Fine Grinding on Klingelnberg Bevel Gear Grinding Machines

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One way to implement the growing performance requirements for transmissions is by optimizing the surface finish of the gearing. In addition to increasing the flank load capacity and the transmittable torque, this also allows for improvements in efficiency. On Oerlikon bevel gear grinding machines from Klingelnberg, fine grinding can be implemented efficiently in bevel gear production — even in an industrial serial process.

High efficiency and power density are basic requirements for a transmission. Particularly in highly dynamic applications in vehicle transmissions, however, the permissible dimensions, weights and inertia torques for the moving parts are strictly limited. Parameters such as material, heat treatment, inherent stress and surface finish are therefore considered with a view to increasing the permissible stress of a gear set. Specifically the last aspect — surface finish — is the focus of attention at Klingelnberg. In the area of aviation components, surface requirements for ground bevel gearings of $Ra < 0.3\,\mu m$, $Rz < 1.5\,\mu m$ or finer are standard. The experience and competence the company has acquired in the area of aviation applications form the basis for implementing fine grinding of bevel gears on Klingelnberg bevel gear grinding machines — and thus also for a technology that can be applied in an industrial series setting.

Stress and Permissible Stress of Gearings

When considering the fatigue life of gearings, the focus is always on the comparison of stress and permissible stress. Stress arises from the external load conditions, the gear macrogeometry, and the tribological system of the tooth contact, which is also influenced by the surface quality of the tooth flanks. The permissible stress of the gearing, in turn, is defined by the material, its heat treatment and inherent stress condition, as well as the macro- and microgeometry.

If the stress on the gearing exceeds the permissible stress, the required fatigue life is not achieved. If the options for adapting macrogeometric variables such as gear geometry, curvature radii and flank topography aimed at reducing stress and increasing permissible stress have been exhausted, the only remaining option is to increase the permissible stress through material or surface effects.

Increased Load Capacity Through Finer Surfaces

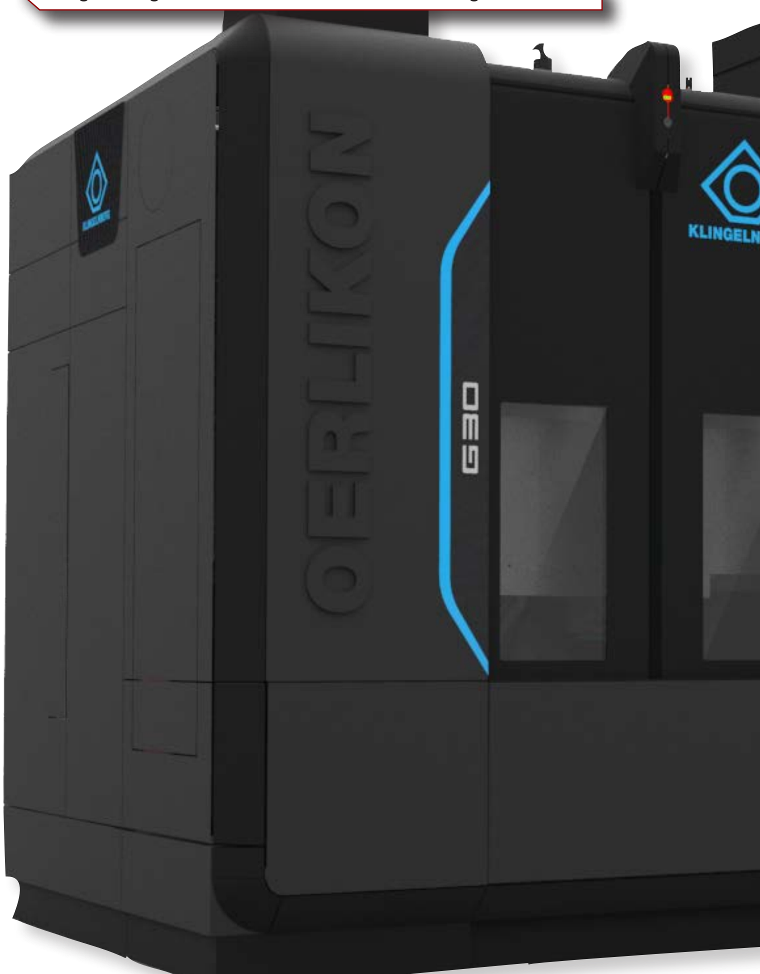
In principle, the permissible stress of mechanical components can also be improved by improving the quality of the surface finish. This is true for mechanical stress, such as bending fatigue under fluctuating load, as well as for breakdown and abrasion in tribocontact.

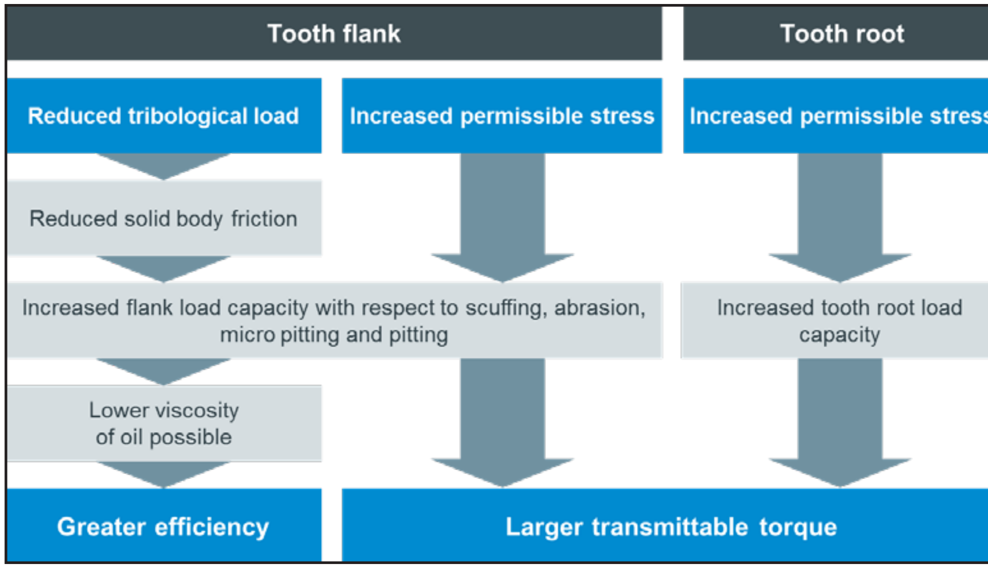
With respect to gearings, a higher quality of the surface finish of the tooth flank means a decrease in the tribological load due to reduced friction (Fig. 1). It also means increased permissible stress due to a reduced notch effect; moreover, an increased micropitting capacity is expected. All of this together leads to an increased load capacity of the tooth flank. A tooth root with a higher-quality surface finish also demonstrates a greater permissible stress due to the reduced notch effect. This also increases the tooth root strength. The potential gained can be used for a larger transmissible torque. If an increase in flank load capacity is not required, this can also be converted to greater efficiency through the use of a lower-viscosity lubricating oil.

Superfine Surfaces in Cylindrical Gear Transmissions

Studies of the influence of surface finish on flank load capacity have already been conducted for cylindrical gear transmissions. Ground surfaces were improved through trowalizing from $Ra = 0.30\,\mu m$ to $Ra = 0.11\,\mu m$ and $Ra = 0.07\,\mu m$, respectively. In this way, the continuously transmittable torque was improved by 20% and 40%, respectively.[1] With one variant, which underwent

Klingelnberg Oerlikon G 30 Bevel Gear Grinding Machine.





Advantages of higher-quality surface finish in gearings.

shot peening followed by trowalizing ($Ra = 0.07$ µm), an increase in torque of 70% was achieved.[2] Moreover, tests on large gearings have shown that micropitting below a roughness of $Ra = 0.3$ µm is avoided altogether.[3] By trowalizing cylindrical gearings, roughness parameters of less than $Ra = 0.06$ µm can be achieved.[4]

With conventional gear grinding processes, roughness values of approximately $Ra = 0.3$ µm are achieved. Through fine grinding processes, surfaces up to approximately $Ra = 0.2$ µm can be realized. To achieve finer surfaces, additional grinding wheels with an elastic bonding system can also be installed on the tool spindle of the grinding machine. Conventional gear grinding is then followed by polish-grinding, with very little stock removal. Roughness values of approximately $Ra = 0.1$ µm are possible in this case. Polish-grinding performed as part of a research project even achieved values of up to $Ra = 0.05$ µm ($Rz = 0.25$ µm).[5,6]

Special Case: Bevel Gear Transmissions

A characteristic feature of cylindrical gear transmissions is that at the generating circle only rolling occurs without any sliding. In the direction towards tooth tip and root, the sliding velocity increases such that — depending on the rotation speed — mixed friction always occurs in one section of the tooth flank. By contrast, hypoid gears (bevel gear transmissions with an axis offset) show a sliding velocity at every point on the tooth flank during operation — at least in the face width direction. For this reason the lubrication condition in tooth flank contact is more favorable, but the efficiency is lower in principle.

In terms of production, bevel gearings also differ fundamentally from cylindrical gearings. Ground bevel gears typically have a curved longitudinal tooth line; as a matter of principle, cup grinding wheels are used to manufacture them. Due to their low form stability, elastic-bonded tools are unsuitable for this purpose.

Fine Grinding of Bevel Gear Transmissions — a Challenge

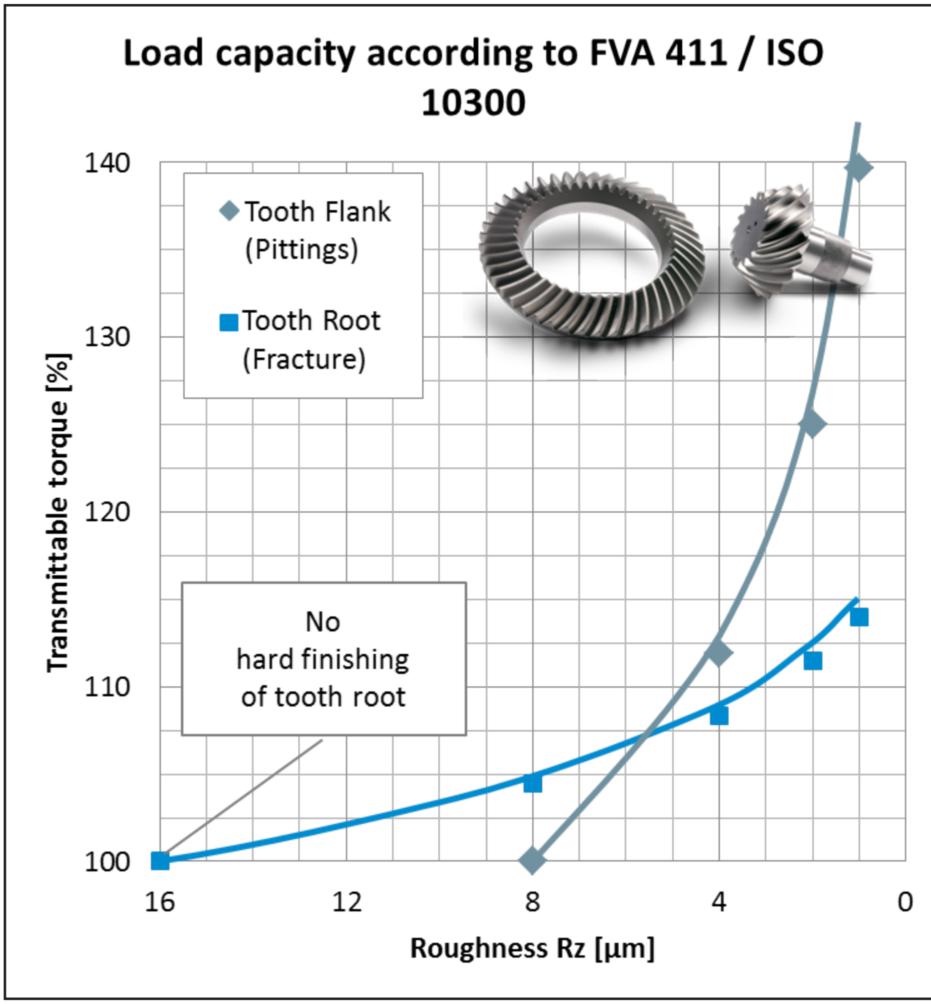
Klingelnberg's strategy is based on the use of a grinding tool that allows both a high-quality surface finish and a satisfactory machining performance. The particular charm of this solution is that fine grinding in this manner can be implemented in existing manufacturing sequences with minimal intervention.

With the appropriate dressing tools, modern grinding tools can be conditioned for a broad range of applications. In the first instance the grinding wheel is dressed in order to reach a very abrasive surface that is capable to remove the bulk of the grinding allowance effectively. Prior to the final grinding, the dressing parameters are chosen such that the desired surface finish can be reliably achieved with the appropriate process control. With the bevel gear grinding machines of the Oerlikon G 30-type designed for machining automotive gears and the G 60-type for the truck applications, machines meeting all these requirements are available on the market. The rigid construction of the machines in the vertical concept and the high precision provide optimal conditions for implementing the fine grinding process. An allowance control unit monitors the geometry of the series components without disrupting the production process to rule out thermal joint damage due to variations in the grinding allowance. Routine automatic inspection of the stock removal ensures the desired distribution of the allowance between the two tooth flanks during the course of the series.

Fine Grinding on Klingelnberg Bevel Gear Grinding Machines Enables Improved Performance of Bevel Gear Sets

Experiments conducted on an Oerlikon G 30 bevel gear grinding machine (Fig. 2) show that with ceramic-bonded grinding wheels used to grind typical automotive bevel pinions, surface parameters of approximately $Ra = 0.11$ µm and $Rz = 0.75$ µm can be achieved. For comparison: Typical requirements for the tooth flank surface of ground automotive hypoid gears today are in the range of $Ra = 0.8$ µm to 1.6 µm or $Rz = 4$ µm to 10 µm. Thus the conducted experiments make it clear that when grinding bevel gears in serial applications on Klingelnberg machines, there is significant potential available for increasing the quality of the surface finish. According to the standard calculation, the flank load capacity of the gearing can be increased through the improved quality of the surface finish by at least 25% to 40%, compared with the series standard (Fig. 3).

The permissible load on the tooth root can still be increased by approximately 15% starting from an unground surface. An improvement in the surface finish thus evidently has the potential to optimize the performance of bevel gear sets. With the Oerlikon bevel gear grinding machines from Klingelnberg, this load bearing potential for the bevel gear can be efficiently utilized in series production.



Influence of surface finish on standard load carrying capacity of an automotive hypoid gear set.

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