CENTRAL DRIVE OR GIRTH GEAR DRIVE FOR BALL MILLS

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Introduction

For medium and high capacity cement mills particularly, this question presents itself to the cement manufacturer again and again.

Alongside the purely economic considerations it is often necessary to also view the situation deriving from the competitive strenght of the mill builder.

Basically the assessment should be a realistic comparison of the differing features between central drive and girth gear drive with respect to reliability and economy.

It is to be repeatedly noticed, however, that ideas concerning these points are often far from complete, and are presented in widely different manners. These deficiencies become apparent when, in the event of damage incurred, calculative checks fail to reveal a definite error.

Drive system

Girth gear drive and central drive are mechanical systems designed to reduce the motor speed to the working speed of the mill. Transmission is via gears.

Gear units comprise basically : Fig. 1

- rotating parts with shafts and gears

  and

- stationary parts, i.e. housings and bearings.

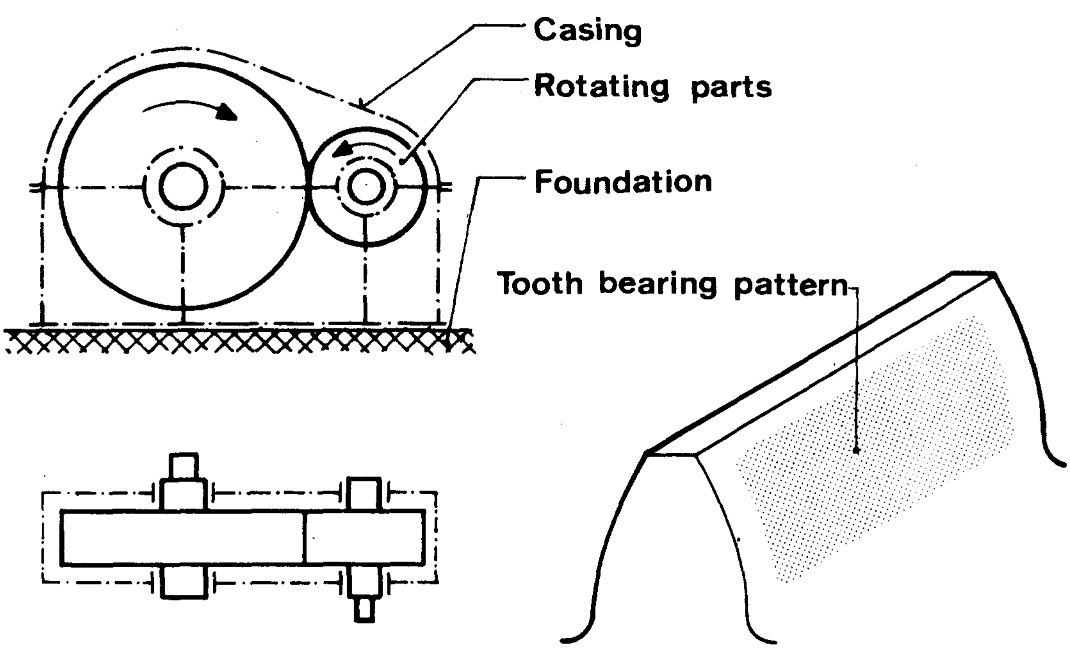

Figure 1:
Main elements of a gearbox and ideal tooth bearing pattern.

Certainly the gear tooth design is probably the most important item. But the position of the plant shafts as governed by the housing design, the kind of connection between the rotating parts, and the monitoring of the operating conditions are of no mean significance.

Power transmission by the rotating parts can only take place flawlessly if these are held in optimum position by the housing during operation. An inadequate housing jeopardizes the safety factor of the gearing. The latter is calculated to recognized formulae, and is referred exclusively to the gear teeth.

The plant engineer, on the other hand, must judge the drive system as a whole.

The difficulty lies in taking all influential factors into account and weighing them in correct proportion in the overall safety assessment.

Strict difference is to be made between well known factors of influence, and such others as are discernible in their effect only, but of which the magnitudes are indefinable.

Modern gear parts do not wear

In contrast to other still widespread contentions, modern engineering can produce gears and install them in mill drive units such that they are not to be regarded as wearing parts. But it is essential to case harden the tooth flanks and grind them with the appropriate flank corrections, and assure that the suitable conditions are attained for assembly and operation. Such conditions are attained ideally with the central drive planetary gear.

With a girth gear drive, on the other hand, these conditions cannot be realized to a comparable extent.

Gears can doubtless be regarded as non-wearing parts when, in a given construction, clearly defined installation conditions, comparable operating and ambient conditions, they are virtually immune from such wear as can impair functioning, whatever their application.

Wearing parts reduce the overall safety and efficiency.

In process engineering therefore the demand is for:

- elimination or minimizing of wearing parts -

Criteria for assessment

I. SAFETY

expressed by

- numerically definable factors of influence (AGMA, ISO, etc.)
- numerically non-definable factors of influence

II. ECONOMY (Fig. 12)

- Spare parts stock for a given number of years of service.
- Determining of operating costs and total costs for a given number of years of service.

Empirical scales of judgement should be developed from these aspects. It is a question of acquiring an impression of the non-definable factors typical for the system, and blending these into the overall scheme of assessment.

Then the significance of the efficiency and energy requirements should be revealed.

Comparison between girth gear drive and central drive.

Example:

Ball mill	9000 HP
Motor speed	990 rpm
Mill speed	14 rpm
Mill diameter	5 m
Mill bearing	22 m

Project A

Two-pinion girth gear drive Fig. 2A

1 Annulus, 2 pinions

2 Reducing gears, each 2-stage

2 Main motors

2 Turning gears

Project B

Central drive Fig. 2B

1 Double planetary gear

1 Main motor

1 Turning gear

I. SAFETY

Numerically non-definable factors which diminish the safety

Divided into 4 groups, viz.:

- System	items 1 - 5
- Manufacture	items 6 - 8
- Installation	items 9 - 12
- Operation	items 13 - 23

SYSTEM

1. Drive subdivision into

A: Reduction gear and girth gear transmission with mill as gear axis. Fig. 2A
Tooth contact of girth gear dependent on deformation and position of mill. Fig. 8

B: Total speed reduction in a closed in, dust proof housing. Fig. 2B
Tooth contact independent on deformation and position of mill.

2. Number of drive elements

A: Many drive elements mounted individually on foundation. Fig. 2A
Increased chance of break-down.

B: One gear housing only mounted on foundation. Fig. 2B
Little chance of break-down.

3. Number of motors (asynchronous)

A. Fluctuations of ± 10% in the torque division between the two motors.
Additional loading due to uncontrollable rotary oscillation.

B: 1 motor
No additional loading
1 motor of double the power has moreover a considerable higher efficiency.

4. Forces acting on mill

A: The tooth engagement exerts forces detrimental to the mill.
As well as delicate alignment problems, tendency to mill position shift and impairment of running conditions.

B: No forms acting on mill.

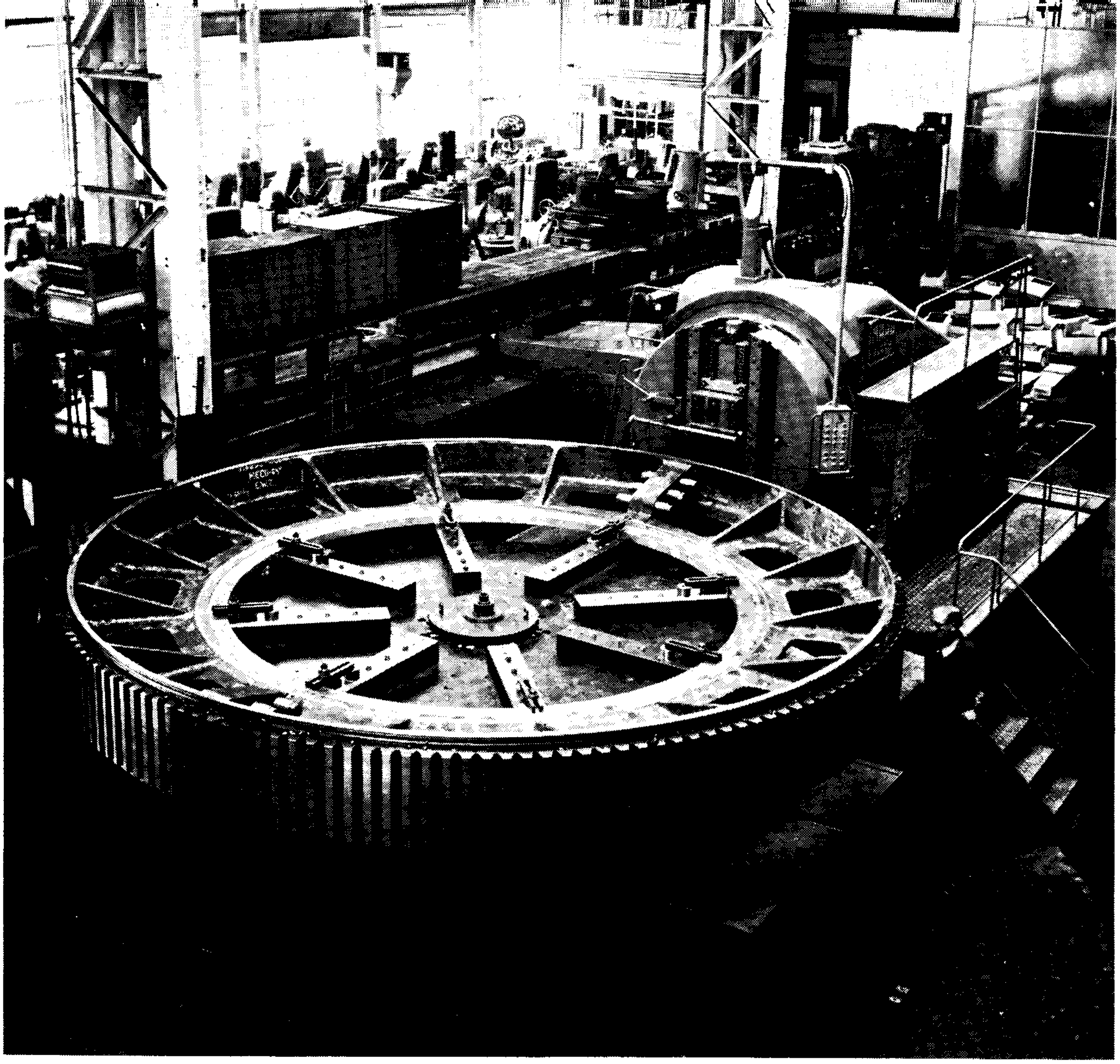

Figure 3:
Gear cutting of a split girth gear for a cement mill having an input power of 2200 HP

5. Separate mill

A: Damage to mill cylinder, neck or stub endanger girth gear and pinion. Repairs entail extra work for girth gear dismantling.

B: Damage to mill cylinder cannot endanger gear teeth. Mill repairs do not entail gear dismantling.

MANUFACTURE

6. Girth gear manufacture

A: Casting of such workpieces free from shrinkage holes and pores, Fig. 3, calls for great skill. The form of the workpiece does not allow a dependable check on the soundness of the material.
Flaws are often only detectable during tooth cutting. This leads to weld filling and a permanent risk of crack propagation.

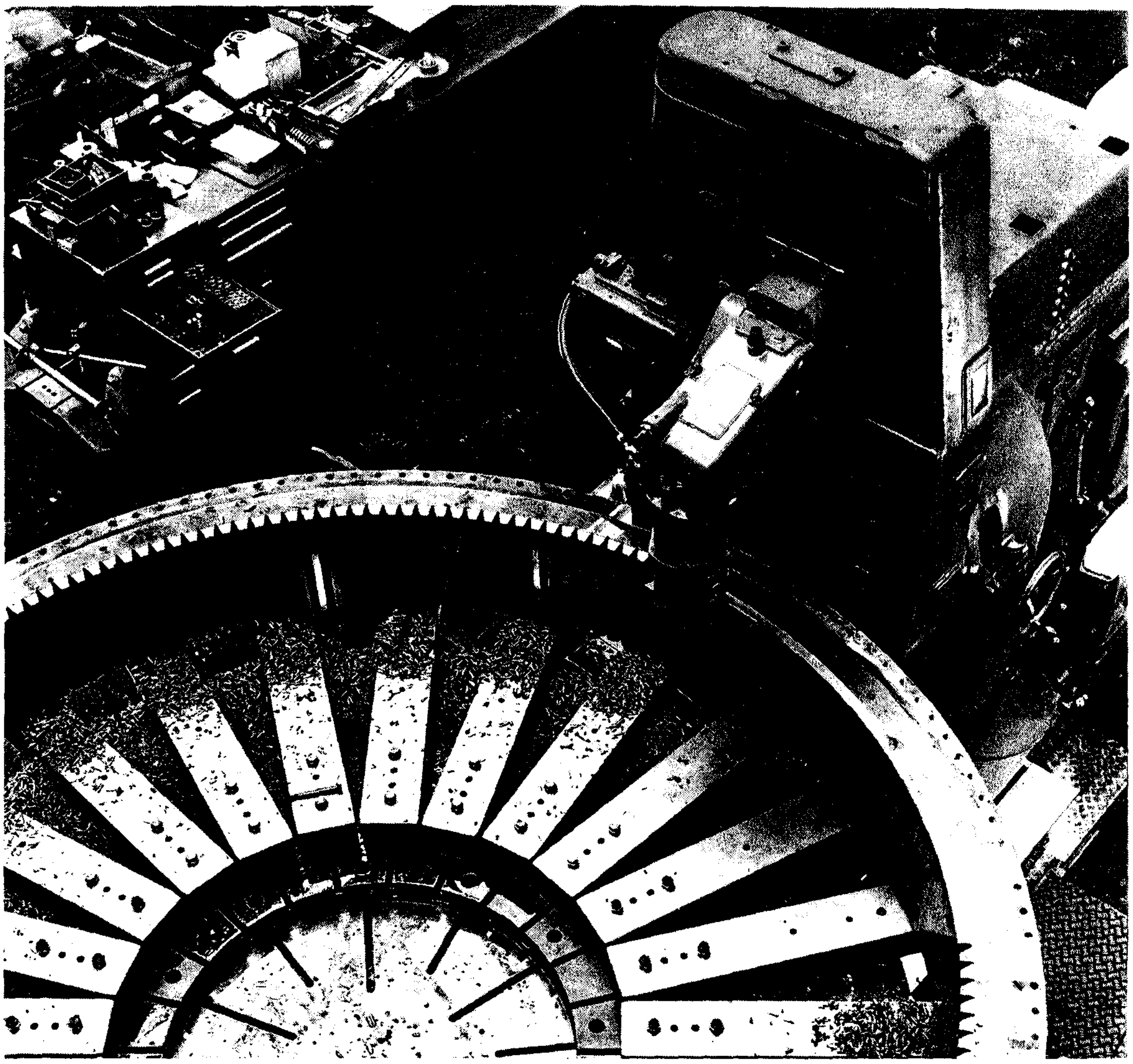

Figure 4:

Gear cutting of an annulus second reduction for a 8500 HP Heavy-Duty-Planetary gear driving a cement mill.

B: The equivalent one-part internally toothed annulus in the transmission train, Fig. 4, is of simple cross-section, is forged, and the material soundness can be checked by the usual methods prior to tooth cutting.

7. Girth gear deformation during machining

A: For cost reasons or due to unavailability of equipment heat treatment of the cast workpieces after rough turning and between rough and fine machining of the reference surfaces for radial and axial run-out and of the location surfaces of the flank halves is often inadequately performed or dispensed with altogether. Fig. 5 and 6.

Internal stresses take effect, deforming the girth gear. The girth teeth are out of round, the location surface is no longer plane, and the joint surfaces of the two halves contact on the inner zones only (gaping, pitch error).

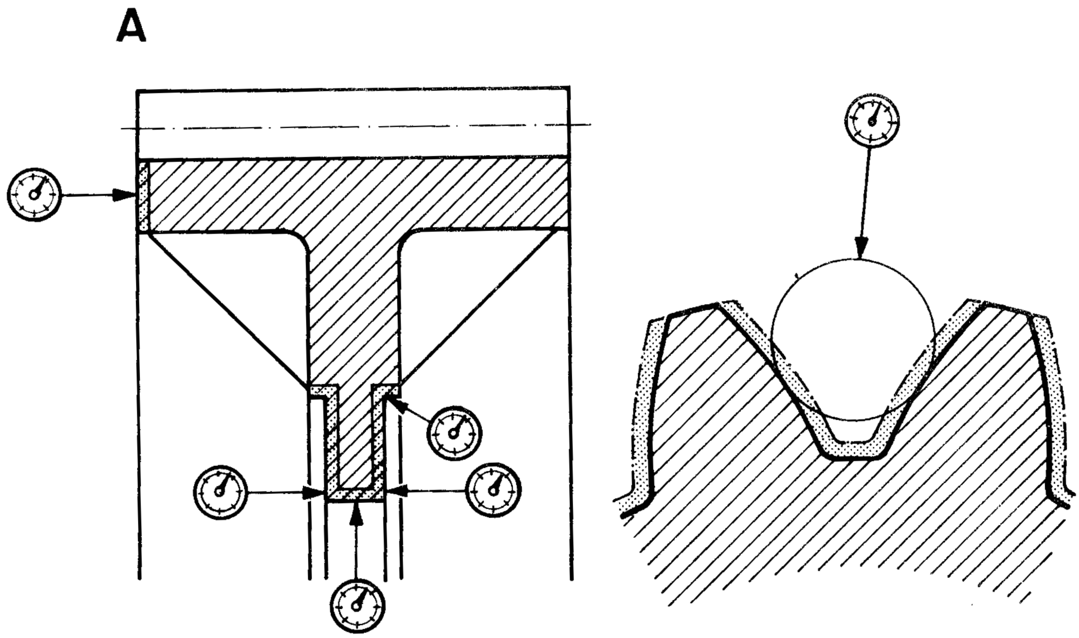

Figure 5:
Checking of the deformations of a girth gear with dial indicators on the reference faces for radial and axial run-out before and after gear cutting. Intermediate checking after the roughing operation.

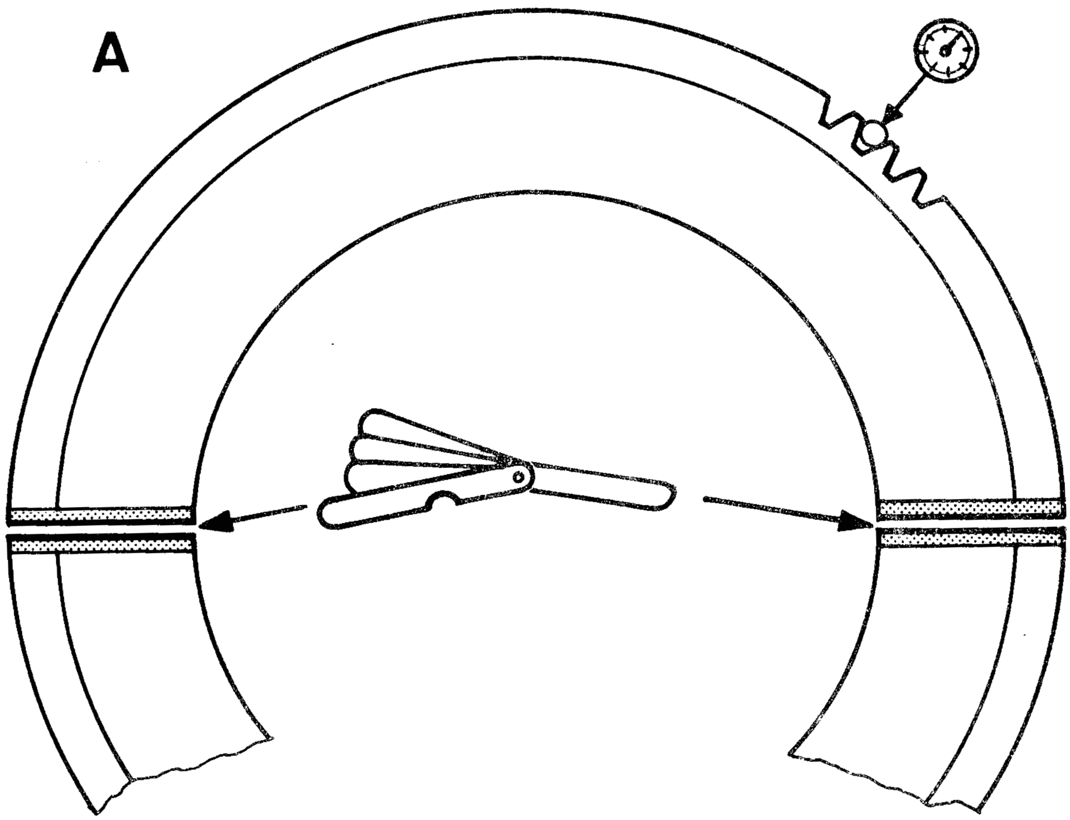

Figure 6:
Intermediate checking after the roughing. Girth gear clamping on the machine table is being released and checks are made with feeler gauge in split faces and with dial gauge and pins in tooth space.

Out of round gear teeth, Fig. 6, cause overload due to acceleration and deceleration.

Pitch error at the joints, Fig. 6, causes knocking in the drive train, vibration and slackening of nuts. Tooth bearing contact degenerates and wear increases. Axial run-out of the teeth around the girth gear is frequently the result of deformed joint surfaces of the girth gear halves and axial run-out of the girth gear location surfaces.

Axial run-out can also be caused by altered stress conditions during operation. Tooth flank overloading, oil film breakdown and wear are the possible outcome.

Improvement may be attained by the following procedure:

- Premachining of the casting skin.
- Annealing process acc. specification.

In normal case:

. Heat workpiece slowly up to 600°C in furnace
. Soak at 600°C for 6 - 10 hours
. Cool down in furnace down to 300°C at a rate of 25°C an hour
. Cool down to ambient temperature in still air.

- Turn workpiece, leaving finishing allowance
- Rough cut gear teeth
- Unclamp workpiece from work-table
- Unbolt the girth gear halves
- Check for deformation, Fig. 5 and 6
- Finish turn radial and axial reference surfaces
- Re-bolt, set up for radial and axial trueness on gear cutting machine
- Finish cut gear teeth, Fig. 3

B: No equivalent influences.

8. Mill flange

A: Radial and axial run-out of the mill flange are not seldom quite considerable, Fig. 7. They impair tooth contact, and are difficult to eliminate later during installation.

B: No equivalent influence.

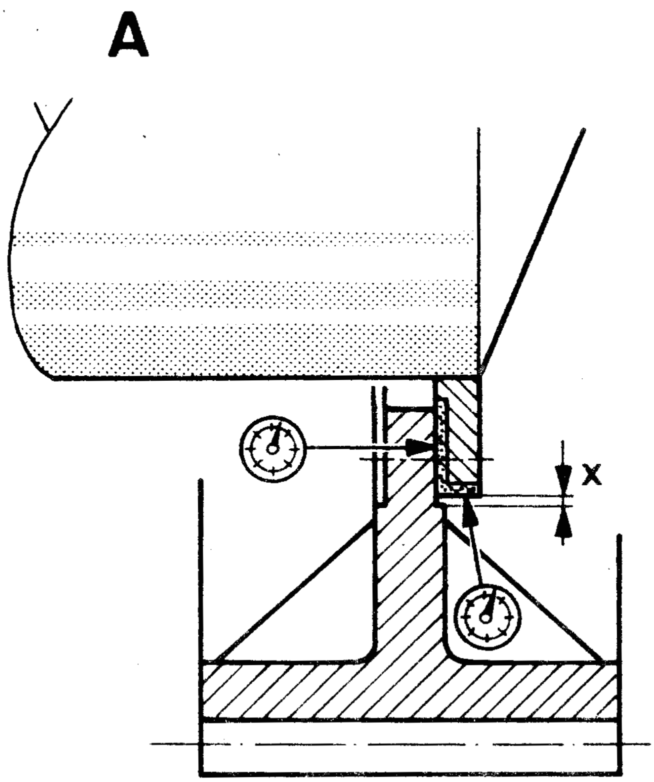

Figure 7:

Machining errors on the mill flange.

Run-out error X on girth gear mounting.

INSTALLATION

9. Foundation and tooth contact

A: Large number of supporting surfaces and accordingly large total support surface area, Fig. 2A.
Increased danger of housing deformation due to uneven bolt-down, and impairment of tooth contact.

B: Two relatively small gear supporting surfaces, Fig. 2B.
No jeopardizing of tooth bearing contact.

10. Size of concrete foundation

A: Large concrete surface at mill drive end, Fig. 2A, with increased tendency towards cracking.
Shaft position shift, impairment of tooth contact, and risk of wear.

B: Mostly common foundation block, Fig. 2B, for mill and drive unit. Risk of foundation cracking negligible. No impairment of tooth contact possible.

11. Fitting of girth gear to mill

A: The spigot reference diameters can have 1-2 mm clearance. The girth gear is to be fitted to the mill body in the same position with respect to radial run-out, as it had for finish tooth cutting on the machine. In practice this is not usually attainable. After installation, the teeth of a girth gear of 7.5 diameter, for example, can be expected to have a radial run-out of 1-2 mm and more; Fig. 7. The resulting fluctuations in angular velocity mean additional loading on the teeth.

B: No equivalent influence.

12. Elastic mill sag by weight of mill balls and material to grind

A: After temporary alignment of the teeth of pinion and girth gear with the mill empty, Fig. 8a, re-alignment should be undertaken with the mill filled with mill balls, i.e. with reference to the elastic sag in cold condition, Fig. 8b.

Final tooth contact adjustments are made on reaching the operating temperature of about 120°C, Fig. 8c.

Service reports reveal that these operations are carried out in part only or not at all.

Moreover the elastic mill sag in hot or cold condition can vary, depending on the position of the man-hole.

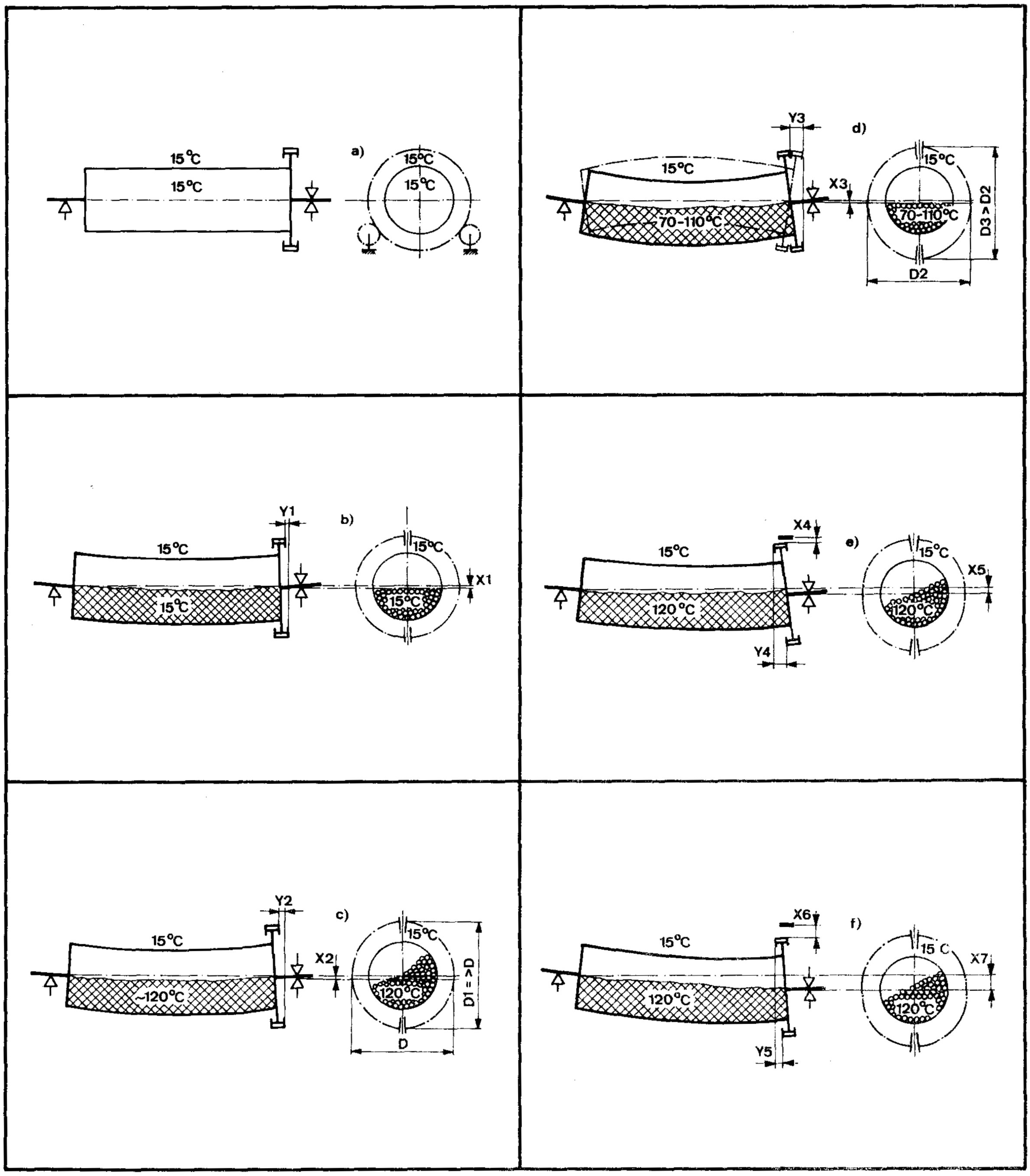

Figure 8:

Girth gear deviation a) to f) during different running conditions.

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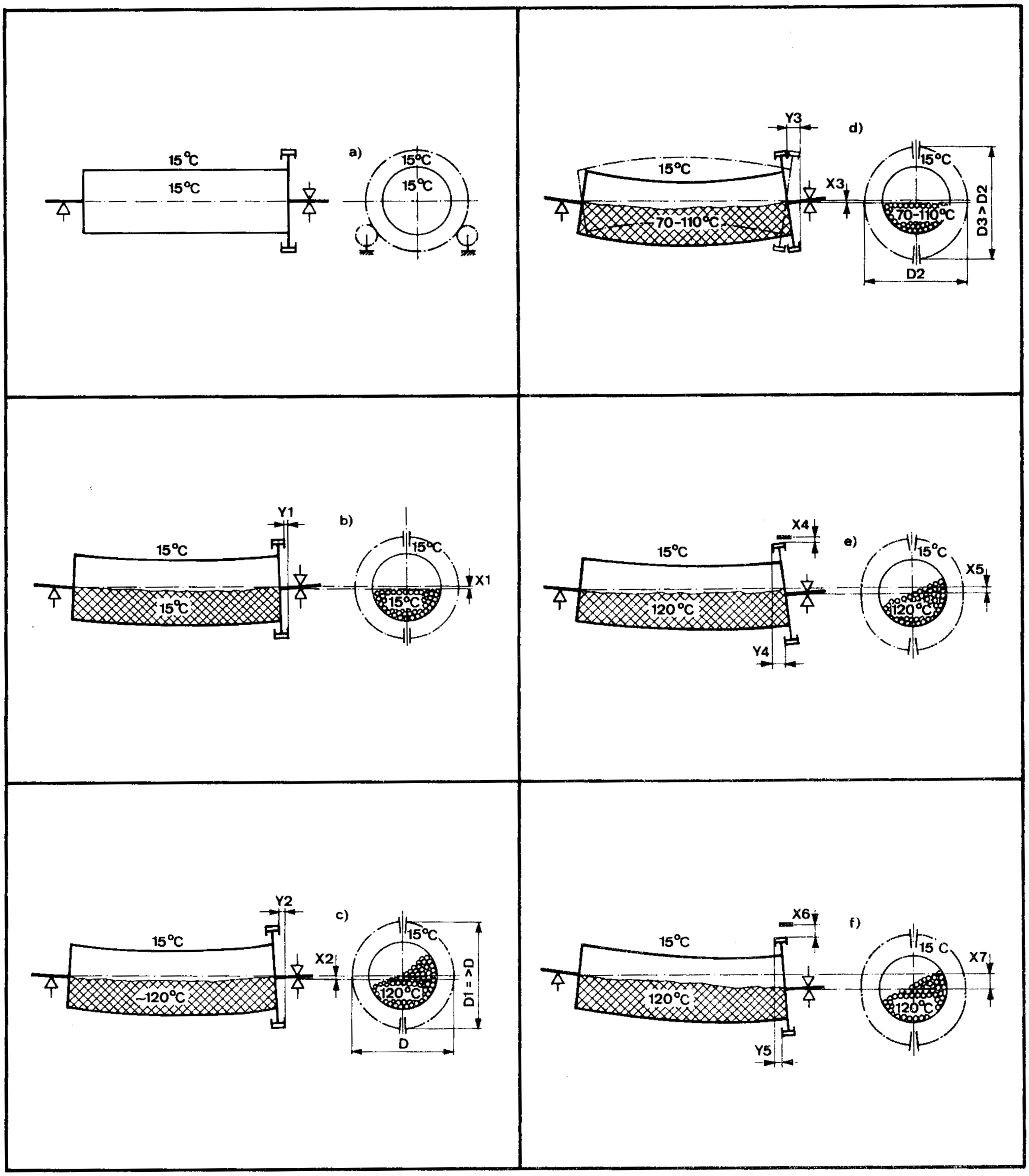

Figure 8:

Girth gear deviation a) to f) during different running conditions.

Some remaining uncertainly is hardly to be avoided.

The exact alignment of two drive units is furthermore a laborious business.

Inadequate tooth contact means risk of wear.

B: Aligning and re-aligning of the charged mill gives little trouble. There can be no detrimental effect on the gear teeth.

Table I to Fig. 8:

Condition	Axial deviation	Vertical deviation Radial run-out
a) Empty mill cold		
b) Charged mill cold	Axial run-out Y 1	Vertical position X 1
c) Charged mill at operating temperature	Axial run-out Y 2	Vertical position X 2 Radial run-out D 1 - D
d) Start - up after shift stop Balls warm	Wobble Y 3	Radial run-out X 3 Radial run-out D 3 - D 2
e) Mill bearing wear	Wobble	Vertical position X 4 Mill axis drop X 5
f) Foundation drop	Wobble	Vertical position X 6 Mill axis drop X 7

Girth gear deviation for unchanged pinion position

(exeption foundation drop)

OPERATION

13. Shaft deflection at full load

A: Numerous sources of deflection due to the forces in housing and shafts can impair tooth bearing contact, Fig. 2A.

B: Design principle practically eliminates such disadvantages.

14. Mill sag on cool-down and restart

A: Plastic deformation of the mill cylinder occurs, Fig. 8d, since due to the hot mill balls the lower mill half cools down much more slowly. (See test report ZKG, edition 3, 1969, Planetary gear drives for large ball mills.)

When restarting, the axial run-out of the girth gear is considerable, until operating temperature is reached, Fig. 8d. During the warming up period, therefore, tooth bearing contact is seriously impaired.

Note:

These disadvantages can be lessened, but not completely eliminated, by turning the mill through 180°C from time to time during the cool-down period.

B: Gear teeth not hazarded, even if the mill is not turned at intervals.

15. Gaping in girth gear joints

A: Pitch errors between the two girth gear halves due to temperature influence can never be avoided completely in practice, Fig. 9. They can at most be limited by taking special precautions.

Knocking, acceleration and deceleration, lubricating film break-down, loading of nuts and bolts and accordingly risk of wear, are results.

B: No equivalent influence.

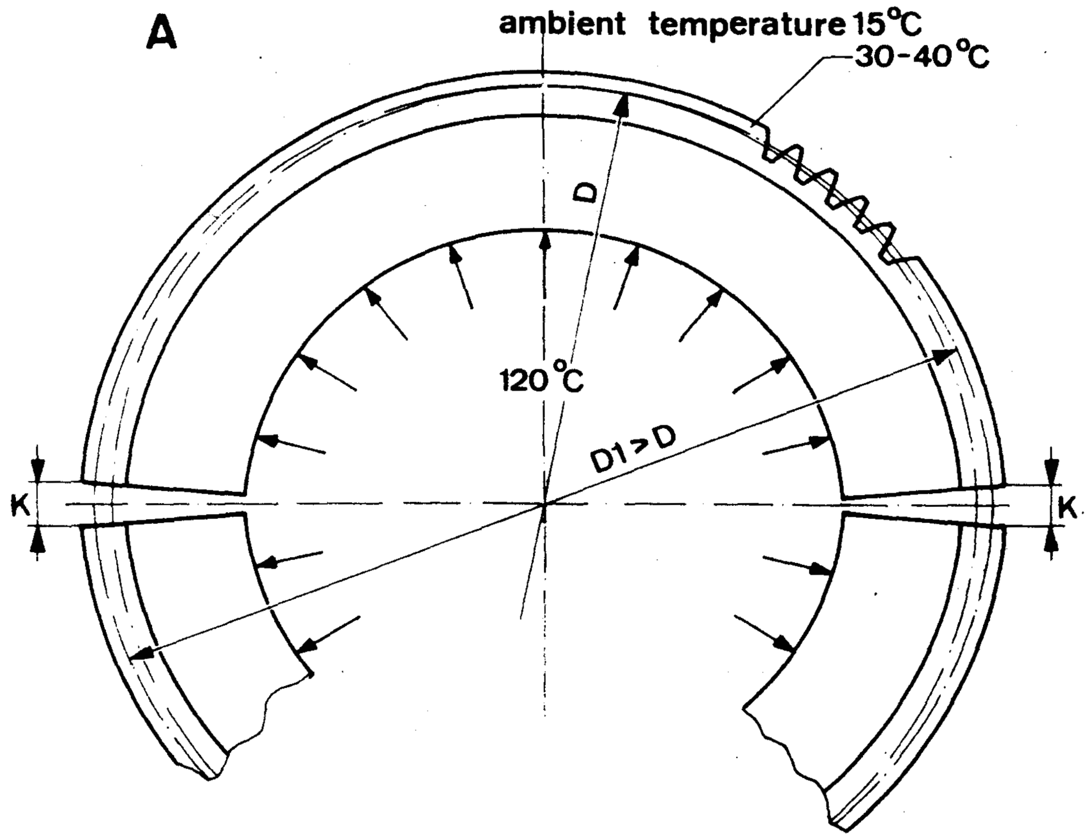

Figure 9:
Gaping (K) of split girth gear faces due to temperature difference during operation (run-out and shocks).

16. Wear in mill bearings

4 - 6 mm wear is possible without detriment to functional efficiency. The girth gear axis takes on a slant, Fig. 8e.

A: Loading of tooth extremities and tooth wear is the result. Even when the mill bearing wear is rectified, pinion and girth gear teeth wear more quickly due to the damaged tooth profile.
Unexpected mill bearing wear is not rare. Possible causes: lubrication break-down, faulty switching, failure to adapt the adjustable bearing support to the altered position of the mill stub shaft.

B: No influence on the gear teeth.

17. Sinking of mill foundation

Unexpected sinking of one of the two mill foundation blocks due to change in the ground conditions through the years mostly throws the concrete block out of the horizontal, and the mill axis skew, Fig. 8f.

Results:

A: Tooth end bearing girth gear and pinion with flank wear and unpredictable production drop-out. Tooth contact remains impaired even after the situation is corrected.

B: Neither jeopardizing of gear teeth, nor forced production stoppage.

18. Lubrication safety

For individual elements of equal quality, lubrication safety drops with increasing number of:

- Lubrication circuits
- Lubrication pumps
- Monitoring instruments
- Various lubricants

A: 3 different lubrication circuits, Fig. 2A, are required.

I Reduction gear

II Annulus transmission

III Intermediate pinion bearings

On the basis of a comparable technique, 4 - 7 pumps are required, together with about 16 monitoring instruments (temperature, pressure of flow rate) and 3 different kinds of lubricant.

B: Requirements:

1 lubricating circuit, 1 pump, about 4 monitoring instruments and 1 kind of lubricant.

19. Functional reliability of the instruments

A: Regular checking with ratification of the functional condition of 16 monitoring instruments, including the appropriate electrical circuits with signal transmission, complicates cement plant supervision considerably.

B: 4 instruments with appropriate electrical circuits simplify functional checks and improve the dependability in the ration 1 : 4.

20. Girth gear lubrication

A: The widely employed interval lubrication via grease pump is highly prone to clogging, and therefore calls for an especially careful, reliable supervision of grease passage through the nozzles, lubricating effect and a demanding maintenance.

B: No interval greasing.

21. Cold start (-10°C to 15°C)

A: Risk of lubrication deficiency in lubrication circuits without technically unobjectionable lubricating heating.

B: Oil heating in tank via heat transfer oil.

22. High ambient temperature (e.g. 40°C)

A: Risk of lubricating deficiency in lubricating circuits without lubricant cooler, due to viscosity change.

B: Temperature governed cooling in main lubrication circuit.

23. Influence of dirt on girth gear lubrication

A: Sealing of the girth gear casing, Fig. 10, not as efficient as with a closed in gear unit. Cement dust collects on casing and girth gear body, forms into heapes, and can penetrate into the gear chamber. Grease mixed with cement dust is a poor lubricant for gear teeth.

B: No equivalent influences.

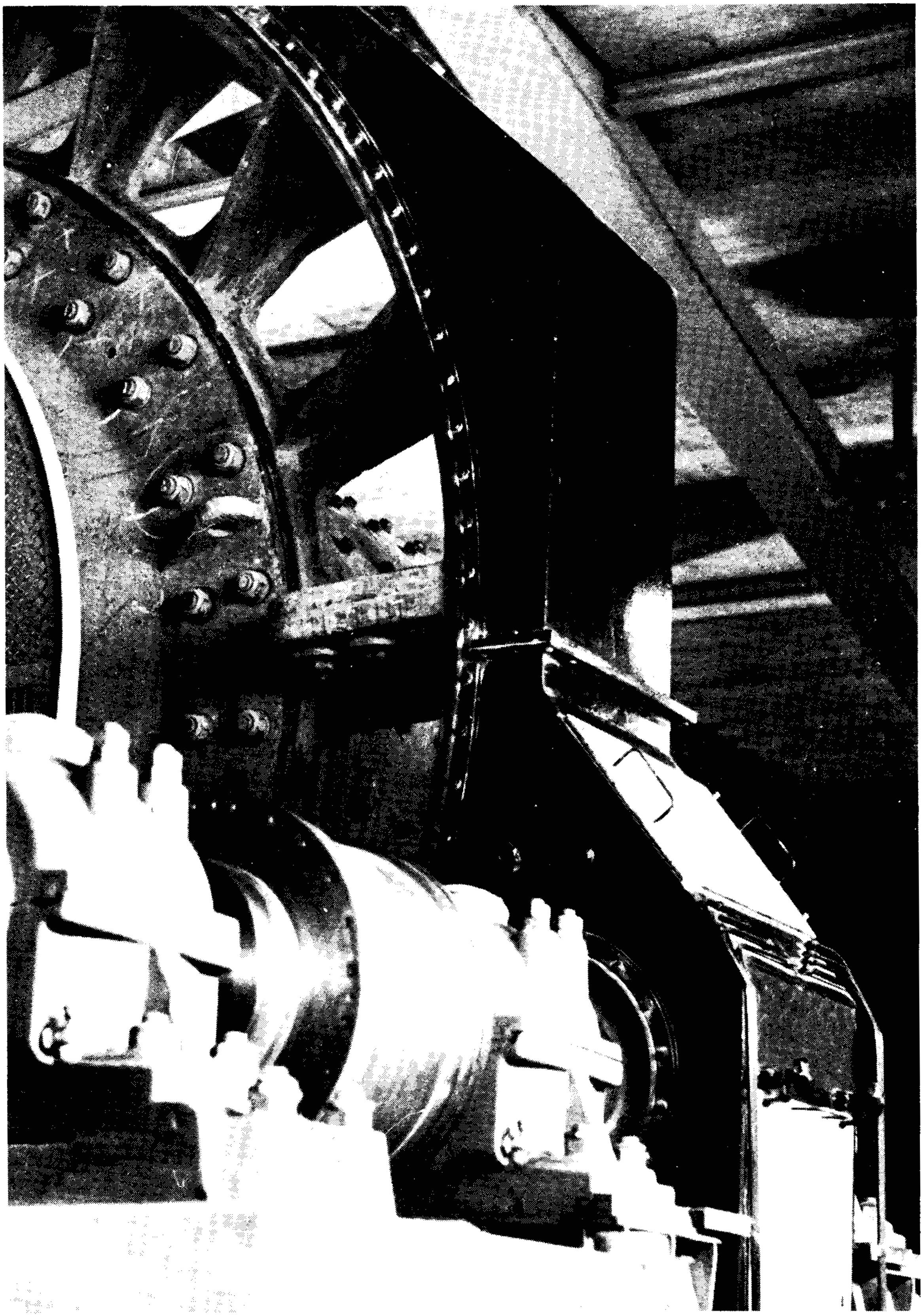

Figure 10:
Girth gear drive of a ball mill with girth gear guard, intermediate shaft and gear coupling.

Conclusions:

If the two drive systems are designed with the same safety factors to recognized formulae, the effective safety in the two systems nevertheless differ widely. With the girth gear drive, Fig. 10 and 2A, the numerically non-definable factors of influence are numerous, whereas with the planetary gear drive, Fig. 11 and 2B, they are negligable few.
A realistic, comparable safety factor calculation is not possible in the case of system A.

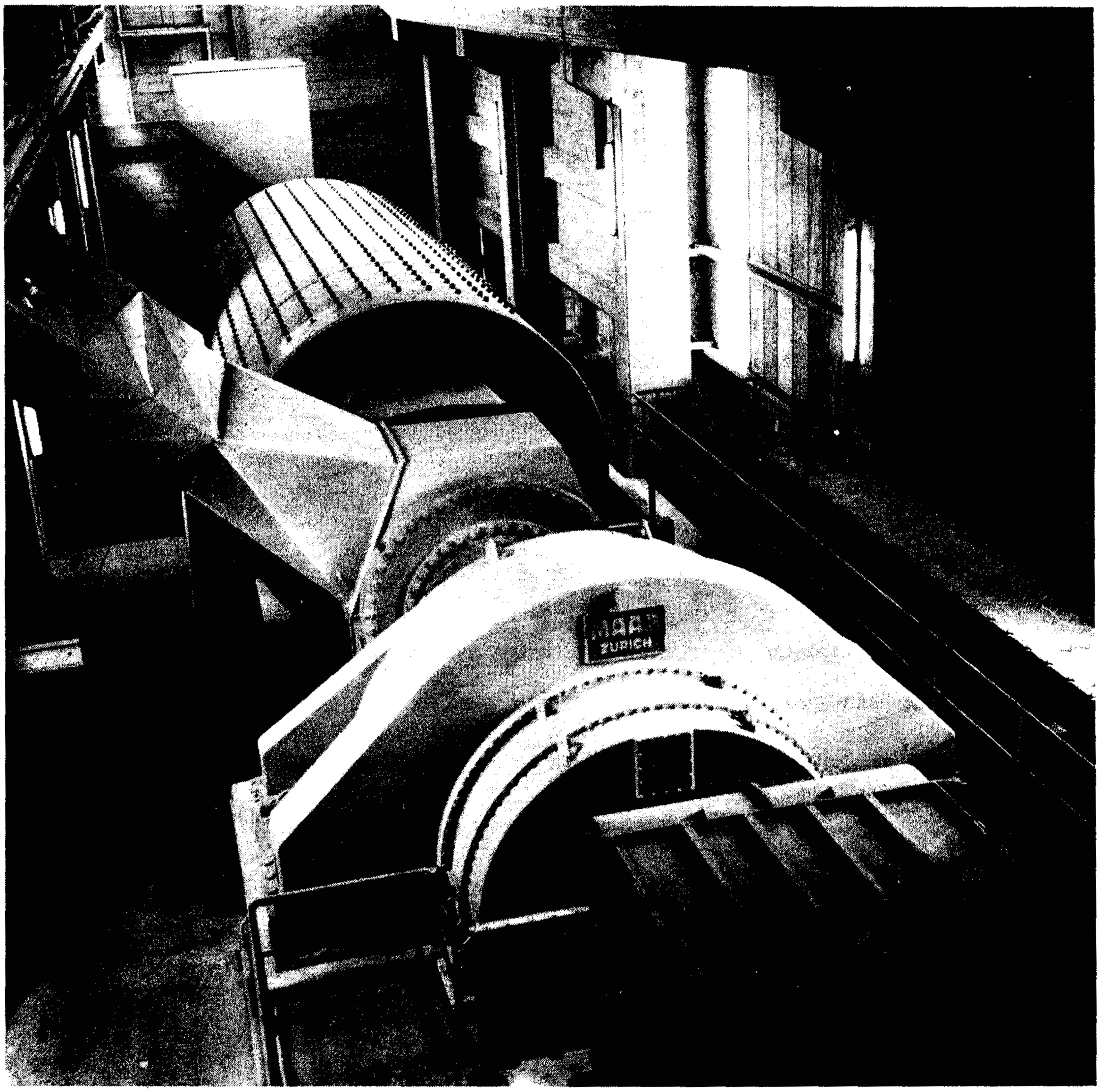

Figure 11:
Cement mill with MAAG Heavy-Duty Planetary gear, Type P2U3-70/110 for max. input power of 6500 HP at 985/14 RPM.

II. ECONOMY

Efficiency

A) Energy losses:

2 tooth meshing points (1 girth gear 2 pinions)	1.3 %
4 intermediate pinion bearings (friction bearings)	0.6 %
2 mill bearing parts	0.1 %
2 reducing gears (2 stage)	1.8 %
	3.8 %
2 elec. motors each about 3.35 MW (power balancing in operation) instead of 1 motor of 6.4 MW	
Additional losses with 2 motors	0.7 %
Total for A)	4.5 %

B) Double planetary gear	1.3 %
Excess losses for A) relative to B)	3.2 %

Note:

Excess energy requirements of double-pinion girth gear drive relative to central drive with planetary gear at 8000 h. a year.

. in 10 years corresponding to — abt. 15.8 Mio. kWh
. Costs at 0.09 Fr./kWh of — 1.42 Mio. Sfr.

- With the energy loss difference, 1 mill of 6.4 MW and 26.3 kWh/t (2700 cm^2/g) 2 million Sfr. can be covered, assuming an interest of 7%.
- The significance of the safety factor becomes manifest in the form of production loss in the event of a mill stoppage.

Standstill months	Production loss	
	in tons	(at S. Fr. 80. -- per t) in S. Fr.
1	135'000	11 Mio.
6	810'000	66 Mio.

Lubricant consumption during 10 years

Costs A = abt. 3.5 times costs B

Wearing parts and supervision

Costs A = 15 - 20 times costs B

Spares stocks for 2 years operation

Costs A = abt. 5 times costs B

Costs for higher initial investment

Depending on the overall quality, the girth gear drive system can be priced at 5 - 20% less than the planetary central drive.

If the spare parts are included and an equivalent manufacturing quality is assumed, the difference in investment costs is usually about 6% (see also lecture by Herrn Tiggesbäumker ZKG 8/1974).

"For purposes of comparison, a higher manufacturing quality for the girth gear drive is not normally selected, since the initial expenditure then approaches that for a central drive. A girth gear drive of higher quality would be justified, however, if technical considerations exclude the installation of a central drive".

System selection and costs

The safety factor and economy considerations are to be combined with the costs and financial situation. The latter can vary from case to case.

Usually the overall costs can be divided into three partially overlapping groups, Fig. 12

- Initial capital expenditure
- Spare parts costs
- Cumulative costs throughout a number of years of service.

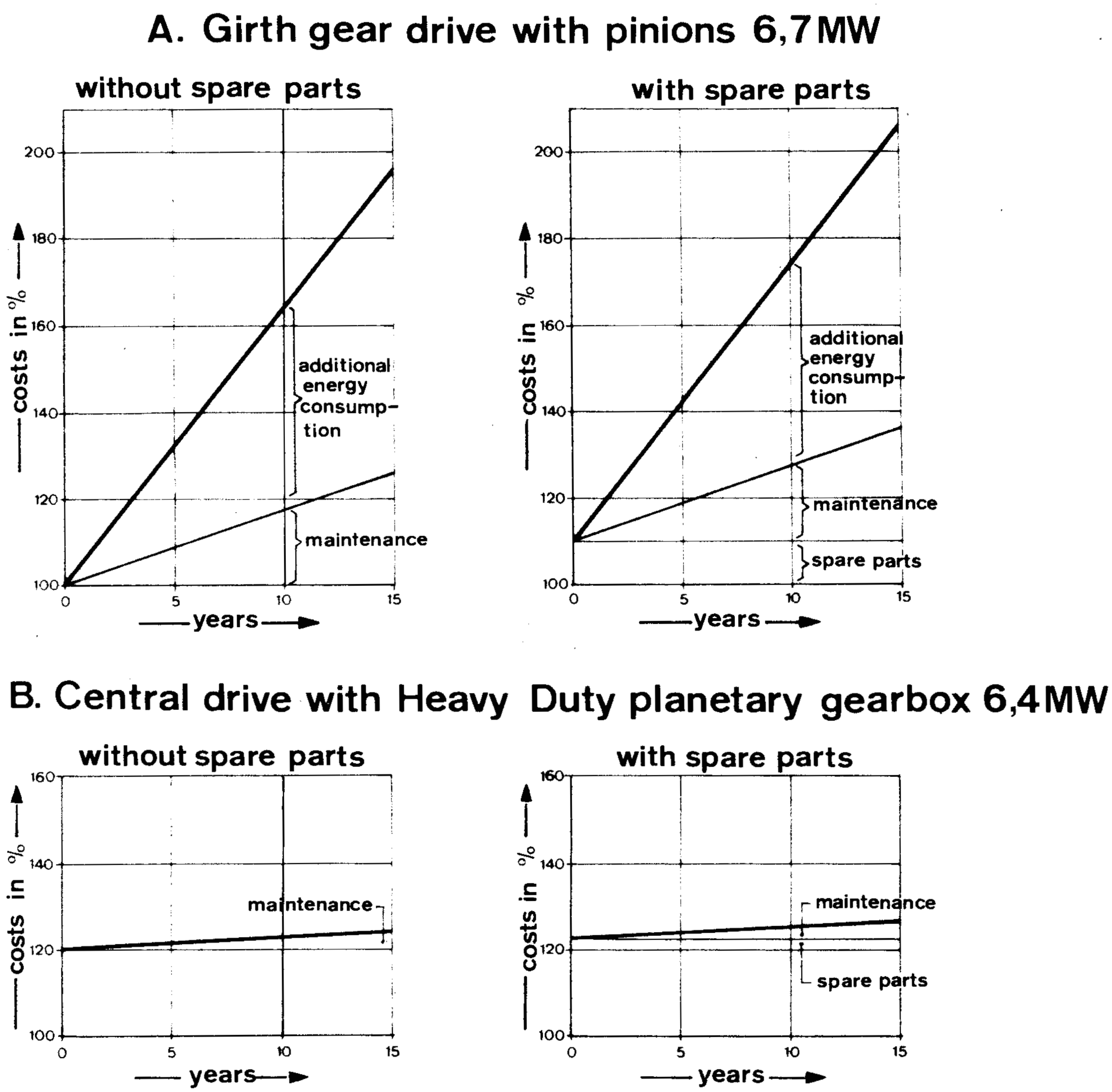

Figure 12:

Total costs for operation (energy, maintenance, spare parts) in function of the operating gears; based on 8000 h per year and S. Frs. 0.09 per kWh.

It would appear most obvious to make decision chiefly on the basis of the cumulative costs, Fig. 12, which also includes energy consumption. For various reasons this is very often not the case.

The primary factor for judgement of the various proposals is often the initial purchasing price alone.

Whilst the cement manufacturer wishes to make the utmost use of his available resources, the plant builders prime aim is sales.

If, on the purchasing side, there are more or less independent temas for planning and purchasing on the one hand, and for later operation on the other hand, an overhead team should keep a healthy balance between the two spheres. This team must doubtless base its decisions on the cumulative costs over a certain period of service. The entities "safety" and "economy" are to play a realistic part in the considerations.

Bottom prices attained by clever manipulation on the part of the buyer can develop into an expensive matter with the passing of the years.

Extreme competitive conditions prompt the flexible plant designer to present his proposals in a manner promising most chance of success.

Spare parts costs and the cumulative costs of say 10 years are often not mentioned until a second transaction phase begins after signing of contract. Above all, under the influence of an inexpensive purchase, the running costs are quitely transferred to the later finite running costs calculations. In reality it is beyond all doubt that production results are painfully dependent on the quality of the plant. This above all, in those cases where there is no surplus of manufacturing energy, and where skilled labour is expensive.

May the above discourse contribute to the formation of an authentic impression as to what part the selected drive system plays in the economic expectations of the projected cement manufacturing plant.

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Summary

Particularly for mills of high productive capacity it is necessary to install drives of high dependability. Safety factor and economy are the governing criteria for assessment. The application of these criteria to both systems is described. Safety factors expressive capacity for the whole plant are only derivable for plants with numerically definable factors of influence. The reason why the girth gear drive system is unsuitable is presented by comparing the most important, indefinable factors of influence.

The overall driving costs development in relation to years of service is explained for both systems by way of an example. The extent of the difference in energy requirements is apparent. The statements permit the practical significance of the effective differences to be recognized, and should be in this sense a realistic aid to assessment.

Bibliography

1) Mälzig, G. und Scheuch, J.:
Ueberprüfung der Auslegung von Mühlengetrieben.
Zement-Kalk-Gips 23 (1970) 417

2) Ackle, W.:
Heavy - Duty Planetary Gears for Driving Large Ball Mills.
Zement-Kalk-Gips 22 (1969) 125

3) Ackle, W.:
Economical Drive System for Large Ball Mills with Heavy-Duty Planetary Gears
Zement-Kalk-Gips 1 (1975) 43