# Grinding Bevel Gears on Cylindrical Gear Grinding Machines

**Werner Kiess**
**Höfler Maschinenbau GmbH, Ettlingen, Germany**

Power train designs which employ gears with cone angles of approximately 2° to 5° have become quite common. It is difficult, if not impossible, to grind these gears on conventional bevel gear grinding machines. Cylindrical gear grinding machines are better suited for this task. This article will provide an overview of this option and briefly introduce four grinding variation possibilities.

DIN 868 defines bevel gears as gears whose reference surface, circular cone and axes have a common point of intersection. Gears with a very small cone also have a common axial intersecting plane.

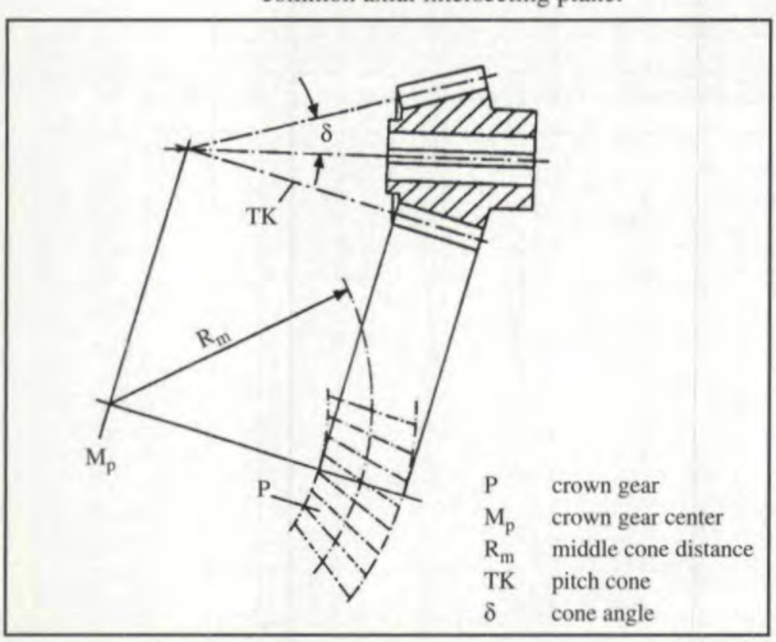


**Fig. 1 — The relationship of the cone angle to middle cone distance.**

Of course, gears without a common axis intersecting plane exist. The axes of these so-called hypoid gears cross each other somewhere in space. The name is derived from the mating of two exact hyperboloids, so even gears with extremely small cone angles are, by definition, bevel gears.

Gear box manufacturers (Refs. 1-3) increasingly turn to cylindrical gear grinding machines to grind spur and helical bevel gears with small cone angles. Most of these gears have cone angles of approximately $\delta = 5°$. The reason for this is that there are currently no bevel gear grinding machines on the market that can grind spur and helical bevel gears. Even if there were, it would be impossible to grind bevel gears with small cone angles as described above because of the extremely long middle cone distance $R_m$ (middle radius of the crown gear, Fig. 1). This can reach lengths up to two meters and even more. $R_m$ is one of the setting axes on a conventional bevel gear grinding machine, but such high numerical values lie outside the operating range of these machines. Therefore, it is appropriate to move the grinding of such gears to cylindrical gear grinding machines. The cone distance is of no significance on these machines, and the grinding wheel is moved along the cone envelope.

There are four principal solutions for solving this problem (see Fig. 2):

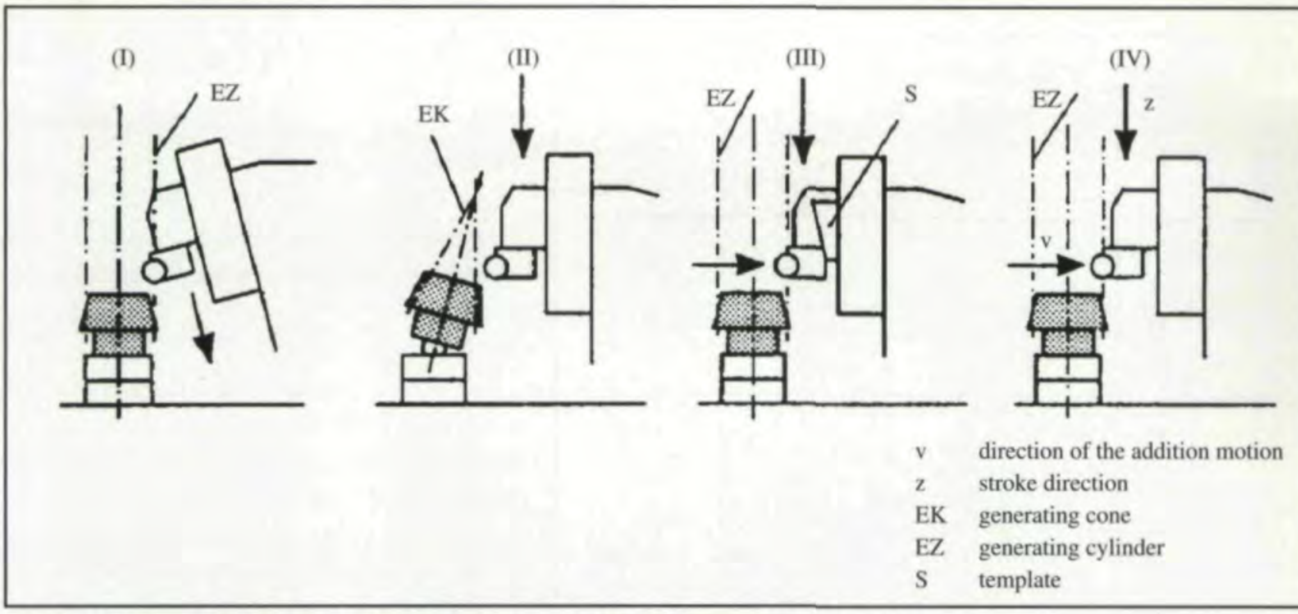


**Fig. 2 — Four possibilities for grinding bevel gears on a cylindrical gear grinding machine.**

I. The gear grinding machine is inclined to the workpiece's cone angle.

II. The bevel gear axis is inclined to its own cone angle. When this solution is used, a kinematic error automatically occurs because the workpiece's generating motion is produced by the machine table. However, this error can be calculated in advance and can be eliminated through numerically controlled machine table correction movements.

III. A template, which corresponds to the workpiece cone angle δ, is mounted on the grinding slide carrier. The resulting additional grinding wheel motion perpendicular to the stroke is produced by a tracing system which translates the template form into the stroke movement. This is the same process that is used to crown a cylindrical gear tooth.

IV. Numerically controlled actuator driven tool slides eliminate the necessity of the template described in Solution III above. The numerical controls take over the task of coordinating the additional forward or perpendicular tool motion.

How do these solutions differ from one another? When grinding cylindrical gears, the double stroke and generating speed must be coordinated with the stroke length and other variables. For Solutions I and II, this coordination is the same as for cylindrical gears. However, the double stroke speed must be reduced by about 20-40% in comparison to the cylindrical gear case for Solutions III and IV. The reason for this is the additional grinding wheel motion, perpendicular to the "normal" stroke motion. As the cone angle decreases, the time loss in comparison to cylindrical gear grinding decreases as well.

For this reason, Solution IV is the preferred variation for bevel gears with cone angles of $\delta \leq 5°$. Solution II is preferred for cone angles of more than 5°. To achieve the desired precision, it is easier to realize a slower, rather than a faster motion with help of numerical controls. Solutions I and III can be considered outdated because of the additional necessity of mechanical modifications.

However, one other consideration plays an important role in grinding bevel gears on cylindrical gear grinders: The principal difference in how the involute is created in each of the above described examples. In Solutions I, III and IV, the generating pitch cylinder is used as a basis for generation. Its diameter remains constant throughout the face width of the gear. In connection with the grinding wheel, the base cylinder also remains constant. Consequently, bevel gears ground in this manner can be viewed as a stack of cylindrical gears with displaced profiles and infinitely small face widths. The profile displacement is not constant, but changes infinitely along the tooth face width. That means that all these infinitely thin cylindrical gear plates use the same involute as the tooth flank. Only the utilized section wanders (Fig. 3).

Involutes produced in this manner are

**Dr.-Ing. Werner Kiess**

*is the head of the quality assurance department at Höfler Maschinenbau GmbH, Ettlingen, Germany. Prior to his work at Höfler, Dr. Kiess worked in the gear manufacturing department of the Machine Tool Research Center in Chemnitz, Germany.*

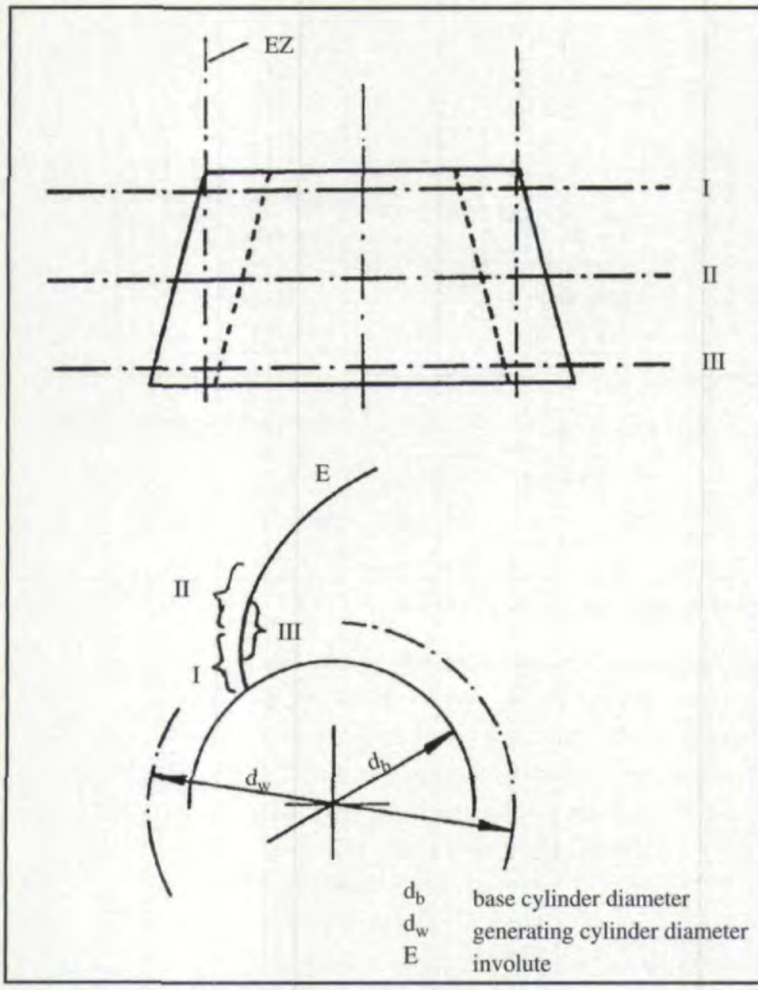


**Fig. 3 — Profile displacement by bevel gear grinding.**

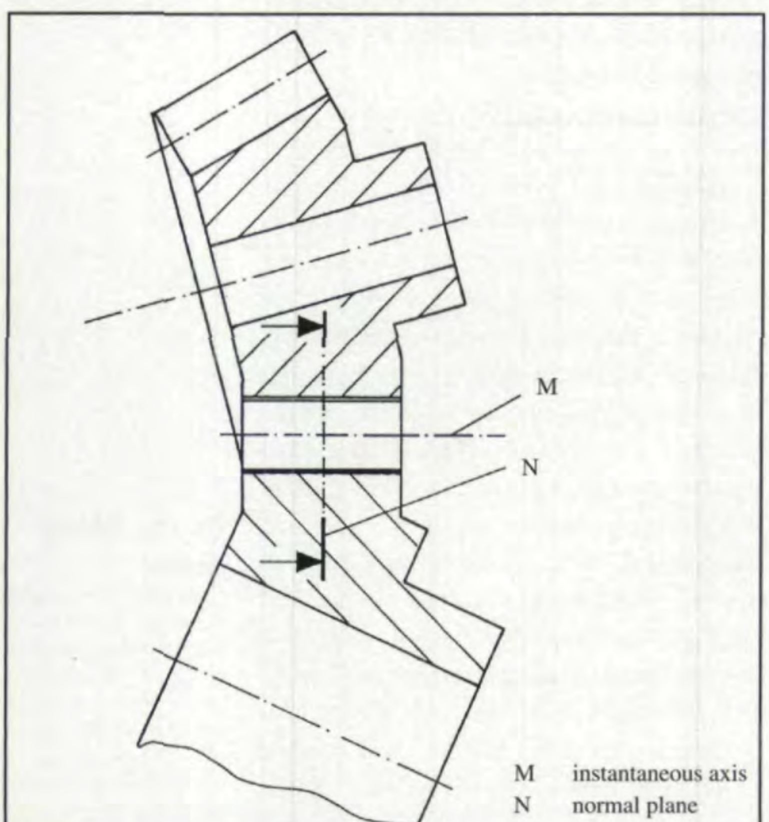


**Fig. 4 — Common surface line of mated bevel gears.**

present in the transverse section because of the utilized generating cylinder. But when two bevel gears are paired, the common surface line is simultaneously the instantaneous axis *M* (Fig. 4). In the plane in which the instantaneous axis is in a vertical position (perpendicular plane *N*), no involute flank rolls with another. At best, the involutes are distorted.

Contrary to this, involutes are created when rolled with the generating pitch bevel in the perpendicular plane on which the instantaneous axis is in a vertical position. Solution II is the best suited example for bevel gears with cone angles $\delta > 5°$ or geometrically exact bevel gears. When creating the involute with the generating pitch cone, the crown gear is the reference element for the layout as well as the production of the tooth system.

A considerable number of spur and helical bevel gears have been ground on Nova CNC cylindrical gear grinding machines using Solution IV. The direction of the pointed end of the cone (up or down) was not important. Gear body geometry and/or the available mounting fixture were the determining factors. In each case, bevel gears with cone angles from 2° to 5° achieved quality levels of (IV) and (III) in accordance with DIN 3962. ■

**References:**


1. Firmenschrift der Zahnradfabrik Friedrichshafen AG. *Diesel & Gas Turbine Catalog 57* (1992). Friedrichshafen, 1992.

2. Rothenhäusler (Zahnradfabrik Friedrichshafen AF): "Getriebe für schnelle und unkonventionelle Schiffe." TU Hamburg-Harburg, 14. bis 16. October, 1992.

3. Beam, A.B. "Beveloid Gearing." *Machine Design*, December, 1954.


**Acknowledgements:**


*All illustrations courtesy of Höfler, Ettlingen, Germany. This article first appeared in German in* Werkstatt und Betrieb *126 (1993) 7, pp. 409-410. It also appeared in* European Production Engineering, *Sept, 1993. Reproduced with permission.*