with α = 25° were created two sets of gearing with different CHD = (0.4 – 0.6) mm and CHD = (0.7 – 0.9) mm. Among the results was a big difference.

Table 4. Sample fractures surface on the tooth and gear from runtime testing (α = 20°).

Indication	*Photo of fracture surface on the gear*	*Photo of fracture surface on the tooth*
CHD07-St-20°		
CHD07-C-25°		

The important criterion for evaluation of the properties of hardened layers were their metallographic structure, progress of hardness and progress of residual stresses on the surface and under the surface of case hardened layer. Fig. 2 shows results of residual stresses for each set of gearing (measured by the method of Bauhausen noise). By means of this methodology, was compared magnetoelastic parameter where did not desirable higher values. The best was set of gearing with higher percent of carbon in the carburizing layer.

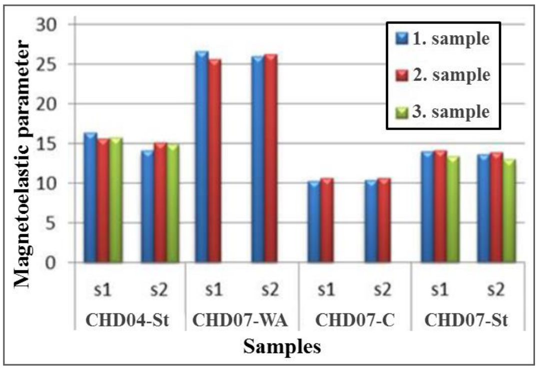


Fig. 2.: Magnetoelastic parameter.

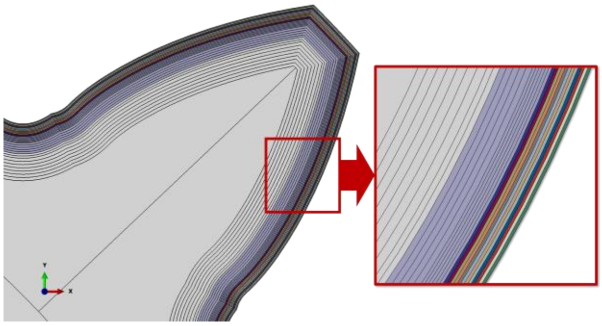


Fig. 3.: Detail of the "part of the layers - shells" casehardened layer.

Comparison of FEM Simulations and Experimental Tests of Gears with Respect of Different CHD and Pressure Angle

FEM model and calculation of gear-mesh is the difficult contact problem. The solution of this problem consists in creating contact between teeth in the gearing (2D FEM model, see Fig. 3) [3]. Simulation of gear mesh is performed quasi-statically during three steps. On pinion and gear there have been created only three teeth. Three teeth are sufficient for the simulation of gear-mesh across the tooth (middle tooth) [4].

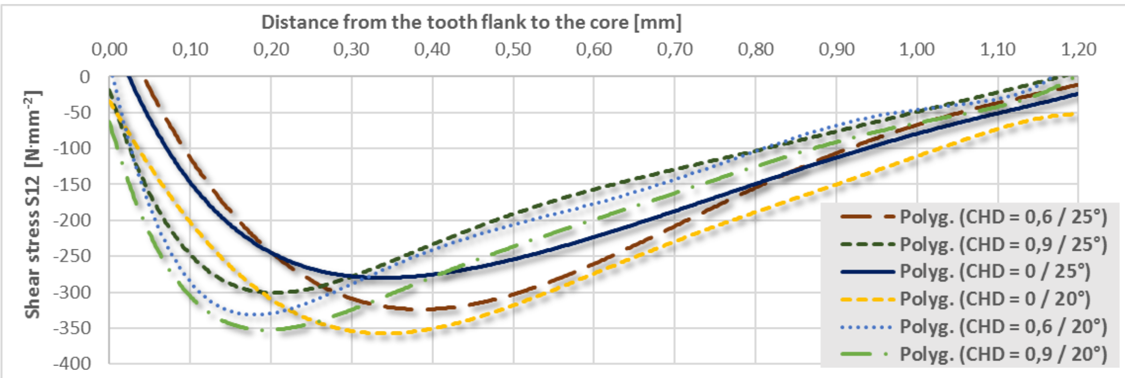


Fig. 4.: Graphical comparison of the main shear stress values (distribution of main shear stress

over the depth – CHD 0; 0.6; 0.9 mm – 20° and 25°).

From distribution of main shear stress (S12) according to Fig. 4 is obvious that with greater thickness of CHD the maximal value S12 is moved nearer to the tooth flank. For pressure angle 20° the area with maximal shear stress is greater than for pressure angle 25° and is placed deeper under casehardened layer. Fig. 4 shows distribution of main shear stress over the depth (path of depth is in the direction of normal line) for $CHD_{20° and\ 25°} = 0$; $CHD_{20° and\ 25°} = 0.6$; $CHD_{20° and\ 25°} = 0.9$ mm.

Conclusions

From a comparison of results of tested gears with respect to different CHD we can say follows. With respect to resistance of pitting and flank breakage it was undesirable lower CHD. Furthermore, it is seen that the excessive increase of carburizing depth was also not efficient.

A positive result has been used higher percent of carbon (C) in the hardened layer with respect to loading capacity (damage to pitting). This positive step was confirmed by analysis of residual stresses.

FEM simulation is very useful tool for verification of experimental and calculated data. This analysis suggests that when using greater pressure angle than 20°, it is necessary to calculate with the fact that position of the maximum main shear stress is moved towards from tooth flank to core. On this problem is necessary to respond by greater CHD. With sufficient increase of CHD the area of critical values of shear stress is reduced. A positive aspect of greater pressure angle is greater resistance to bending stress.

Acknowledgments

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