SPECIFIC DESIGN OF GEAR BOXES FOR ROLLING MILLS[1]

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Abstract

Gearboxes are essential components in steel plants and rolling mills. This paper discusses the main points which have to be taken into consideration for the design and production of gearboxes. This analysis is based on years of experience as well as on the latest results in research. Furthermore this paper includes the choice of the right application factor and the necessary securities on tooth root break, pitting and scuffing.

Key words: Gears; Gearboxes.

PROJETO ESPECÍFICO DE CAIXAS REDUTORAS PARA LAMINADORES

Resumo

Caixas redutoras são componentes essenciais na siderurgia e em laminadores. Este trabalho discute os pontos principais que devem ser levados em consideração para o projeto e fabricação de caixas redutoras. Esta análise é baseada em anos de experiência bem como nos mais recentes resultados em pesquisa. Adicionalmente este trabalho inclui a escolha do fator de aplicação adequado e as seguranças necessárias para quebra na raiz do dente, fadiga e escoriação.

Palavras-chave: Engrenagens; Redutores; Caixas redutoras.

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1 INTRODUCTION

Gears have been used since early antiquity. They were installed in corn mills, windmills, watermills and so on. With the invention of the steam machine and the discovery of electricity the industry of power transmission increased rapidly. The results are compact gearboxes with high power density and good efficiency. Today gears are used in different kinds of industries. Of course the steel and non-ferrous industry is one of the most important and difficult applications.

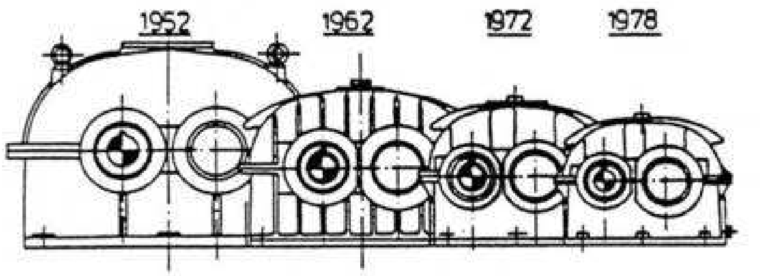
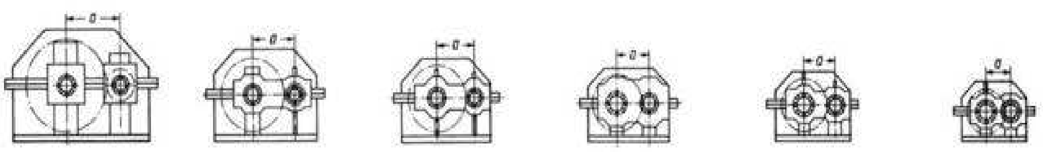


Figure 1: Stages of development.

The above illustration shows the stages of development relating to the size of industrial gears with the same nominal power. The gear case surface grows less and the thermical stress gets critical.



Center Distance						
Heat Treatment	Normalised	Through hardened	Pinion: Case carburized Wheel: Through hardened	Gas nitrated	Induction flank hardened	Case carburized
Machining	Hopped	Hopped	Grinded/ Hopped	Micro-hopped	Hopped And lapped	Grinded
Weight	174 %	100 %	71%	54%	49%	33%
Safety against pitting stress	1,3	1,3	1,3	1,3	1,4	1,6
Safety for tooth root	6,1	5,7	3,9	2,3	2,3	2,3

Figure 2:

Source: Niemann, 1985

Due to these smaller sizes of the gear boxes the following problems may occur:

- Higher temperature of the gear box due to smaller surface and less carrying-off heat
- Higher deflections have to be considered due to smaller pinion shafts

For decades the material qualities have been upgraded continuously and new hardening processes have been developed. In the 1950’s normal carbon steel was used for example. A reliable hardening process for the sizes of the wheels was not known at this time. Bit by bit alloyed steel was applied and as a result smaller parts like pinions could also be hardened. According to the wheels size, nitrating was developed. Nevertheless a negative consequence of that was the too low case thickness. Due to the further development of the steel production in terms of a better cleanliness by the vacuum furnace and due to the upgrading of the alloy, wheel with a diameter of multiple meters can be carburized today. At the same time test methods where developed which assure the quality.
Nowadays, the goal of research and development in the field of power transmission is not to invent new performances but first of all to optimise known functions. A great number of research projects have resulted in findings relating to precision, deformations and mass action. Therefore reduced gear size, efficiency-improvement and higher power density characterise the advancement in gear manufacturing.

2 DISCUSSION: CAUSE OF DAMAGE

For further reflexion of a constructive design of a gearbox it is necessary to analyse possible causes of damage. Several damages are:

2.1 Break of Tooth Base

The cause of a break of tooth root is a high force which acts on the flank of the teeth. This can be a peak load which occurs for example at pillow in a rolling mill or changing directions from the left to the right side of teeth. This has to be considered when calculating a reversing mill or intermediate gears. The tooth root safety factors can be upgraded by protuberance toothings.

Tooth hobbed without protuberance

Grinding allowance

Grinding notch

Tooth hobbed with protuberance

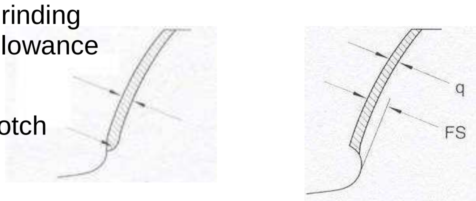
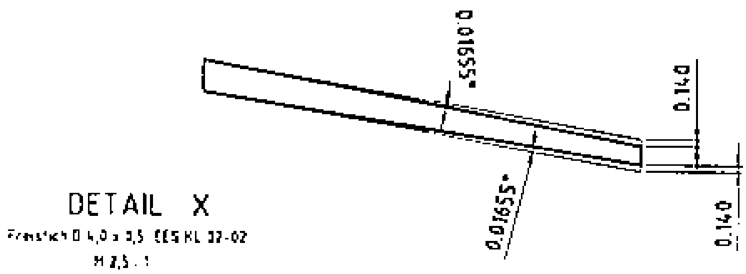


Figure 3:
Source: FVA

2.2 Pitting

Generally speaking pit marks emerge from continuous overcharge of contact areas. This is caused by a constant excessive load or basically by an inadequate contact pattern, which can emerge for example from a bending of a pinion or of a shaft. Therefore it is important to consider the real percentage contact area. This can be calculated by the bending line of both shafts and the torsion of the pinion. To gain pitting safety longitudinal corrections by grinding is a possibility.



m=24
width=470 mm

Figure 4: Longitudinal correction sample.

Source: Eisenbeiss GmbH

2.3 Scuffing

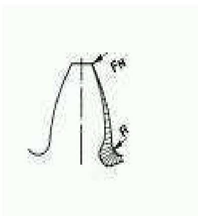
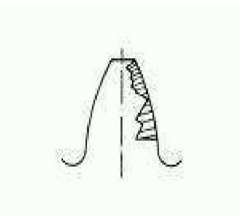
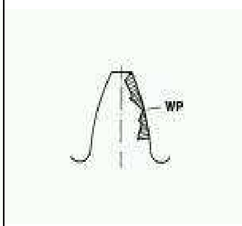
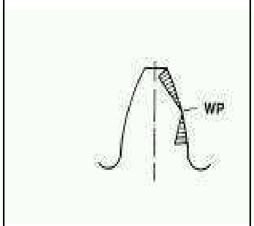
Scuffing emerges from inadequate lubrication and results in temporary welding of the tooth flanks to each other. This damage appears due to the specific gliding only between pitch circle and tooth point and tooth root respectively, because a percentage of gliding does not exist on the reference circle diameter. Upgrading the way of lubrication (changing oil viscosity, clean oil) or optimizing conditions or lubrication system can put things right.

2.4 Wearing

Wearing is not very essential in the modern design of gearboxes, because it only appears in case of slow motion and lubrication by grease.

2.5 Overview about the Different Damages

Table 1.

Kind of damage	Tooth breakage 	Pitting 	Scuffing 	Wearing 
Calculation parameter	Bending stress	Hertzian (contact) Pressure	Contact temperature + Specific sliding	Specific sliding
Frequent change of load	+		++	
Peak loads	++	+		
Continuously overload	+	++		
Bad tooth contacts		++		
Inappropriate start up		+	++	
Too low or too high speed			++	+
Lack of lubrication		(+)	+	++
Wrong oil		(+)	++	++
Dirty oil or grease			+	++

Source: Technische Universität Dreseden, 2000

Torque and drive should be analysed when considering the right application for different damages. Accordingly the following limits:

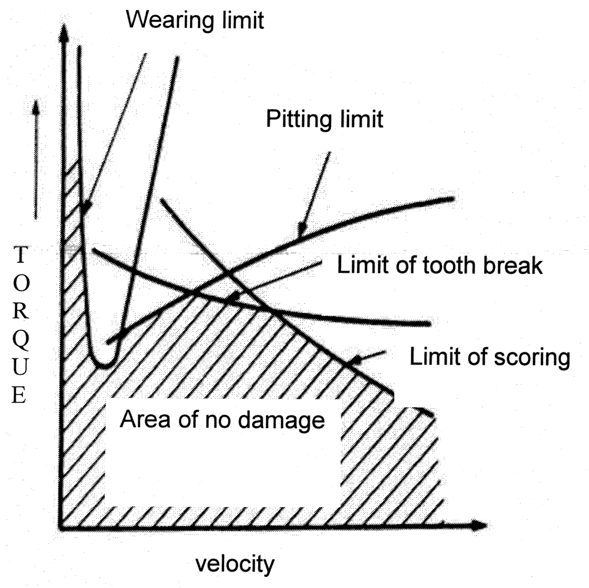


Figure 5:
Source: Eisenbeiss GmbH

Considering a wire rod mill the results are the following:

- **Roughing Mill:** slowly running at a high torque → safety on pitting has to be considered
- **Intermediate Stands:** depends on the size of the wire, slow to middle in the speed at a high torque → Safety on pitting or tooth break has to be analysed. In every case a shear pin or Safe Set coupling mill avoids peak loads.
- **Finishing stands:** high speed at low torques → for Safety scuffing in combination with tooth root break needs to be checked.

3 DESIGN OF TOOTHING

It is important to choose the right Service factor according to AMAG or application and safety factors according to DIN. An over dimensioning as well as an under dimensioning has to be avoided. An under dimensioning leads to a higher speed of toothing and as a result to a higher danger for scuffing.
The following chart is the basis for defining the service- or application factor:

Table 2: Definition of service- or application factors

	Moderate shock loads	Medium shock loads	High shock loads
Up to 3 attempts per hour	1,25	1,5	1,75
4 to 10 attempts per hour	1,35	1,6	1,85
11 to 60 attempts per hour	1,5	1,75	2
More than 60 attempts per hour	1,75	2,0	2,25

Source: DIN 3990/part 1 adapted by Eisenbeiss GmbH

Examples:

- **Moderate shock loads:** continuous zinc and aluminium strip rolling mill (design at max. rolling torque)
- **Medium shock loads:** block rolling mills, Briddle Rolls, mandrels
- **High shock loads:** cold strip rolling mills (design at max rolling torque), stripper

The qualification of toothing in several cases of application is influenced by the following factors:

- **Macro geometry:** Module, number of teeth, tooth width, helical angle, angle of pressure, correction of toothing
- **Micro geometry:** quality of toothing accuracy of surface, roughness in the tooth rood radius
- **Lubrication:** viscosity of oil, clearness of oil

The macro geometry is defined by the gearbox design. If the maximum bending of 0,05 x module was permitted for many years, it can be passed over promptly when calculating the wheel bending and the torsion of the pinions of the shafts. In that case the exact value of safeties can be shown and if required it can be approved by grinding of tip relief or longitudinal corrections. This enables the realisation of smaller distances of pinions in gearboxes of cold rolling mills.

Consequently the diameter of working rolls can be reduced and higher rolling forces can be reached. Another possibility results from the number of teeth and of the modules (module = diameter/number of teeth). The result of choosing a higher module is a long axis of the tooth root. This leads to a higher capability of the tooth root and simultaneously the safety of pitting reduces. Conversely a big number of teeth leads to a high safety on the design of pitting. The following example should clarify this showing a scaled drawing of a tooth at a wheelbase of 400 mm:

1

Number of teeth: 16:61

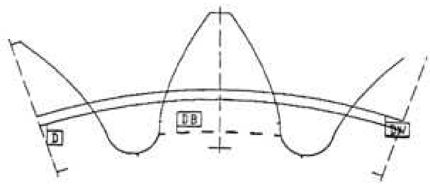
Module 10

Safety tooth root 1,660

Safety against pitting: 1,221

Safety against scuffing: 3,77

Torque: 80 kNm



2

Number of teeth: 19:77

Module 8

Safety tooth rod: 1,927

Safety pittings: 1,173

Safety against scuffing: 2,84

Torque: 80 kNm

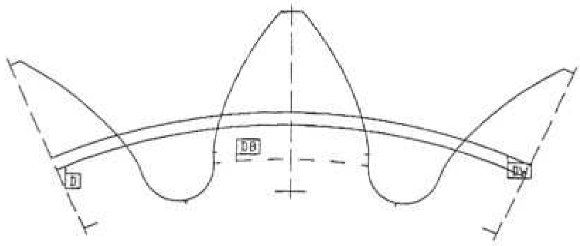


Figure 6:

Source: Eisenbeiss GmbH

If the macro geometry influences the tooth rod and the safety against pitting, the micro geometry and the lubrication has an essential influence on the safety against scuffing and only partially against pitting.

3 CONCLUSIONS

We found out that it is possible to use the smallest gearboxes without risk in similar application cases due to the modern technology of gearboxes. Thus, new technologies or higher speed of lines can be realised. Particular dangers need to be analysed in order to create suitable measures.

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