Cylkro® Gears: An Alternative in Mechanical Power Transmission

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An alternative to bevel gears uses a cylindrical pinion and a face gear for power transmission in a variety of applications.

Introduction

Bevel gears have been the standard for several decades in situations where power transmission has to occur between shafts mounted at a given angle. Now a new approach has been developed that challenges the bevel gear's de facto monopoly in such applications. The concept is based on the principle of the crown gear; i.e., a cylindrical pinion mates with a face gear. Crown Gear B.V. in Enschede, Holland, is the developer of these specialty gear teeth, which are marketed under the trade name Cylkro®.

Features of the Cylkro Gear

The Cylkro transmission is an angular gear pair consisting of a cylindrical pinion with an involute tooth profile mating with a Cylkro gear. The upper gear pair in Fig. 1 is a normal cylindrical gear pair. Shown beneath it are three Cylkro gears using the same pinion with different shaft angles and gear ratios.

The geometry of a Cylkro gear is determined by the following factors: the geometry of the mating pinions, the relative positioning of the pinion axis in relation to the Cylkro gear axis and the pair's gear ratio. The pinion's geometry remains constant along its face width. The geometry of the Cylkro gear can be regarded as a rack; however, the pressure angle varies over the face width (See Fig. 2).

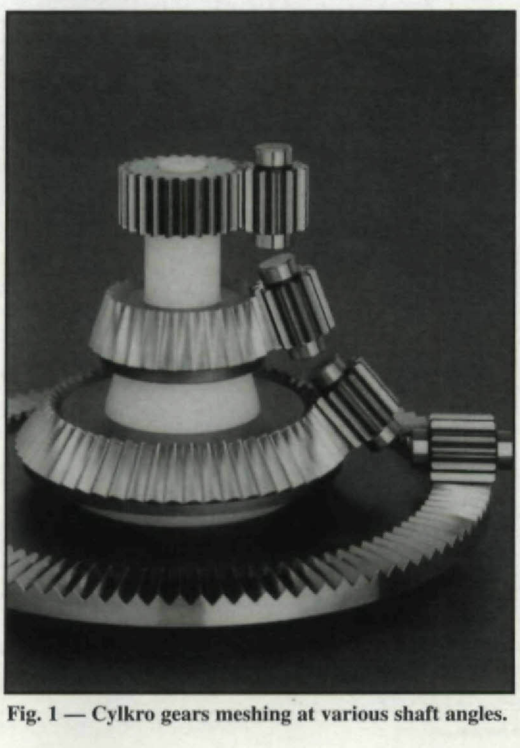

Fig. 1 — Cylkro gears meshing at various shaft angles.

Development

The general principles of face gear geometry and the necessary cutting techniques were readily available in the 1930s, but specific knowledge of the precise geometry and load distribution characteristics of face gears were lacking. These topics were the first to be researched and applied to the development of Cylkro gears. Advanced computer programs were used to develop and optimize the geometry. Many production methods were evaluated, and the generating hob process was chosen as the most efficient.

The next step in the development process was the design of a new generation of HSS and hard metal generating hobs. Initially the milling cutter profiles were pinion-shaped. During subsequent development rounds, the cutter shapes were gradually adapted for the production of Cylkro gears on commercially available CNC hobbing machines.

The power packing optimization abilities (minimal power transmission-volume ratios) of the first production batches were tested extensively. Testing and measurement methodologies and instrumentation were developed along with the production process. DIN 3962 and 3965 standards were applied. The manufactured geometry can now be compared exactly with the theoretical geometry, allowing a quality-controlled manufacturing process of the face gears.

It is now possible to manufacture Cylkro gears suitable for power-intensive transmissions. In this article the most frequently used form of Cylkro gear transmissions, i.e., 90° shaft angles using spur gear teeth, will serve as the basis for all examples, unless otherwise indicated.

Technology

Geometry. The geometry of the pinion, its position in relation to the axis of rotation of the Cylkro gear and the transmission ratio determine the geometry of the teeth. Formulas have been applied to calculate the geometry of the teeth in every possible application and for every shaft angle between 0° and 110°, with or without an offset pinion, and with spur or helical pinions.

Contact path lines. A transverse cross section of a Cylkro gear can be treated as a rack and pinion pair. The rack's pressure angle is a variable value along the entire face width of the gear. The variable pressure angle ensures that pinion and gear teeth keep smooth contact path lines between them (see Fig. 3).

Since contact path lines are skewed, the characteristics of Cylkro gear pairs are similar to those of helical cylindrical gear pairs with the same helix angle. This is true for the gear's rotation characteristics, its acoustic performance, its power transmission capabilities and its overlap ratios.

Transmission power packing density. The strength of material calculations for bending strength and pitting resistance meet DIN 3990 and ISO 6336 standards. Cylkro-specific factors in these standards were incorporated, and the newly emerging standards were verified and proven correct by means of finite element analysis methods (FEA/FEM) and with back-to-back life tests (see Fig. 4). All factors commonly used in strength of material calculations, such as the Ka factor, the dynamic Kv factor, etc., were also used with these gears.

These development efforts, especially gear tooth optimization, have resulted in transmission power packing densities equaling or exceeding those of bevel gears, depending on transmission ratios and shaft and helix angles.

Manufacturing. Cylkro gears are manufactured with standard CNC-controlled hobbing machines. This guarantees an efficient and continuous work flow, allowing high precision dimensioning. The production steps are lathing the blank, cutting the teeth in the non-hardened base material, hardening to HRc 61 ± 1, machining the locating faces (datum planes), finish-cutting the teeth flanks with hard metal milling cutters or grinders and honing a fine-finishing profile adjustment if necessary.

The new generation milling cutters developed by Crown Gear can be sharpened without running the risk of changing the cutting geometry. The geometry of the milling cutter is determined by the pinion's gear teeth characteristics, such as its module, number of teeth, helix angle and addendum modification. Cylkro gears can be manufactured with these milling cutters regardless of axis angles, transmission ratios or axis centerline offset.

Cylkro gear verification uses 3-D, CNC measurement banks. The gear's calculated standard profile parameters are stored in the 3-D measurement bank and compared with the actual measured 3-D values. The deviation patterns are obtained in the form of a computer output with micrometer orders of magnitude (μ range). The patterns are directly related to the quality of production.

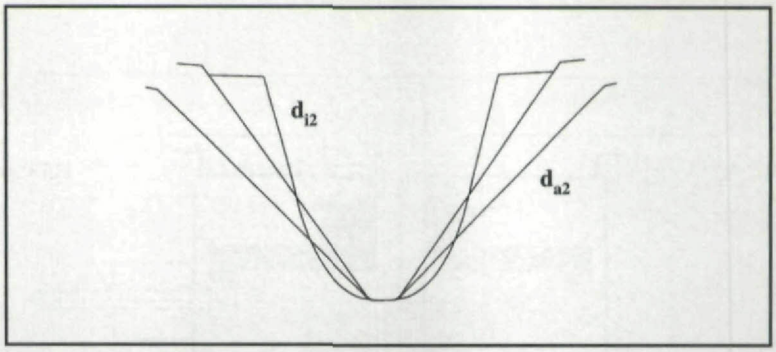

Fig. 2 — The variable geometry of the Cylkro gear.

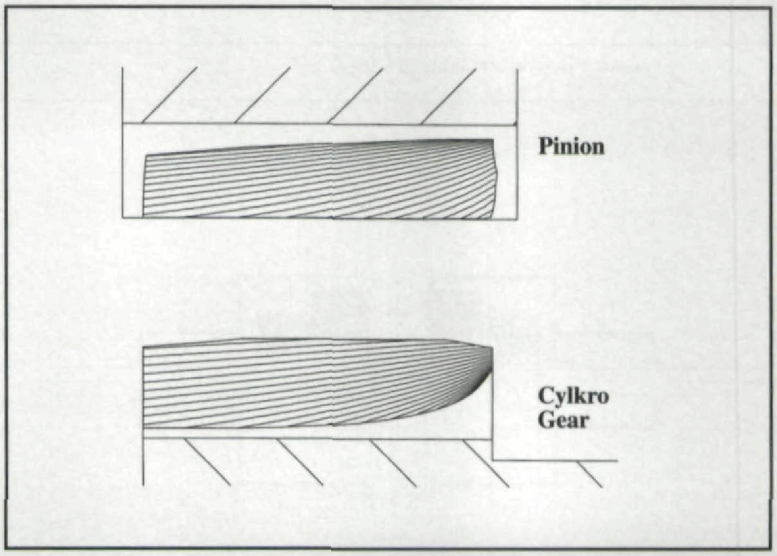

Fig. 3 — Lines of contact at the pinion and the Cylkro gear flank.

Fig. 4 — FEM stresses on a Cylkro tooth.

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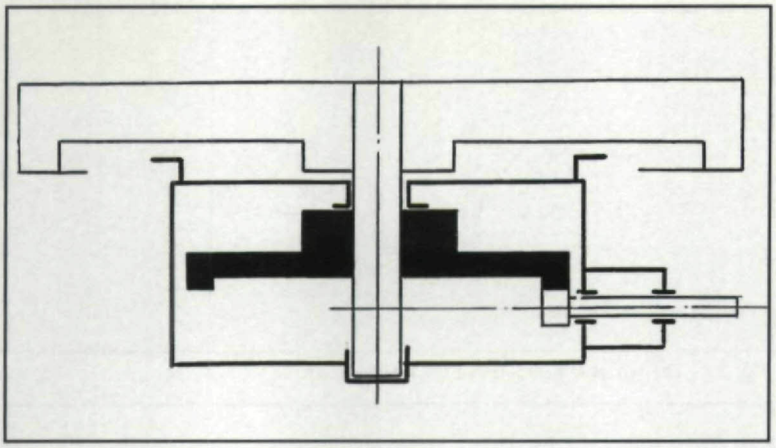

Fig. 5 — Single-stage driven turntable (i = 10).

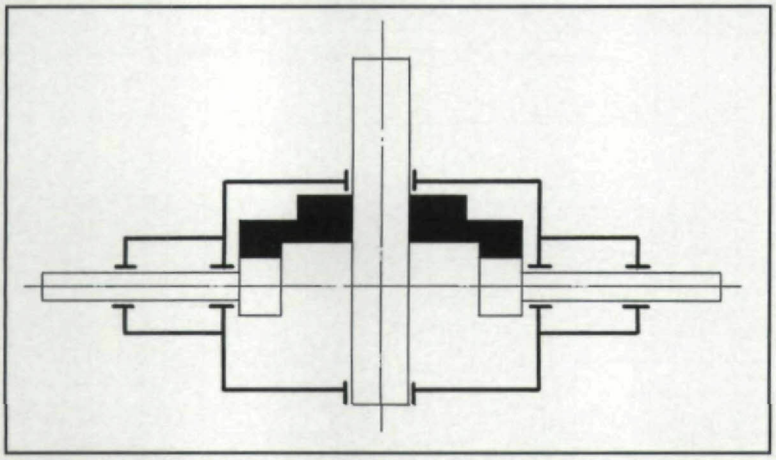

Fig. 6 — Multi-power design for a pinion as an integrated part of a shaft.

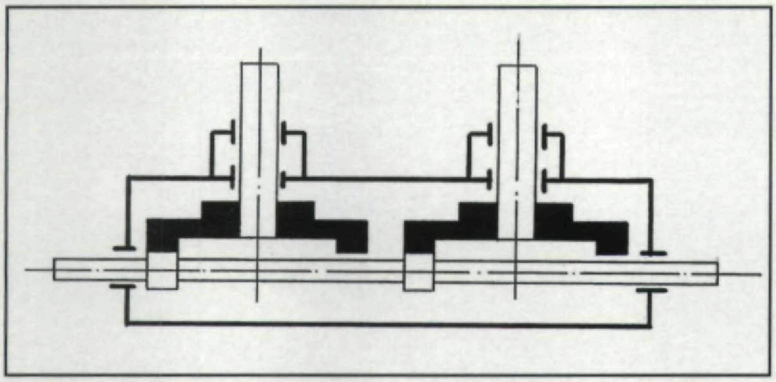

Fig. 7 — Centrally driven shaft with several distribution points.

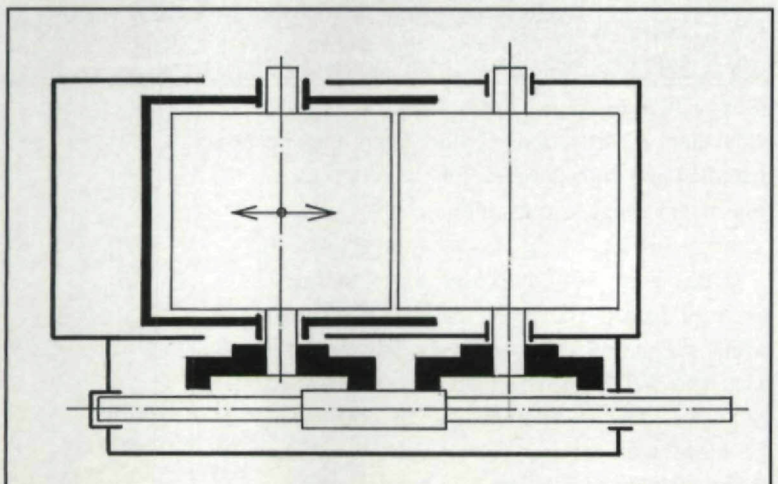

Fig. 8 — Rolling mill drums with adjustable throughput. (Patented by Crown Gear.)

Properties. Cylkro gear systems have the following characteristics:

- The pinion is a normal spur gear whose axial position has no influence on the meshing zone.
- Assembly time is reduced because only the axial position of the face gear needs to be set.
- Lapping is unnecessary because all gears irrespective of their tooth numbers or shaft angles may be interchangeably meshed with the common pinion upon which the particular generating hob geometry is based.
- Axial load on a pinion with straight spur teeth is non-existent.
- Meshing is smooth thanks to the system's oblique contact lines and high contact ratio.
- The systems offer high transmission ratios in one stage.
- Cost-effective manufacture on conventional CNC gear hobbing machines is possible.
- Using straddle-mounted pinions is possible.
- Zero backlash high-accuracy applications may easily be realized.
- High-strength teeth and good contact geometry give high torque capability.

Technical and economic benefits. The unique features of Cylkro gears bring certain economic and technical benefits that would not normally be possible with bevel gears or that would be possible only at great cost.

The absence of the need for any axial adjustment of the pinion shaft during mounting, repair or maintenance is a time saver, especially with high-tech assemblies. The construction of the pinion bearing can be greatly simplified thanks to the absence of axial loads. The use of bilateral pinion bearings is possible when the assembly requires extremely rigid construction. The Cylkro gear construction is characterized by a high degree of efficiency as a result of the sliding effect of generating tooth flanks while in motion.

Other economic benefits lie in the simplicity of the cylindrical pinion, which has obvious manufacturing cost advantages over conical pinions. Furthermore, Cylkro gears can be produced with much more economical tooling and machinery than bevel gears. The same machine tool can be used for coarse and fine machining, eliminating special machinery for finishing passes. The lapping process may be eliminated altogether thanks to the high tolerance finishing pass gears receive in the standard production process.

Applications. The unique properties of the Cylkro gear allow new approaches to design and manufacturing. Cylkro gear sets can be made in a wide range of gear ratios, with axial freedom of the pinion and a free choice of shaft angle.

A wide range of gear ratios. Theoretically the Cylkro transmission is suited for all possible gear ratios (i -> ∞). However, the effective face width of the Cylkro teeth in the area of the inner diameter will be reduced as a result of root undercutting when using small gear ratios (i -> 1.5) for a shaft angle of 90°. In these instances, the mechanical power transmission capability of Cylkro gears is smaller than in bevel gears of comparable size. Cylkro gears may definitely be used as power transmission gears when gear ratios equal or exceed i = 1.5.

No technical limitations exist regarding the production process for large gear ratios. A gear ratio of i = 12, for instance, would normally be designed in several stages, reducing the physical weight and, consequently, the material cost of the gear train. For some designs, however, it is advisable to design a single, large stage transmission.

The largest gear ratio achievable with bevel gears (i = 6 ~ 8) is determined by the production process itself. Cylkro gears, however, can handle large gear ratios in one single stage without any difficulties.

A typical application can be found in environments requiring a high degree of constant angular velocity. For example, Fig. 5 shows an application where a gear ratio of i = 10 is combined with tight angular velocity precision for the turning table. It is obvious that the total cumulative pitch error of this Cylkro gear is averaged over the largest possible gear diameter. With a diameter half the size or with a double-staged gear, the error deviation would approximately be twice as large. The Cylkro gear design combines both large gear ratios and precision constant angular velocity. Cylkro gear dimensions play a secondary role. Different gear ratios can be achieved simply by changing the number of teeth on the Cylkro gear. For some applications one gearbox can be used for several gear ratios with the same housing, bearings, pinion(s), etc.

Axial freedom of the pinion. Cylindrical gears may be offset freely in both axial and radial directions within reasonable limits without negative impact on the lines of action of the teeth. This degree of freedom in either direction does not exist in bevel gears. Bevel gears individually require precise installation and tuning to achieve a good bearing contact and the right backlash tolerance.

The Cylkro transmission combines both types of gears. It requires adjustment only in the axial direction to obtain a good bearing contact (the pinion teeth's base tangent lengths do not affect this). Axial pinion motion is perfectly possible.

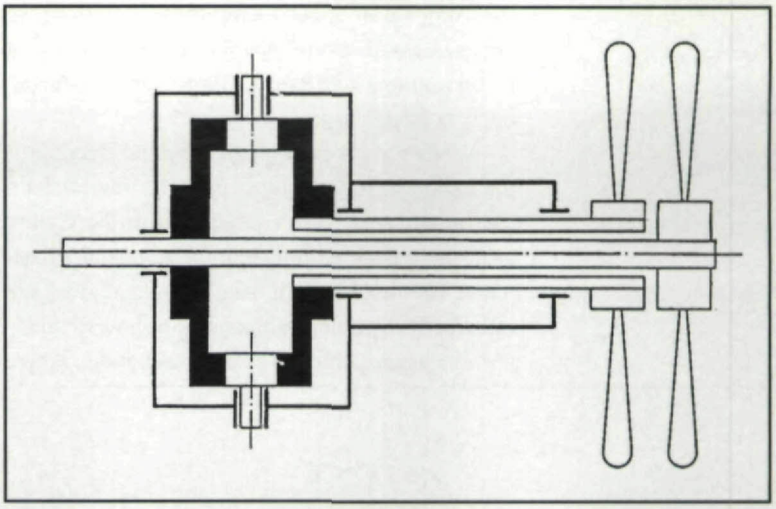

Fig. 9 — Coaxial counter-rotating propellers.

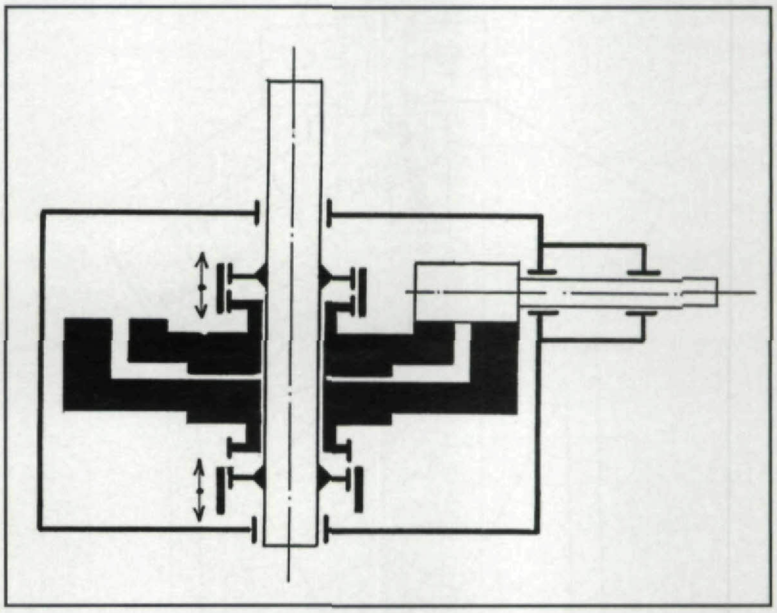

Fig. 10 — Ninety degrees (90°) dual-speed gearbox.

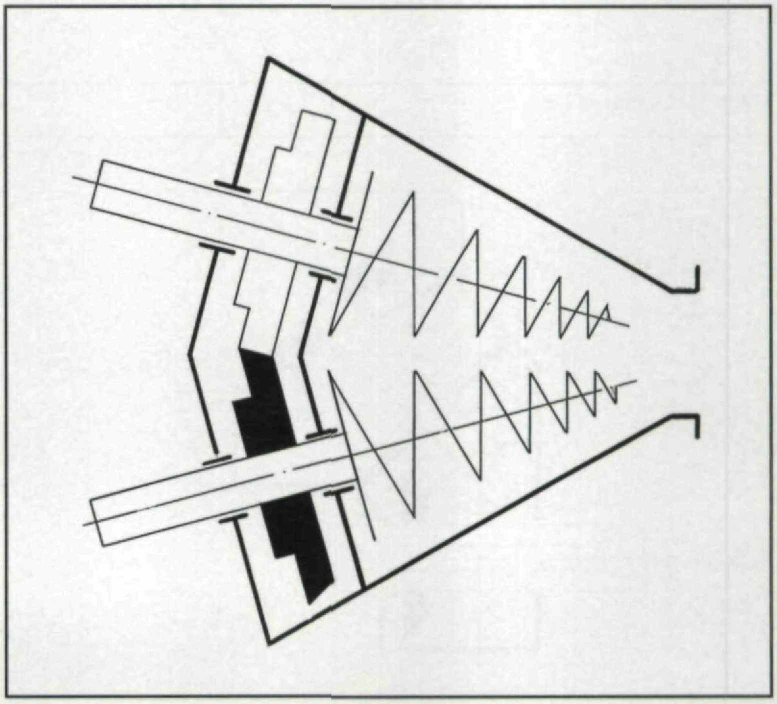

Fig. 11 — Dual-feed screw for an injection molding machine.

Adjustments are greatly simplified; moreover, the engagement of several pinions on one Cylkro gear or one pinion with two Cylkro gears simultaneously is made easy.

Another good example of the axial freedom is the pinion as an integrated part of a motor shaft. The motor shaft mates directly with the Cylkro gear; there is no requirement for any axial adjustment. The motor's own axial movement does not influence the bearing contact. Fig. 6 shows a multi-power design, which is used in situations where one Cylkro shaft drives several rapidly turning pinion shafts or in situations where more than one motor drives one Cylkro shaft.

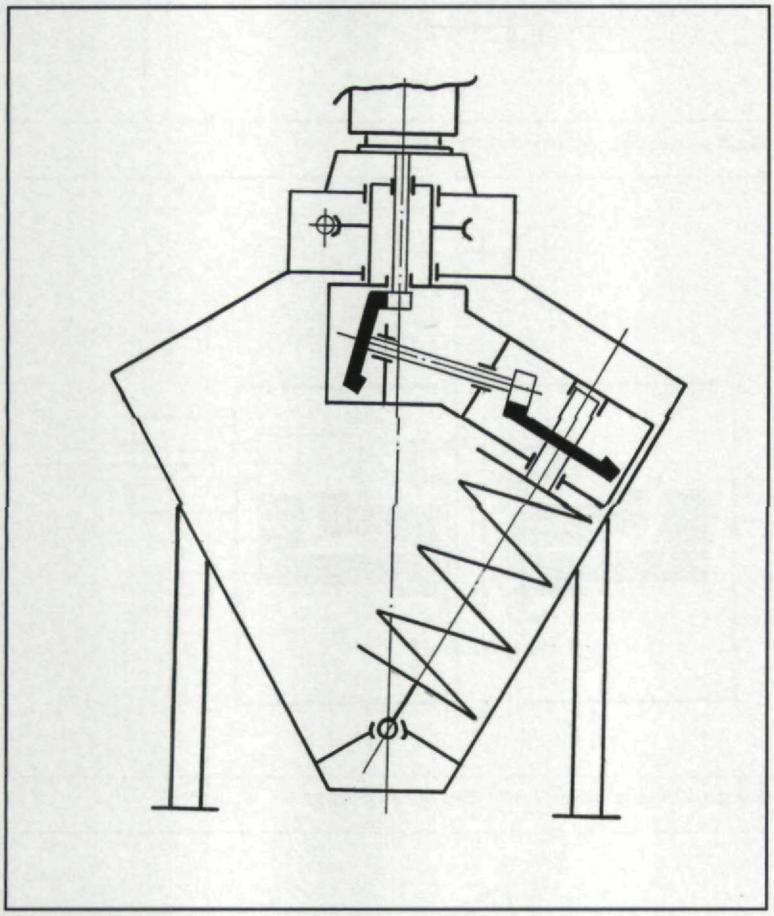

Fig. 12 — Conical mixer.

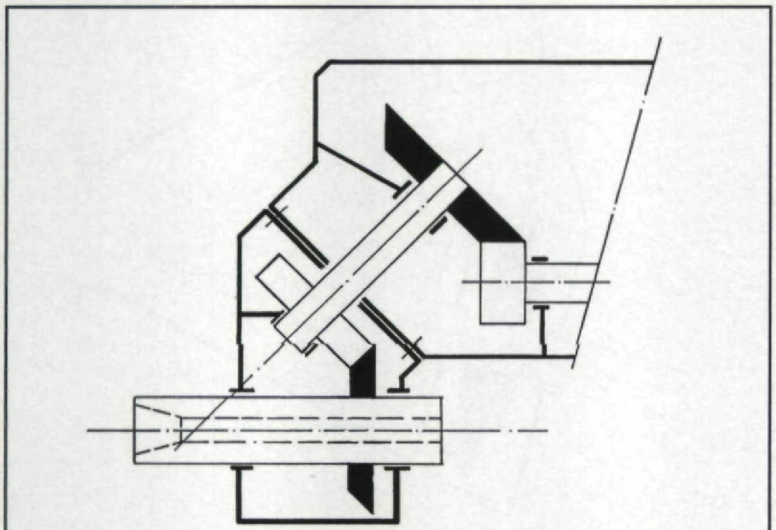

Fig. 13 — Milling machine heads.

Fig. 7 shows a common driving shaft onto which a set of pinions is mounted, each driving a Cylkro gear. This construction is commonplace in farming machinery. Axial dilations of the pinion shaft because of temperature changes, for example, have no influence on the lines of action of the teeth, nor on the rotational symmetry of the outgoing shafts.

The rolling mill drum design shown in Fig. 8 is an even better demonstration of the axial freedom of the pinion. Thanks to the possibility of the axial displacement freedom offered by the Cylkro gear design, the rolling mill drum's centerlines can be adjusted to accommodate milling material plate thicknesses. It is also possible to mount mill drums with other diameters. This does not affect the bearing contact or any relative motion of one drum against the other. When necessary, both drums may have different diameters. Of course, this would result in a similar requirement for different diameters of the respective Cylkro gears.

Fig. 9 shows a construction for distributing mechanical power to two counter-rotating propeller blades, where the propellers are mounted on coaxial shafts. Counter-rotating propellers are used in shipbuilding to get higher propulsion yields. Half of the available mechanical power is transmitted directly on the inner shaft, and the other half is transmitted to the outer shaft through a planetary setup of pinions mating with the second Cylkro gear. The design allows different rotating speeds on each shaft if required.

Fig. 10 shows a dual-speed perpendicular gearbox. Two Cylkro gears, each with different numbers of teeth, driven by a common pinion are coupled to a shaft through a clutch mechanism. The clutch ensures that the outgoing shaft stays connected to one Cylkro gear at a time.

Another application that takes advantage of the axial freedom of the pinion is the assembly that drives the pressure cylinder in a printing press. The position of the circumference of the printing press cylinder relative to the feed cylinder must be adjusted very precisely. A helical pinion with an adjustable (tunable) axial position on the driving shaft causes a proportional rotational offset of the Cylkro gear for a given axial pinion shift.

Shaft angle's freedom of choice. The freedom to select almost any shaft angle, as well as all other features and benefits of the Cylkro gear, is crucial to making optimal use of this design. The angular Cylkro gearbox does not affect the bearing contact in any way.

A typical application in gearboxes with small shaft angles is used for driving a ship propeller. Normally the motor is mounted horizontally, while the propeller shaft is mounted at an angle of 7° to 20°.

Fig. 11 shows a drive mechanism for dual-feed screws working under an angle of 15° to 20°, as commonly found in extrusion and injection machines for the plastics transformation industry. The dual-stage drive mechanism shown in Fig. 12 is part of a conical mixer with a still-standing reservoir. The drive mechanism could be executed in a different way. It could, for instance, be mounted on the bottom side of the reservoir.

The drive mechanism for the tool flange of the milling machine in Fig. 13 has a connecting shaft equipped with a pinion and a Cylkro gear. The milling machine's head can rotate freely around its drive shaft. The Cylkro gear on one end of the connecting shaft can be freely adjusted along its axial position; therefore, the pinion on the other end of the shaft will interfere with the tooth's contact path.

Currently several kinds of Cylkro gears are being tested in helicopter gear assemblies. A simple demonstration of the ease of adjustments for each Cylkro set is shown in Figs. 14 and 15, where the use of power distribution is shown. Note that the shaft angles differ from the classical 90°. Fig. 14 demonstrates power distribution in the first stage, and Fig. 15 does so in the second stage. ○

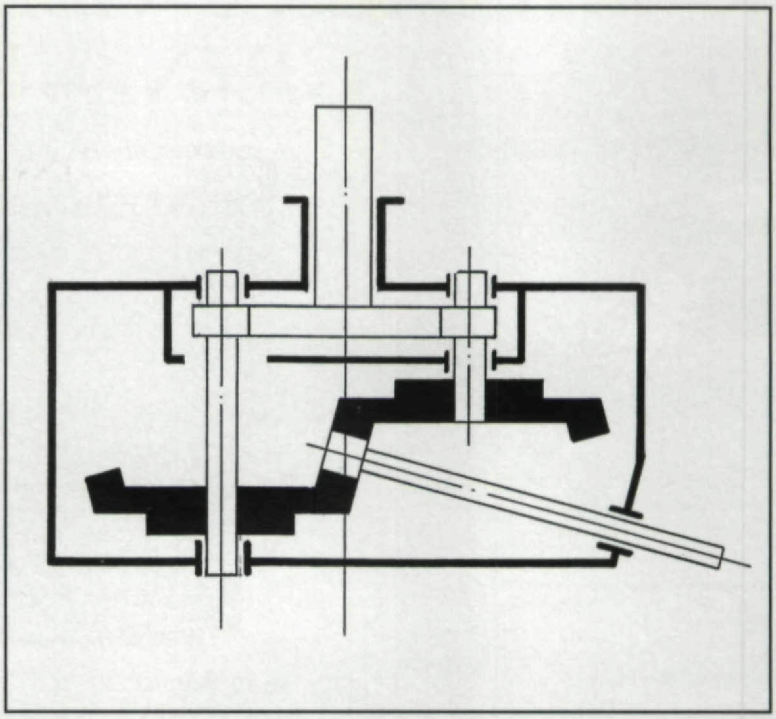

Fig. 14 — Helicopter gear assemblies. (Patented by Lucas Western, Inc.)

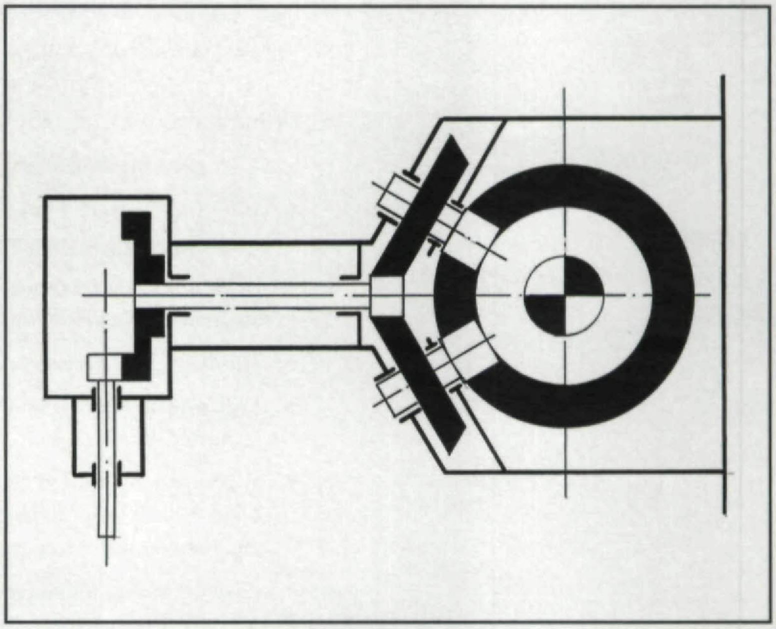

Fig. 15 — Helicopter gear assemblies. (Patented by Daf SP.)

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