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Presentation title	**RINGSPANN Precision Clamping Elements for Gear Wheel Production**
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1. Introduction

Gear transmissions are indispensable for machine and plant engineering. The German transmission manufacturing industry is among the global leaders in the field, thanks not least of all to the research activities of the FVA (Forschungsvereinigung Antriebstechnik im VDMA).

In response to the need to increase the performance and reduce noise emissions, standards of precision for many transmission components have become more demanding in recent years. Moreover, manufacturers have been compelled to reduce the costs of producing transmission components progressively in order to remain competitive. Both objectives have been achieved by taking full advantage of the performance capacities of production machinery and tools in terms of precision, while reducing set-up and cycle times substantially. These achievements are not attributable to high-tech machinery and tools alone, however. The third critical component is the development of precision clamping elements for workholding systems.

Precision clamping elements are developed and manufactured by a small number of companies. RINGSPANN is one such company, and has been working in this market with success for over 65 years. Over the years, RINGSPANN has acquired a wealth of experience with thousands of precision clamping fixtures and realized numerous technically sophisticated applications of innovative clamping solutions. These include clamping applications in the fields of machine-tool production, automobile and aircraft manufacturing and especially for gear clamping applications.

As the name suggests, RINGSPANN is specialized in clamping solutions for circular-cylindrical parts. The basic mechanical principles of clamping element design are outlined in Chapter 2. The characteristics and advantages of RINGSPANN precision clamping elements are discussed in Chapter 3. Typical examples of gear clamping applications are shown in Chapter 4.

The rapidly rising demand for wind turbine transmissions in recent years poses yet another challenge for precision clamping technology: the need to clamp large, heavy gears and other transmission components. RINGSPANN also offers precise and innovative solutions here as well. These are presented with reference to sample applications in Chapter 5.

2. Functional principles of RINGSPANN precision clamping elements

2.1. General remarks on precision clamping elements

An absolute prerequisite for all precision clamping elements, regardless of type, is that the functional surfaces of these parts, such as bores, outside edges and at least one planar surface are machined precisely in an earlier work phase.

This prerequisite applies to all worked parts, including gears. In a typical production process, the bearing bore or a centring diameter as well as an adjacent flat surface are produced by milling or grinding in a clamping system. These surfaces are used as clamping and contact surfaces in the subsequent gear production process by milling, grinding or lapping. The degrees of precision achieved in these processing steps always depend on the precision of the previously produced reference surfaces.

2.2. Basic form and concept of the RINGSPANN system

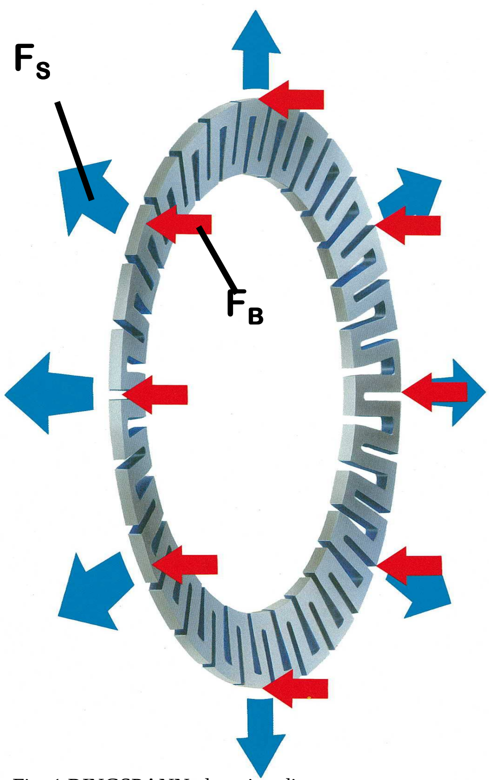
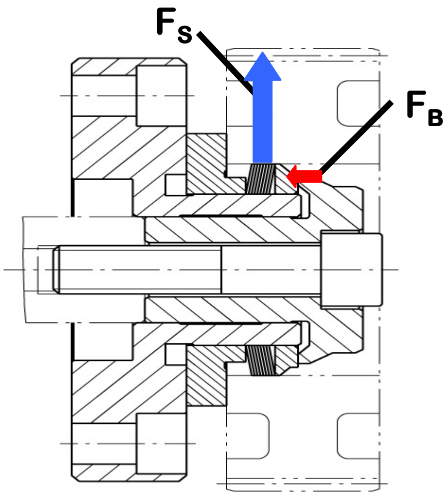


Fig. 1 RINGSPANN clamping disc

The RINGSPANN clamping disc is a flat tapered ring made of special hardened spring steel (see Fig. 1). The alternating slots cut in the inner and outer edges lend the clamping disc a high degree of elasticity. All surfaces are precision-ground on machines developed especially for this purpose. The clamping disc is either pushed with slight pressure onto a shaft journal (mandrel) or inserted into a bore (chuck) as a single element or a bonded disc pack. In each case, the free cylindrical edge of the clamping disc is the clamping surface.

The component is set against the clamping surface either with its pre-machined bore or its pre-machined outer edge. Figs. 2.1 and 2.2 shows a simple clamping mandrel with a bonded disc pack.

The application of actuating force F_B induces a tipping movement of the clamping disc (see Figs. 3, 4 and 5). The radial movement generates pressure with clamping force F_S, whereas axial motion is used to press the component against an axial contact surface by the effect of axial friction forces and thus to align it without axial runout.



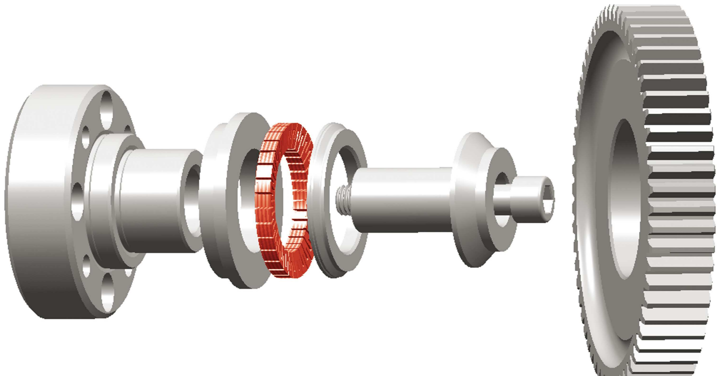


Fig. 2.2 Clamping mandrel in 3-D exploded view

Fig. 2.1 Clamping mandrel with bonded disc pack

The effect of the change in diameter and the planar alignment is that the component is precisely centred and aligned. The clamping action is effected uniformly around the entire circumference. This simple, consistently applied idea guarantees maximum clamping precision without time-consuming alignment.

The axially induced actuating force F_B (see Fig. 1 and Fig. 2.1) causes an elastic change in the taper angle, as shown in Fig. 5. If the inside edge is supported on a mandrel, the outside diameter is enlarged (see Fig. 3 and Fig. 5) by a value equivalent to the radial clamping stroke. If the outside edge of the clamping disc is supported, the inside diameter decreases. Fig. 4 shows how the planar alignment is produced by the tipping movement.

Fig. 4 planar alignment

Fig. 3 Enlargement of the outside diameter

The functional principle of RINGSPANN precision clamping elements is based on a modified knee-lever effect as shown in the schematic diagram in Fig. 5. The applied actuating force F_B is converted into radial clamping force F_S which is 5 to 10 times as high and clamps the component securely.

If the clamping edge of the clamping disc is worn uniformly, the transmissible torque increases in response to the same actuating force because the clamping disc is forced to move further upward in order to clamp the component.

Even difficult applications, such as clamping in short bore lengths or the clamping of thin-walled components which are susceptible to deformation can be effected quickly and reliably with the functional principle of RINGSPANN precision clamping elements.

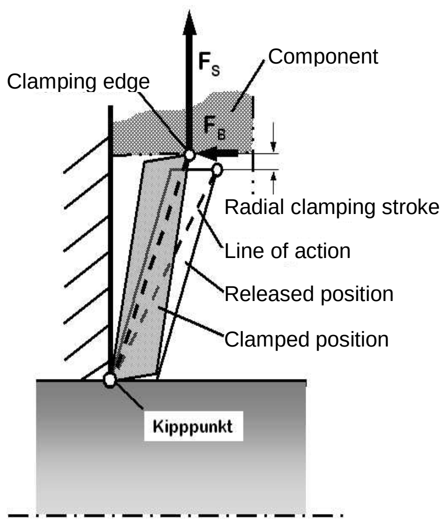


Fig. 5 Functional principle of the knee-lever effect

2.3. Modifications and advances in the development of the RINGSPANN clamping disc

In view of the variety of components, processing methods and machine parameters, several types of compact clamping elements have been developed on the basis of the RINGSPANN clamping disc. All of these variations are based on the functional principle outlined above. The different clamping elements are listed below (see also Fig. 6):

- disc clamping elements, no. 3
- flat mandrel clamping elementsno. 4
- flat chuck clamping elements, no. 5
- basket chuck clamping elements
- diaphragm clamping elements

The different clamping elements offer a wide range of possibilities for the design of complete clamping mandrels and clamping chucks.

The RINGSPANN bonded disc pack (see Fig. 6, no. 2) provides for maximum clamping diameters of up to 200 mm in combination with mandrel clamping elements and 170 mm in combination with chuck clamping elements.

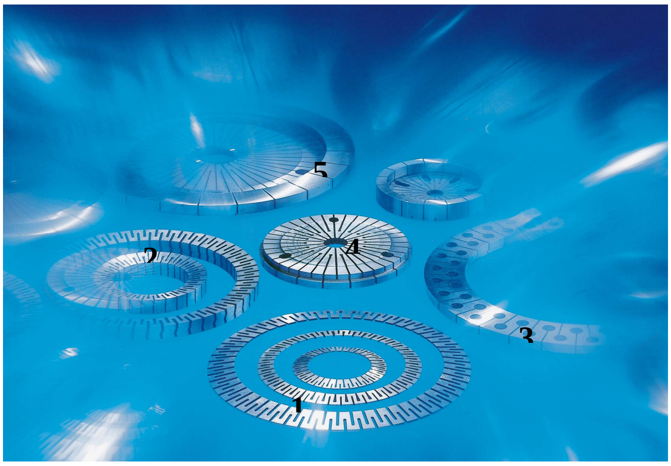


Fig. 6 Selection of RINGSPANN clamping elements

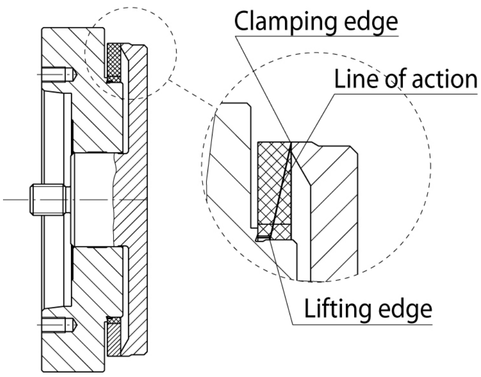


Fig. 7 disc clamping element

Disc clamping elements (see Fig. 6, no. 3) are suitable for clamping diameters of up to 450 (mandrels) and 550 mm (chucks), respectively. These are flat discs which are also alternately slotted from the outside and inside in alternation. However, the knee-lever effect is achieved through the axial shift between the supporting and clamping edges, as shown in the detail view in Fig. 7. As with normal RINGSPANN discs, the (dotted) line of action runs from inside to outside at a certain angle. Clamping is actuated in precisely the same way as with smaller clamping discs.

Another variation is represented by flat mandrel clamping elements (see Fig. 6, no. 4 and Fig. 8), which are typically very short and rigid. They are manufactured as listed in the catalogue for clamping diameters of up to 490 mm. These discs are also alternately slotted from the outside and the inside. The line of action of the knee-lever principle runs more or less as described above (see detail view in Fig. 8), except that the actuating force in the case of flat mandrels is not applied directly in the clamping area but at a central position far to the inside by a thrust bolt. The Tip torque, generated by the radial lands as levers, erects the line of action with the clamping mandrel head, and clamping is effected.

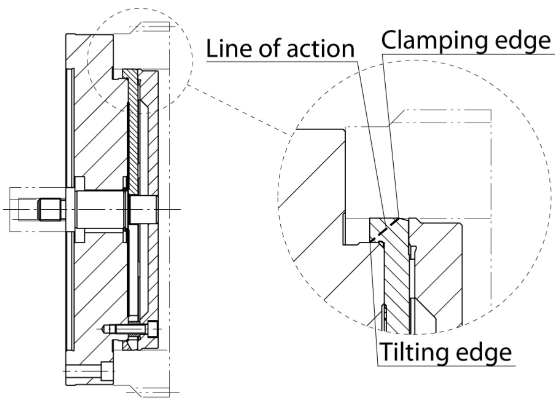


Fig. 8 Flat mandrel clamping element

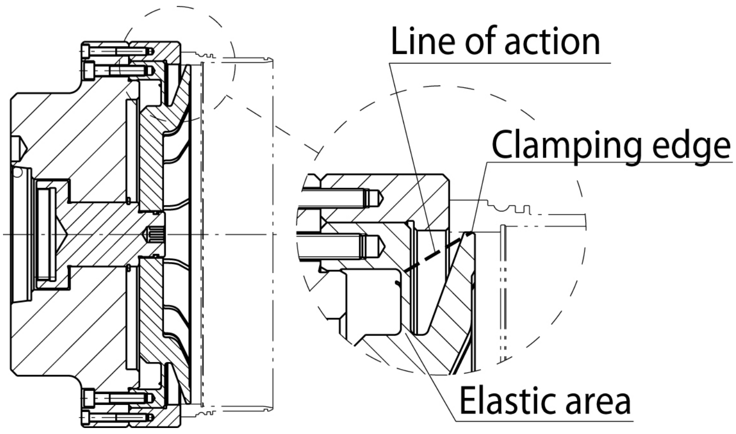


Fig. 9 Diaphragm clamping element

Diaphragm clamping elements with diameters of up to 1200 mm have been developed and manufactured especially for large rotors in aircraft engines in many cases. These elements work according to the same principles as the clamping elements described before. Clamping is also effected by a shift in the line of action (see Fig. 9, detail view). The fulcrum of the inner end of the line of action is located in the elastic area of the diaphragm. The clamping element is slotted from the inner edge only. The elastic joint of the diaphragm gives the element its elasticity but also provides for very high radial rigidity in order to ensure a high degree of clamping precision. The actuating force is exerted by a central thrust bolt.

3. Characteristics and advantages of RINGSPANN clamping elements

- **High degree of clamping precision**
  True running accuracy of less than 0.01 mm is easily achievable for clamping diameters of up to 300 mm (0.02 mm for larger diameters).

- **Centring and alignment**
  Components are centred during the clamping process, drawn against the contact surface, which is designed to prevent axial runout, and thus aligned.

- **Short clamping lengths**
  The RINGSPANN functional principle allows for short clamping lengths with high torque transmission.

- **Space-saving configurations**
  RINGSPANN clamping elements provide for short spindle overhang and high spindle rigidity.

- **No warping**
  RINGSPANN clamping elements grip the entire circumference of the component, thereby preventing non-concentric component deformation. This makes it possible to clamp components more tightly and achieve higher machining output.

- **Long service life and low maintenance**
  Slippage of functional elements is reduced to a minimum during the clamping process. only the ring-shaped tipping edges are shifted. Therefore, these clamping elements require no lubrication. The original precision of the clamping element is preserved for an extended period of time.

- **Insensitive to debris**
  Slots and openings are sealed with extensively tested elastic filling materials from the aviation industry. Clamping elements can be cleaned without difficulty.

- **Ease of maintenance**
  Clamping discs and other clamping elements can be replaced easily within minutes and thus reduce down times and associated costs.

4. Examples of typical gear clamping applications

Four typical examples of gear clamping applications using RINGSPANN precision clamping elements are described in the following sections.

4.1. Clamping mandrel for gear noise testing in automotive gearbox systems

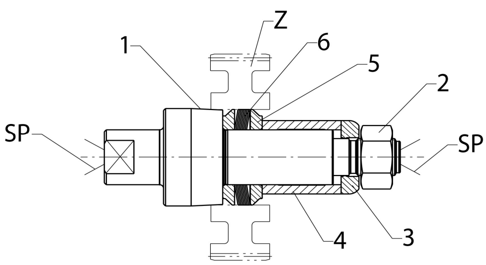


Fig. 12 Clamping mandrel for gear noise testing

Fig. 12 shows a design that has proven effective over many years. It is a bonded disc pack clamping mandrel used in testing for gear noise and roll-off behaviour (Z). A large number of these mandrels have been manufactured for use in testing gears of widely varying sizes between engine ends (SP) during the past 50 years.

Gears are drawn against the flat taper (1) by planar alignment, pre-centred and aligned. Clamping and release are actuated manually by turning the hex nut (2). The nut presses against the pendulum ring (3), which ensures that force is applied centrally. The pendulum ring (3) then pushes the long guide bushing (4) to the left, thus actuating the bonded disc pack (6) via the thrust ring (5) This configuration ensures true running accuracy of ≤ 0.01 mm over very long periods of use.

4.2. Clamping mandrel for use in milling lorry crown gears

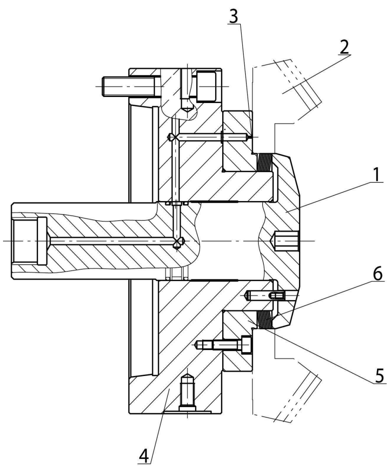


Fig. 13.1 Clamping mandrels used to mill lorry crown gears

The bonded disc pack clamping mandrel is loaded by an automatic component load unit. The mushroom bushing (1) has a large insertion groove to prevent collisions. Loading is further facilitated by the additional insertion play of approx. 0.2 mm. During clamping, the crown gear (2) is aligned, brought into parallel contact and clamped. The true and parallel run accuracy achieved in this way amounts to 0.01 mm. Exact parallel contact is monitored by an air-system control unit (3). The clamping system can be converted quickly for use in processing other types of crown gears by replacing the interchangeable clamping sets consisting of the mushroom bushing (1), the base mount (4), the thrust ring (5) and the bonded disc pack (6).

Fig. 13.2 Clamping mandrel used to mill lorry crown gears

4.3. Clamping mandrel for automotive crown gear lapping and testing

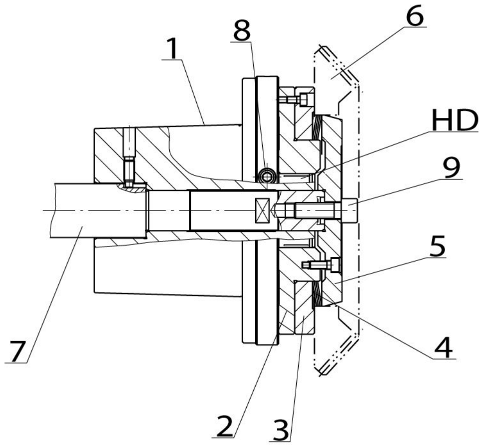


Fig. 14.1 Clamping mandrel for lapping and testing automotive spur gears

Base mount 1, a hydraulic expansion-sleeve clamping mandrel HD [7], is permanently installed in the machine spindle of the lapping and testing unit. It centres and clamps the various interchangeable clamping sets consisting of a mounting flange (2), a contact ring (3), a bonded disc pack (4) and a mushroom cap (5). Force required to clamp the crown gear (6) is exerted via the machine draw bar (7). The mushroom cap (5) actuates the bonded disc pack (4), which centres the crown gear, aligns it through planar alignment and clamps it in place. The parallel and true running accuracy of the entire system lies within a range of less than 0.006 mm. The entire interchangeable clamping set can be replaced by removing the radial clamping screw (8) on base mount (1) of the hydraulic expansion-sleeve clamping mandrel HD and the central screw (9) of the mushroom cap, after which a different set can be installed. This procedure takes only a few minutes. Thus the system is also ideal for economical production of small batches.

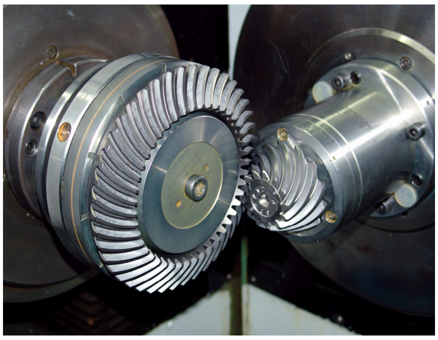


Fig. 14.2 Clamping mandrel for automotive crown gear lapping and testing

4.4. Clamping mandrel used to grind the oblique teeth of automobile spur-gears

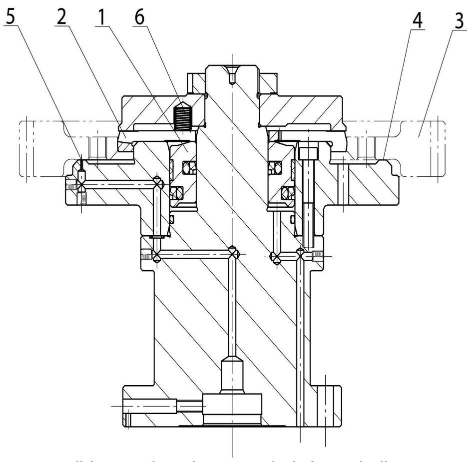


Bild 15.1 Clamping mandrel for grinding automotive spur gears

This clamping mandrel has a flat-mandrel clamping element (see Chapter 2.3.) The clamping surface of the spur gear is very short. The element is actuated hydraulically from the machine spindle. The piston (1) is pressed against the clamping element (2) of the flat mandrel, thereby actuating it. In the process, the spur gear (3). The air-system control unit (5) monitors the correct seating of the spur gear. The clamping system is centred and stabilized additionally by a quill inserted vertically through the centring bore of the base element. System tension is released by removing hydraulic pressure. Several pressure springs (6) in the cover help press the piston (1) back against the frictional force of the gaskets.

Fig. 15.2 Clamping mendrel used to grind automotive spur gears

5. Effective applications of clamping elements for transmission components of wind turbine systems

5.1. Two flat-mandrel clamping elements as centring inserts for the milling of teeth on a wind-turbine hollow shaft

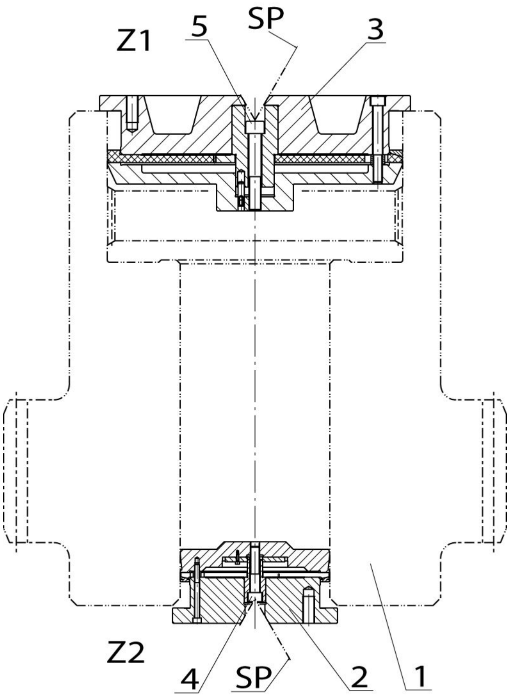


Fig. 16 Flat-mandrel clamping elements as centring inserts in a hollow shaft.

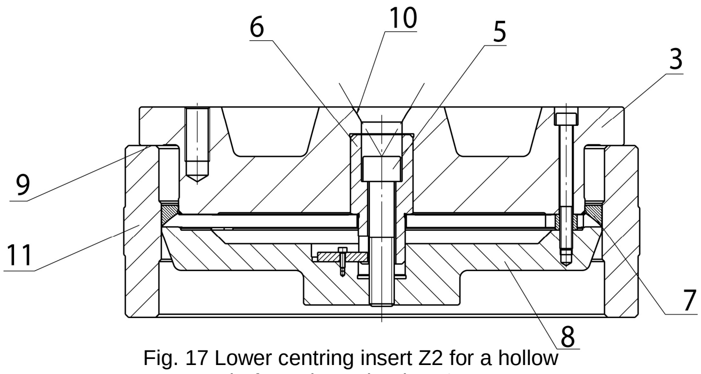


Fig. 17 Lower centring insert Z2 for a hollow shaft as shown in Fig. 16

The hollow shaft (1) has pre-drilled mounting bores at each end with diameters of 195.0 mm and 384.5 mm, respectively and adjacent flat surfaces (see Fig. 16). Flat-mandrel centring inserts Z1 and Z2 with large insertion grooves are inserted into these mounting bores and then clamped by hand by turning the hexagon socket head cap screws (4 and 5).

Fig. 17 shows an enlarged view of the lower flat-mandrel centring insert Z2. The actual clamping element (7), the actuating unit – consisting of the hexagon socket head cap screw (5) and the thrust bushing (6) – and the lower cover (8) with insertion groove are easily recognizable in this diagram. When turned, the hexagon socket head cap screw (5) pushes the thrust bushing (6) downward and pivots the lands of the flat-mandrel clamping element (7). As a result, the line of action pivots into the clamping position as described in 2.3. Given a screw tightening torque of 75 Nm, the transmissible torque is 5.800 Nm. The flat-mandrel clamping elements centre the inserts while inducing a planar alignment against the contact surface. The configuration and function of the lower centring insert Z2 are identical.

The flat contact surface (9) is located at the edge of the base element (3), which contains the centring bore (10). The precision of the centring bore (10) in relation to the supporting diameter of the clamping element (7) and the flat contact surface (9) is of crucial importance. Control ring (11) is shown on the left in Fig. 17. By this ring the clamping precision of the centring insert is regularly controled.

The union of component and centring inserts Z1 and Z2 following clamping is set in the milling machine between the centring tips, and milling work can begin without further alignment of the component after a short set-up time. Once milling is completed, the teeth facing the clamping surfaces (bores and flat surfaces of the hollow shaft (1)) will meet the maximum required true and parallel run tolerance of 0.02. mm.

Two clamping sets are available for every type of hollow shaft. While one hollow shaft is processed, the next shaft is equipped with clamping sets, thereby minimizing machine down time.

5.2. Flat-mandrel clamping element for milling of teeth in a wind turbine transmission bell housing

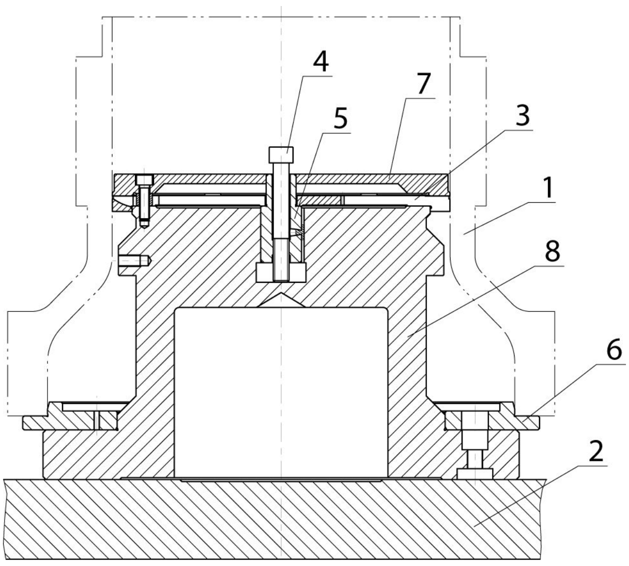


Fig. 19 Flat mandrel on machine table for transmission bell housing

Figs. 18 and 19 show a different type of flat-mandrel clamping element (clamping diameter 340 mm). This type performs an operation similar to that described in Chapter 5.1. In this case, a transmission bell housing (1) is processed on a clamping element that is bolted firmly to the machining table (2) and requires only one flat-mandrel clamping element (3).

Clamping is actuated manually by turning an hexagon socket head cap screw (4), which moves the thrust bolt (5) upward and pivots the lands (6) of the flat-mandrel clamping element (3). This pivots the line of action into the clamping position as described in 2.3. At the same time, the transmission bell housing (1) is pressed against the flat backstop plate (6) and aligned in parallel. Given a screw tightening torque of 40 Nm, the transmissible torque is 2.800 Nm.

When processing different versions of the transmission bell housing within a certain dimensional range (clamping bore and length), the system can be set up quickly to accommodate a different component simply by replacing the clamping element (3) with cover (7) and the backstop plate (6). The base unit (8) remains in its aligned position on the machining table.

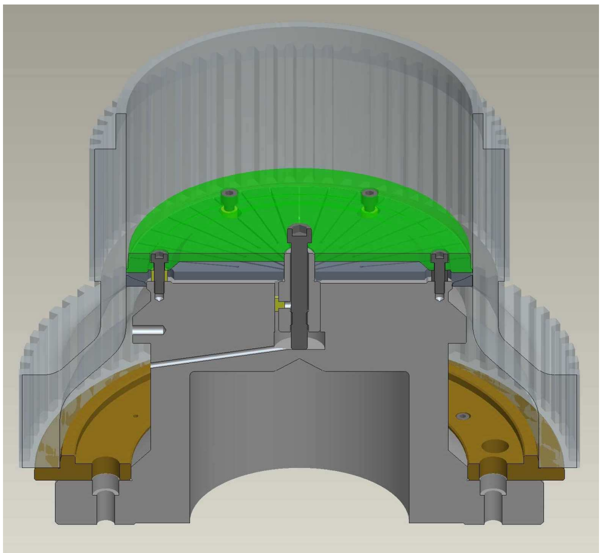


Fig. 19 Flat-mandrel for transmission bell housing – 3-D view

5.3. Flat-mandrel clamping element for a large pinion in a wind turbine planetary transmission

Transmission for wind turbines are already being manufactured in series for power outputs of up to 5 MW today (and even up to 7.5 MW as planned by ENERCON). Due to their low rotational speed, these transmissions increase output rotation into high speeds in order to enable the use of space-saving, lightweight, cost-effective generators. This increase in rotation speed can best be achieved with one- or two-phase planetary transmissions, to which normal spur-gear stages are often connected.

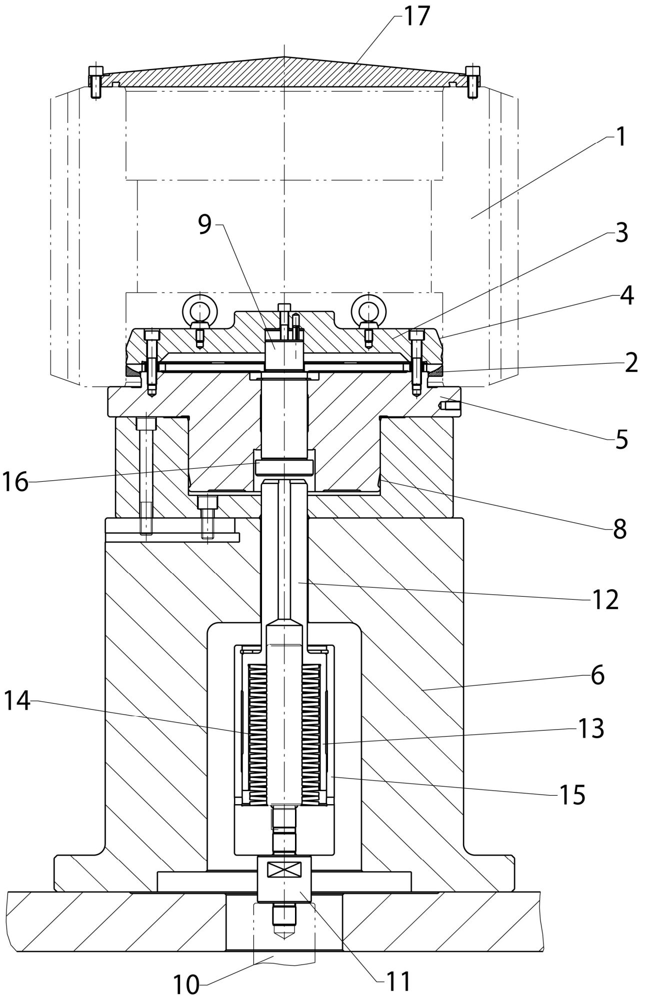


Fig. 20 Flat-mandrel clamping element with hydraulic expansion clamping chuck for milling of a large planetry pinion, power activated

Planetary transmission for the outputs cited above are very large and pose demanding requirements for transmission manufacturers. In order to ensure high power density at a high level of efficiency and low noise emissions, transmission components must exhibit high rigidity and high degrees of precision, especially in gearing geometry. Planetary pinion (1) (example, see Fig. 20), was designed for a transmission of this kind. It has an outside diameter of 540 mm, a gearing width of 300 mm and a weight of approx. 300 kg. The bore used to mount the rolling bearing has a diameter of 360 mm and is the clamping surface for the gear production process.

A highly complex clamping fixture was developed and manufactured for this planetary pinion (1) (see Figs. 20 and 21). As in the two preceding examples, this central clamping element is a RINGSPANN flat-mandrel clamping element (see Chapter 2.3). The flat-mandrel clamping element (2) rests for loading, held by a solid cover (3) with a large insertion groove (4) on a base unit (5). Base unit (5) is firmly clamped in a high-precision hydraulic expansion sleeve clamping chuck HF with axial retraction. The hydraulic expansion sleeve clamping chuck HF itself is mounted on a solid clamping element mount (6), which is positioned on the machining table.

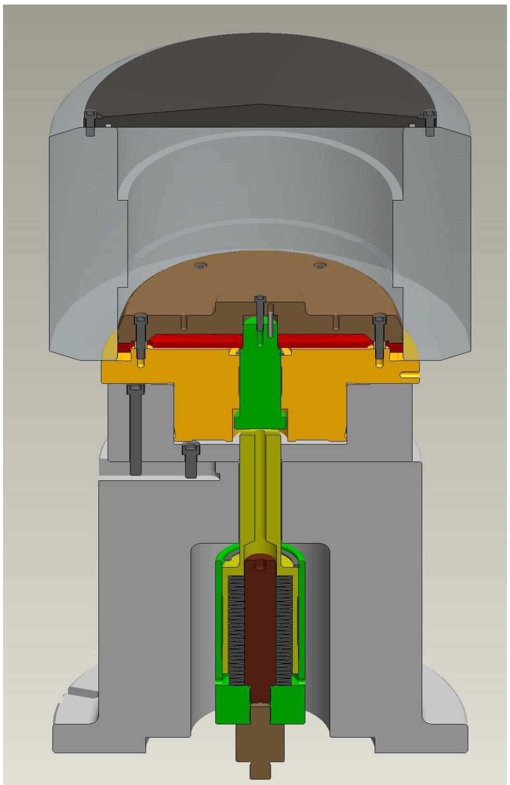


Fig. 21 Flat-mandrel clamping element with hydraulic clamping chuck for million of a large planetary pinion, power actuated. 3-D view

The incorporation of the hydraulic expansion sleeve clamping chuck HF makes it possible to switch to a different RINGSPANN flat-mandrel clamping fixture for a new component easily and with minimal loss of time. The hydraulic expansion sleeve clamping chuck HF is actuated simply with an Allen key. Clamping precision lies within a range of < 0.005mm. The clamping width of this chuck is quite small, however, and would not be sufficient for normal clamping actuation for planetary pinion (1) at normal component tolerances. It is important to ensure that base unit (5) of the flat-mandrel has a standard insertion contour of (8) in the lower section. This facilitates insertion at very limited tolerances.

The clamping element is actuated by the thrust bolt (9) inserted through the base unit (5). The bolt rests unactuated in the lower position by virtue of its own weight. The power activation unit (10) on the machine is bolted to the lower threaded journals (11). The actuating rod (12) connected at this point contains a force limiter (13). The force limiter consists of a long disc spring column (14) housed in a guide tube (15). Spring tension is set so that the actuating force for the clamping element (2) lies between 16,000 N and 30,000 N. These different forces result from the different stroke lengths of the thrust bolt (9) in combination with the component tolerances. In any event, however, the maximum downward stroke length of the thrust bolt (9) is 12.5 mm, as it is limited by the abutment collar (16). The transmissible torque at the minimum actuation force of 16,000 N is 2,400 Nm.

The clamping element is protected against contact with the coolant-lubricant by a seal cover (17), as shown in Figs. 20 and 21. This seal cover is set with a simple gasket in the bore for the rolling bearing and seals the interior hermetically.

Thanks to the efficient design of this clamping element, it is not necessary to add a central counter-brace from above after clamping, as is the case on other, older configurations. That solution required more complicated handling and generated higher machine costs. Sealing was also more complicated than described above.

6. Summary and outlook

Precision requirements for industrial transmission components and gears, in particular, have grown progressively more demanding in recent years. And production costs had to be reduced at the same time. The only way to meet these challenges was through the use of highly advanced machinery, clamping elements and tools. The innovative clamping elements needed for this purpose serve as the indispensable interfaces been machines and components.

Therefore, the preceding article focuses on the extensively tested and proven functional principle of RINGSPANN precision clamping elements. It began by describing the function, characteristics and advantages of the various configurations before proceeding to a discussion of clamping elements currently used successfully in the production and testing of various types of gears. Since components are usually clamped in bores during gear production – milling, grinding, lapping and testing – the article discusses only so-called mandrel clamping elements. RINGSPANN also offers chuck clamping elements for all functional principles.

Three examples of clamping solutions for transmission components in wind turbines, including in particular large gears for planetary transmissions, were discussed in the final chapter. The transmissions have become considerably more important in recent years due to the boom in renewable energy use and are now produced in larger quantities. In anticipation of future developments, RINGSPANN has already developed precision clamping technology for very heavy components with clamping diameters of up to 1,200 mm.

7. Literature

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