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ZURICH

Gear-cutting, -Grinding and -Measuring Methods

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1. G E A R   C U T T I N G

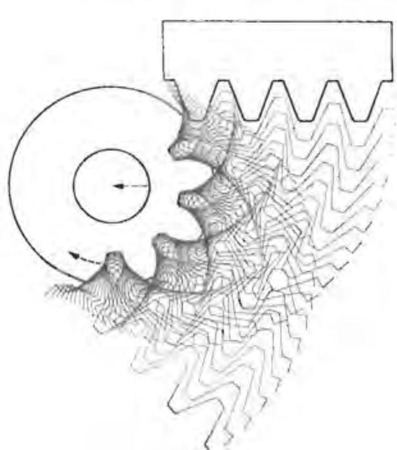
Medium and large gear wheels as applied in turbo-gearboxes, steel and cement mill drives etc. are mainly made either by hobbing the teeth - whereby the tool is a simulated worm - or cutting the teeth by a shaping or planing method.

Fig. 1

MAAG gear cutting machines (Fig. 1) operate on the planing principle. The largest machine can cut gears with a diameter of 7.35 metres and 50 tons. For external gears, the tool is a rack type cutter; (Fig. 2).

Fig. 2

The involute curve of tooth flanks is generated by enveloping planes swept by the straight tool edge (Fig. 3).



The necessary generating motion of the work table is obtained by combined translation and rotation. Internal gears are normally cut by use of circular cutters. (Fig. 4)

Fig. 4

For larger gears and pitches however, form tools and/or single-point tools are applied. (Fig. 5)

Fig. 5

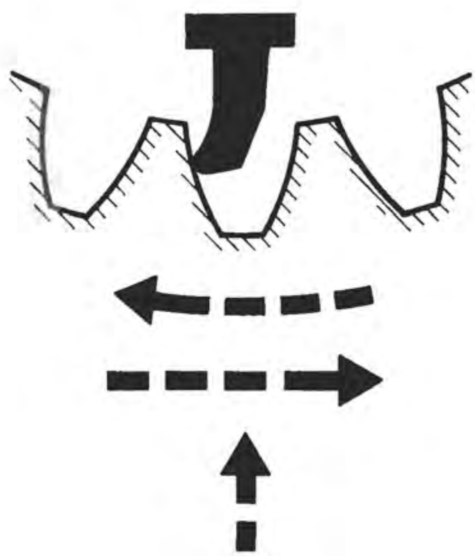


Fig.6

Fig. 6 shows the principle of cutting internal teeth using a single-point tool.

In our own works, this method is very often applied especially for moduls larger than 10 to 12. Advantageous are the high accuracy of the generated tooth flanks - pitch, lead and profile and the excellent surface finish.

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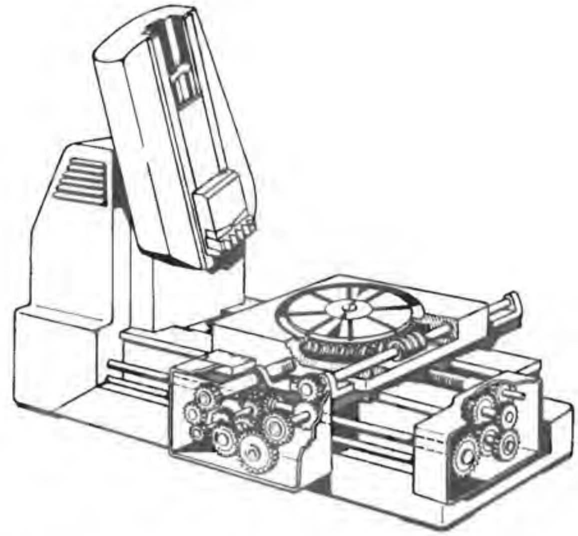

Fig. 7

A notable feature is the standstill of the work during the cutting stroke. The generating accuracy, and therefore the flank accuracy, is not affected by the cutting load. As only frictional and inertia forces, but no cutting forces have to be overcome, an extremely long service life of the generating mechanism is obtained.

Other advantages:

- simple and inexpensive tool
- universal application of the machines (Fig. 8)
- high efficiency, especially on larger gears and coarse pitches
- high accuracy

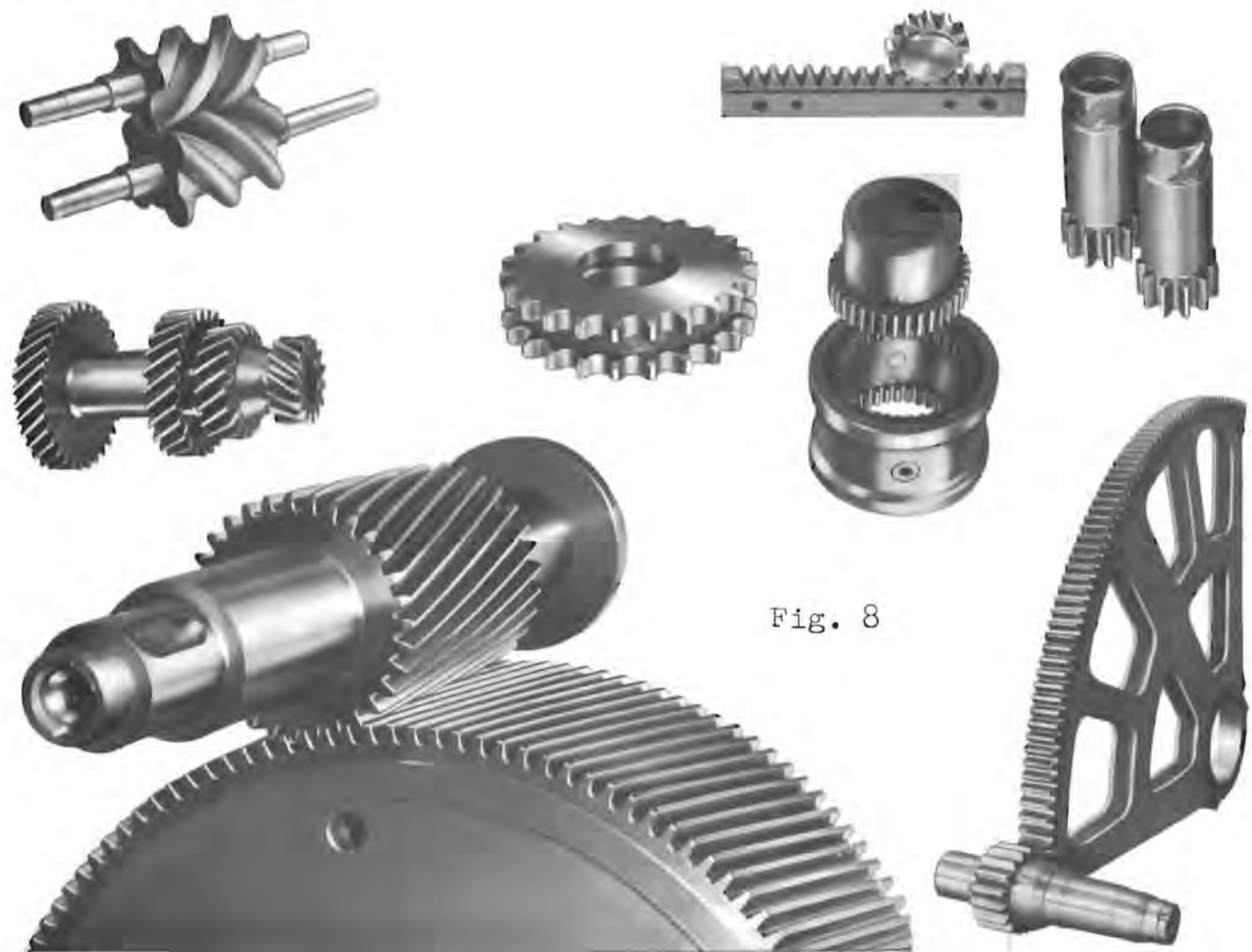

Fig. 8

2. GEAR HOBBING

Gear hobbing is basically similar to the function of a worm-wheel drive: the hob - that is, the tool - simulates a single - or multiple - thread worm, whereby the threads are gashed lengthwise to form a series of cutting teeth.

While hobbing, a continuous generating and indexing motion takes place. Regarded in a transverse plane, each hob tooth cuts a straight tangent line, and the accumulation of these tangents form the involute shape of gear teeth.

The hob is fed slowly across the face width of the work.

The generating process requires accurate relationships between various elements driving the work-table and the hob. Some limits to the hobbing accuracy are given by the fact that this relationship is affected by the cutting forces. Furthermore a hobbed flank cannot be of a smooth surface, but is composed of a series of bumps - due to the cylindrical form and circular motion of the tool.

Practically all hobbed gears are therefore subjected to a subsequent finishing operation, as for instance shaving or grinding.

3. GEAR FINISHING PROCESSES

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Methods of finishing gear teeth are grinding, honing and lapping for hardened and unhardened flanks, and shaving for teeth up to approx. 40 Rockwell C scale.

3.1 Gear Shaving

Gear Shaving removes small amounts of metal from flanks of unhardened gear teeth and can partly correct inaccuracies inherent in gear roughing operations. It is mainly used to improve the quality of hobbed gears.

The so-called rotary crossed-axes shaving method is widely used for spur and helical gears of all sizes.

During the shaving cycle, the cutter meshes with the work-piece and is traversed back and forth across the work.

3.2 Gear honing

The honing process was originally developed to remove nicks and burrs. Further development work revealed that minor corrections up to about 1/100 mm in tooth shape and improved surface finish and better sound characteristics could be achieved.

The honing tool is an abrasive-impregnated plastic helical gear. This tool is run in mesh with the work gear in crossed-axes relationship and is traversed across the work-piece, similar to the shaving process.

3.3 Gear lapping

Gear lapping is done either by running the gear in mesh with a gear-shaped lapping tool or by running two mating gears together. Hereby, an abrasive lapping compound is the medium that accomplishes removal of metal.

Minute heat-treatment distorsion or precutting errors of involute profile, helix angle, pitch and radial runout can be corrected.

When gears run together, there is a variation in sliding velocity along the involute profile: it is a maximum at the root, decreases to zero at the pitch line and increases to another maximum value at the tip of the teeth. Therefore, the lapping time must be well controlled. If the gears are run for excessive periods of time, the accuracy of flank is impaired.

To make up for the lack of sliding in the vicinity of the pitch line, an auxiliary sliding action in the direction of the gear axis has to be supplied.

3.4 Gear Grinding

Gear grinding is mainly applied to remove errors resulting from inevitable distorsion caused by heat treatment.

On the other hand, grinding is also used to finish teeth of unhardened gears, in order to attain high accuracy and surface finish.

The properties of ground gears are exploited wherever a gear drive must be of small, compact construction and where high power or accurate motions must be transmitted.

In industrial gear production, various methods are used:

a) Form grinding

Form grinders normally use a wheel to grind both sides of the space between two adjacent gear teeth simultaneously.

The tooth profile is obtained by dressing the involute form into the grinding wheel.

After the grinding wheel has passed through the tooth space, the work is indexed to the next tooth and so on around the component.

b) Generating grinding with a conical disc wheel

The grinding wheel is dressed on its sides to an angle equal to the normal pressure angel of the teeth.

During grinding, the involute profile is generated by a combined translational and relevant rotational motion.

c) 0^{o} and $15/20^{o}$ - MAAG grinding method

Disked grinding wheels are used. These wheels are conically concave towards the tooth flanks, so that only a narrow rim is active. Another characteristic feature is that no coolant is required. Fig. 9 and 10 show examples of MAAG gear grinders which cover a capacity range from very small gears up to a diameter of 4.75 meters and a weight of 50 tons.

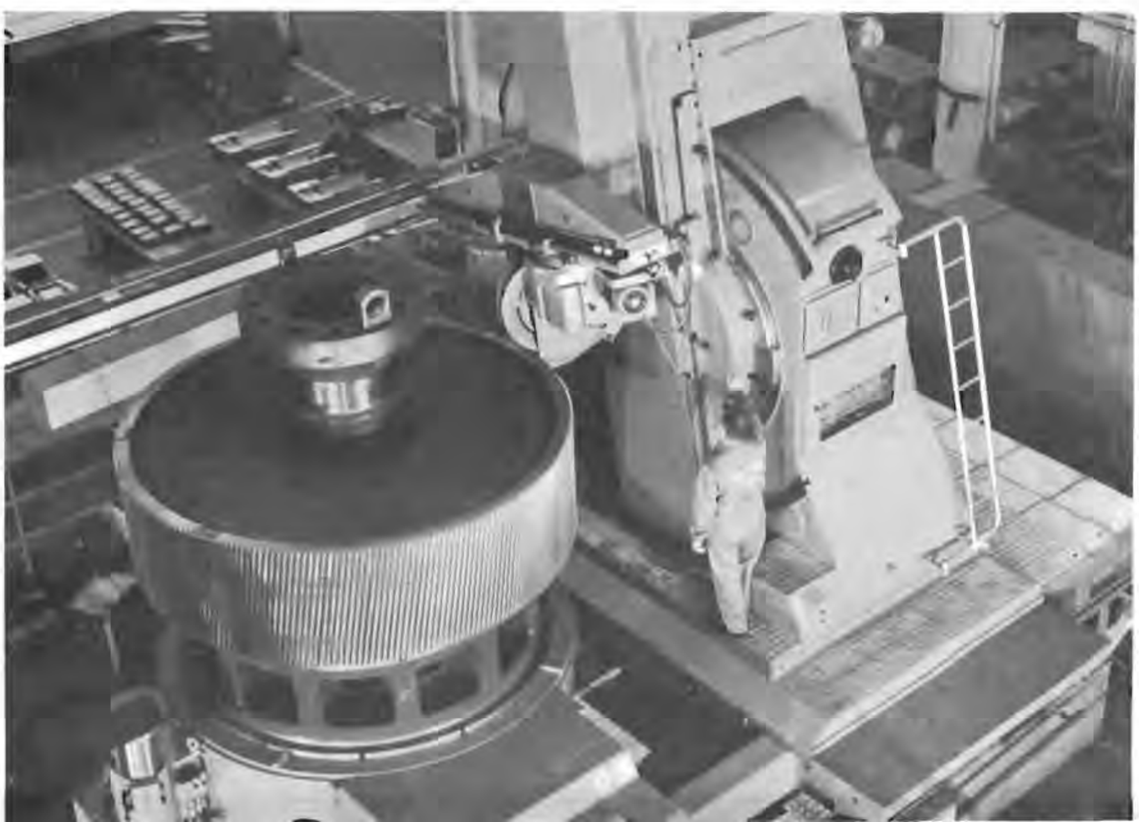


Fig. 9

Fig. 10

On small and medium sized machines, the necessary generation motion is produced by rolling a pitch block - which is fixed together with the work - along the steel tapes placed in the generating plane.

When the wheels are set to the 0 dgree position, i.e. when the 0^{o} method is applied, the acutal rolling circle is equal to the base circle of the gear. In the case of the 15/20 degree method, rolling must be performed on the pitch circle.

All MAAG-gear grinders posess a special compensating unit. Its diamond feelers sense even minute amounts of grinding wheel wear and initiate an appropriate compensating feed of the grinding spindle.

Furthermore the machines are equipped with devices for grinding profile and lead corrections.

Special features

- High degree of accuracy due to a precise generating motion (no wear of relevant elements) and the constant position of the active rims of the grinding wheels.
- Constant profile and lead accuracy, because shape of profile only depends on the generating and axial feed motions but not on any wear of the active grinding rim.
- No danger of grinding cracks, because no cooling medium is applied.

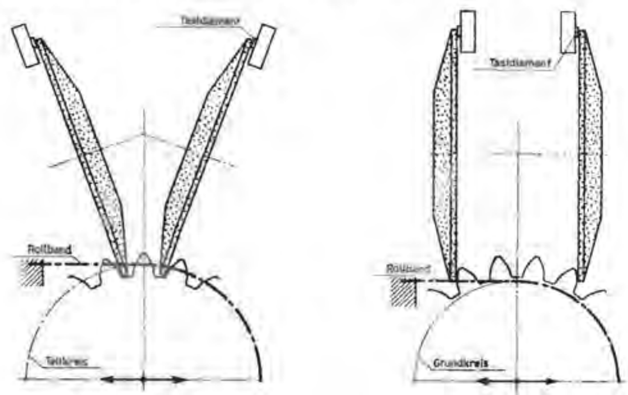


Fig.11

4. GEAR CHECKING METHODS

A wide variety of equipment and techniques are used to inspect geometrical quality of gears.

The field of gear inspection can be divided into two broad categories: the measuring of dimensional elements such as profile, lead, pitch, radial runout, tooth thickness; and the functional inspection by meshing with a mating gear to determine contact quality, composite error or noise level.

4.1 Pitch Checking

a) Base pitch checking

The prime requisite for correct meshing of two gears is the equality of their base pitches. As the actual value is indicative of both the pressure angle and the base circle diameter, not merely the regularity but also the value of base pitches are inspected. This is performed by means of instruments which are pre-adjusted to setting gauges.

Fig. 12 illustrates the principle of measuring base pitch accuracy and Fig. 13 shows an appropriate instrument.

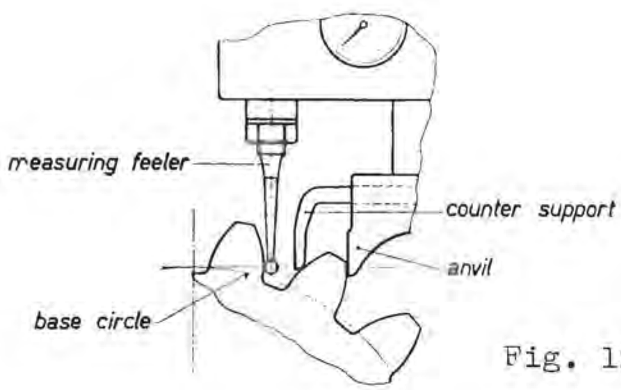


Fig. 12

Fig. 13

b) Circular pitch checking

In the case of circular pitch checking, distances of flanks are measured, on or near the reference cylinder, This measurement may be taken in the normal or in the transverse section.

The principle of measuring circular pitches is shown in Fig. 14. Both simple hand actuated instruments and modern electronic instruments are used.

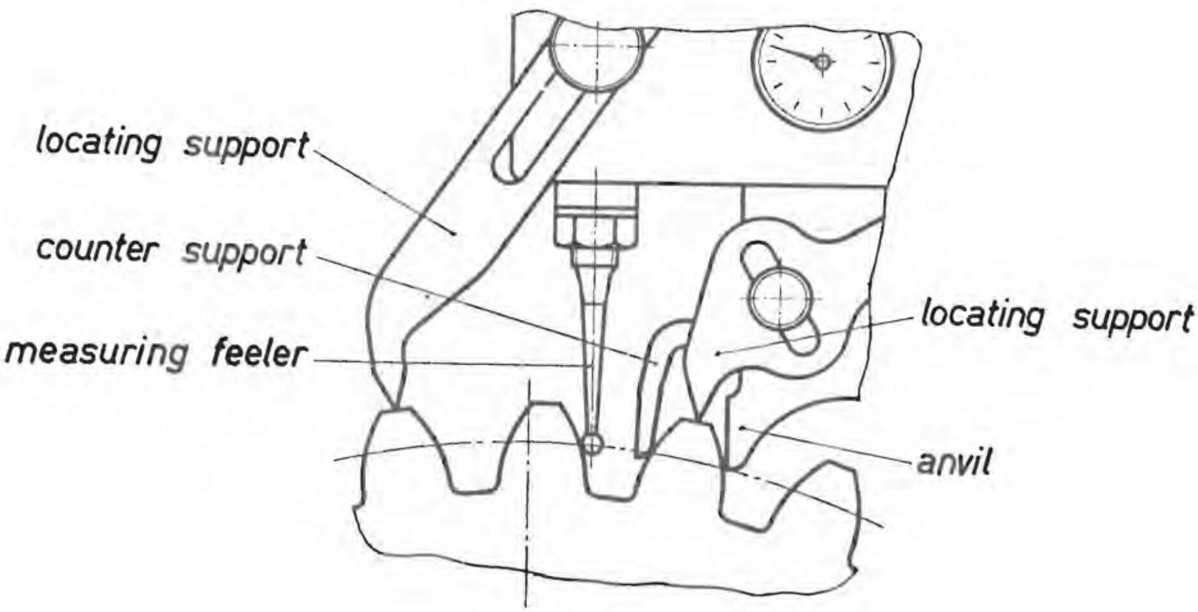
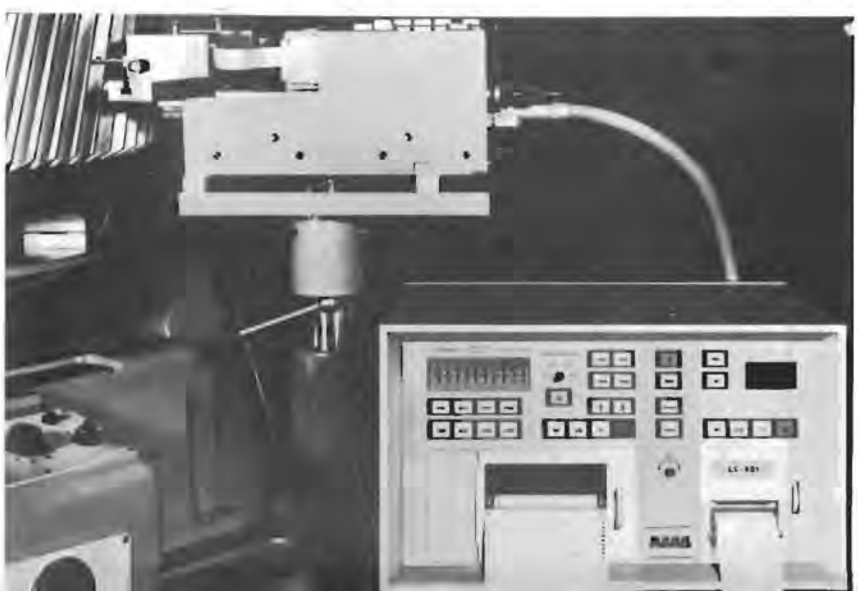


Fig. 14

Fig. 15 shows the automatic pitch checking equipment type ES-401



Basing on the results of the circular pitch checking, values and diagram of cumulative pitch errors may be constructed (Fig. 16). On the electronic instrument, this is done automatically after completion of single pitch measurement or span gauging.

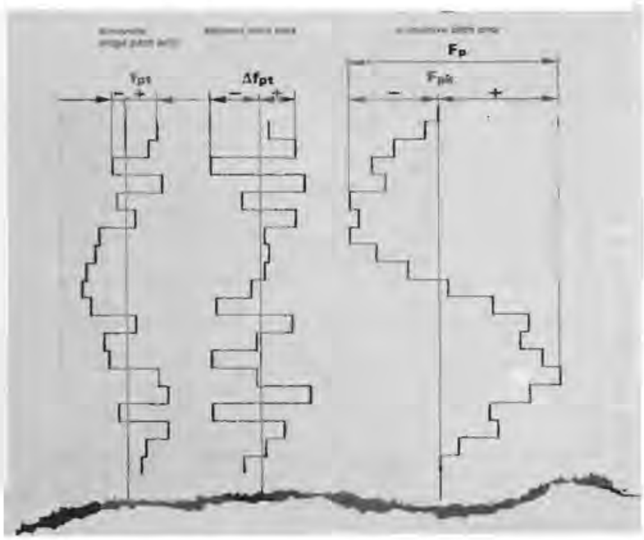


Fig. 16

4.2 Profile and alignment checking

For gears up to a diameter of approximately 1m these tests are usually performed on machines which generate the true involute and the true helix and record the deviations to an enlarged scale on graph paper.

Fig. 17 shows such a machine Type MAAG SP 60 and Fig. 18 illustrates its principle. On the described checkers, surface finish and - together with the appropriate attachment - pitch accuracy may also be measured. Furthermore, there are also instruments which allow such measurements on the gear grinding machines.

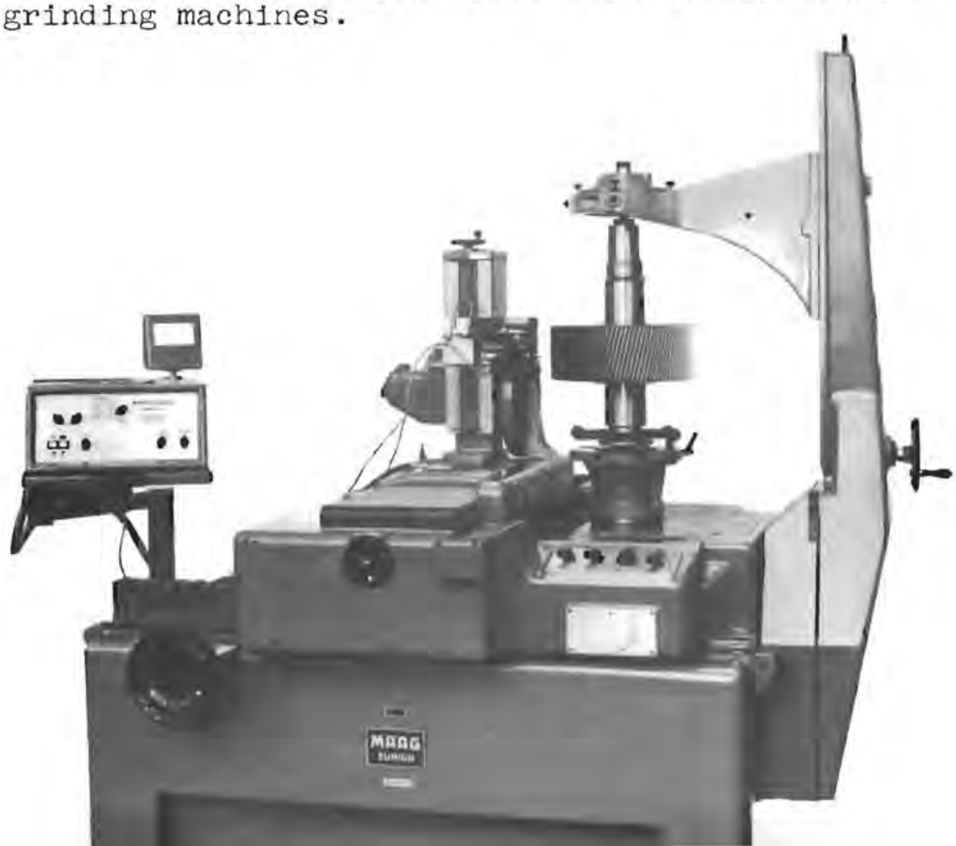


Fig. 17

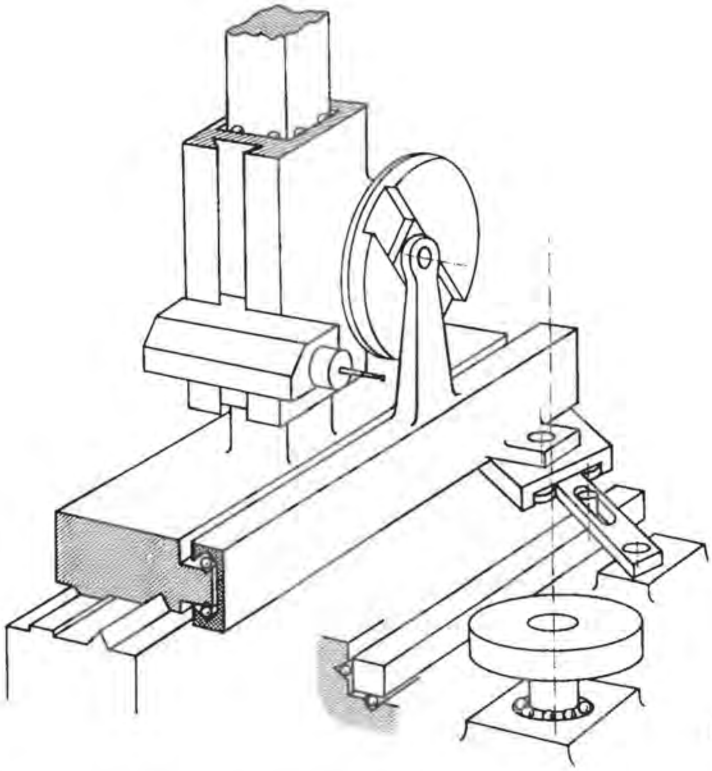


Fig. 18

The FPS testing apparatus (Fig. 19)allows checking of profile and helix angle corrections without removing the work from the machine or altering its position.

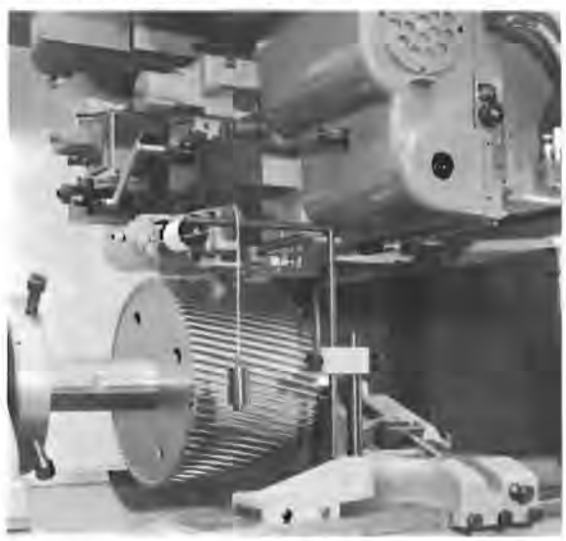


Fig. 19

In the same way the portable HMS Tester enables the helix angle to be checked on the grinding machine itself. (Fig. 20)

Fig. 20

Another portable apparatus - type F-360 - was designed for checking involute profiles on gears up to 3.6 m in diameter. The generating motion is obtained by straight edge rolling on a base circle segment. (Fig. 21)

Fig. 21

4.3 Double flank composite checking

Double flank rolling is probably the most used method of inspection for small and medium sized gears. Gear and mating or master gear mesh without backlash during one full revolution and variation in centre distance is recorded. Consequently the errors of both flanks are recorded as a total. Fig. 22 shows the MAAG tester type DAS-40.

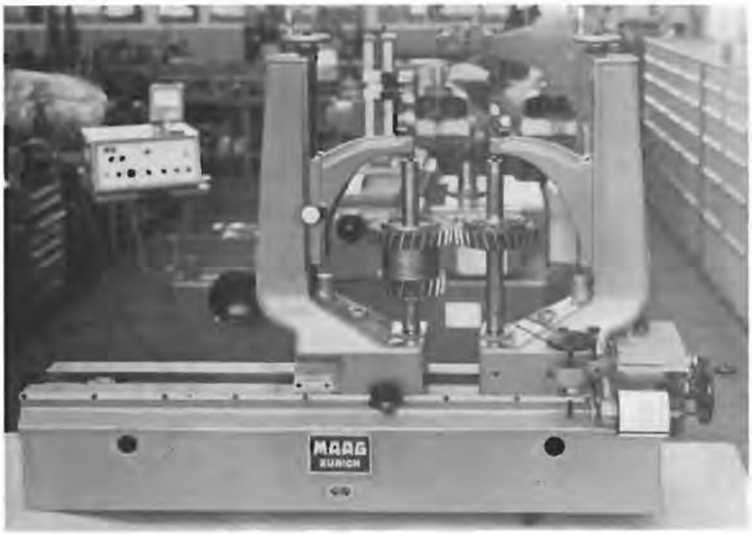


Fig. 22

4.4 Single flank composite checking

For single flank rolling tests, gear and mating gear are rotated in mesh at the prescribed centre distance, under slight flank contact pressure. Over a run of full rotation, fluctuation in angular transmission is measured and recorded.

The single-flank composite error test simulates most closely the conditions prevailing when gears are in actual operation.

Fig. 23 illustrates the MAAG single flank tester* and Fig. 24 shows its working principle.* type ER-40

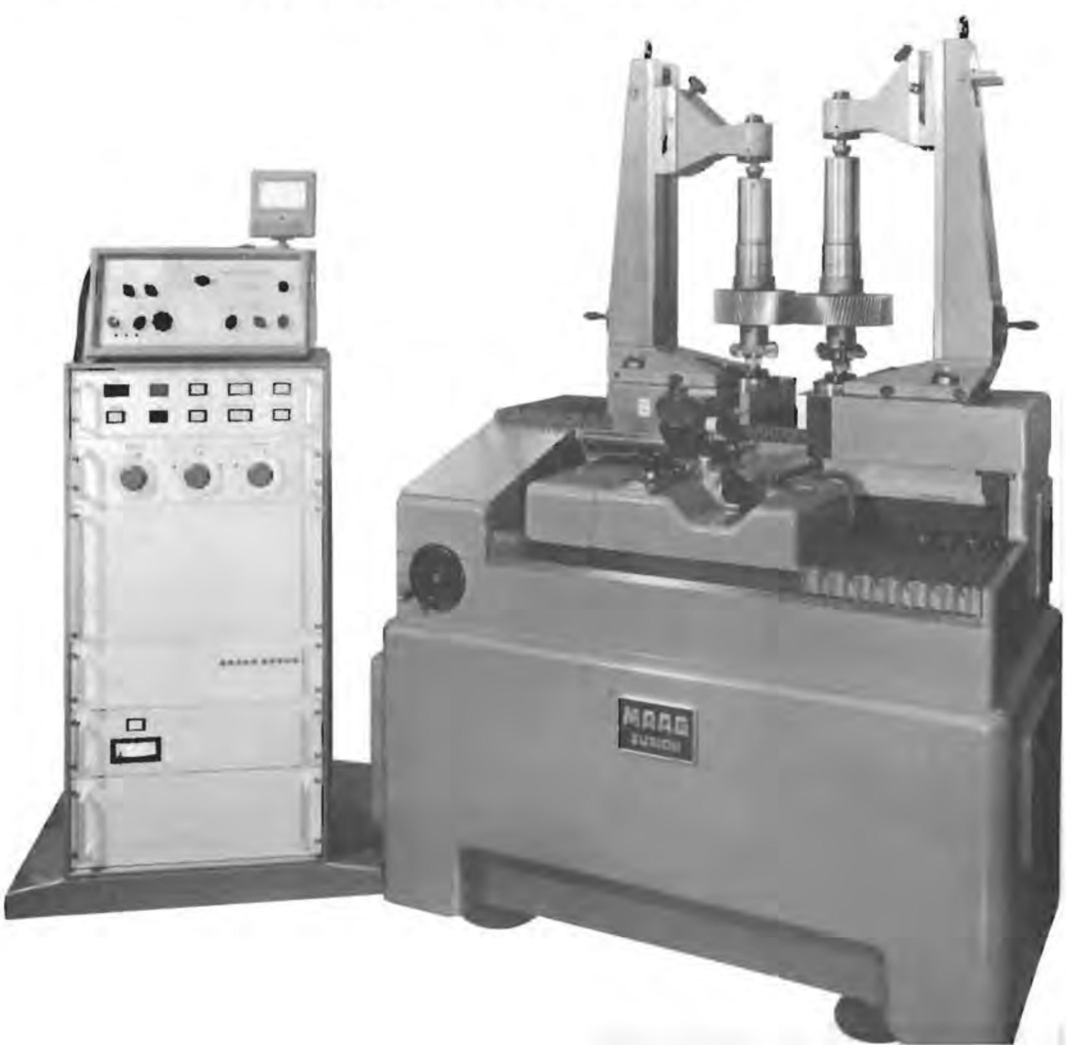


Fig. 23

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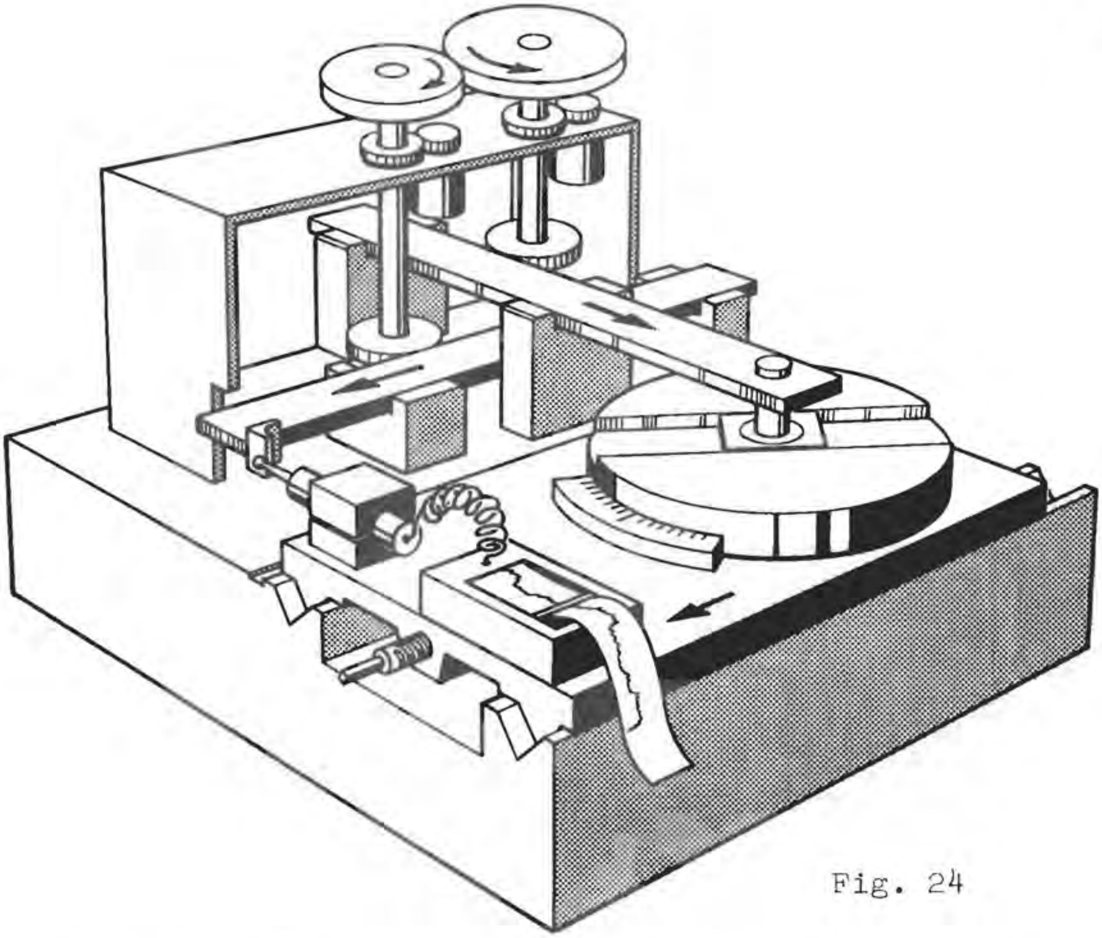

Fig. 24

4.5 Meshing rig for measuring tooth contact and backlasn

In our production shop, all large gear pairs are placed on a sturdy roller system and accurately adjusted to centre-distance and true shaft alignment. Under*this fine-adjusted meshing situation, backlash and equality pressure angle and helix angle can be checked most precisely. The system allows the turning of even very heavy gears by hand. *of

Fig. 25 shows the gear meshing rig type MR-380. Its centre distance capacity reaches from 1 to 3.8 meters.

Fig. 25

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