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**1. INTRODUCTION**

The power supply for the German Railways is based on a separate network with a low frequency 16.66 Hz current, which is produced by large generators that have a speed of 1000 rpm. Steam turbines or, nowadays, gas turbines are employed to drive these generators. Their speed is of course considerably higher than 1000 rpm, and for this reason gearboxes have to be installed between the turbines and the generators.

The relative high power of up to 65 MW at low speeds leads to an outstanding gearbox design with regard to size and manufacturing capabilities. All gear components such as gear wheels, bearings, shafts and housing become extremely large and heavy and require utmost attention for each step in design and manufacture. Even bolts and screws will be oversized and have to be made as tailor-made. The designer of such gears has to care not only for a correct design, but also for the availability of gear cutting and grinding machines, turning machines, balancing machines, heat treatment capacities, transportation facilities and assembly of the gears.

Finally, when all these difficulties have been overcome, there has to be carried out a no load test run at the gear makers own test bed facilities!

MAAG has a long tradition in making gears for the German Railways power generation plants. Table 1 gives an overview on the various gears that have been built during the last thirty years. The first units with a power of more than 60 MW have been installed in 1961 at Bayernwerke Aschaffenburg and Stadtwerke Bremen. These gearboxes have a center distance of 1750 mm and a tothing face width of 800 mm! They still are in operation today and opened the way in designing gearboxes of that kind. Especially the knowledge on bullgear and tothing modification design that we gained at these early years has been very useful and still is the base of our general design philosophy for high speed gears. Of course, this experience over the years has improved the design. Today, other materials are used such as special nitriding steel for the big bullgears, whereas in the old days the bullgear was made with a through-hardened steel. The tothing design has reached a nearly perfect state and the tothing manufacturing capabilities with the new Maag SE wet grinding machines, which are able to grind ISO 1 quality even for big wheels with a diameter up to 5000 mm, cannot be improved in the future anymore.

It is the goal of this paper to present some design features of the latest gear orders for the Kirchmoeser plant in Germany, as well as to point out some specialities in making gears of this size and weight.

Plant	Driver	Driven Machine	Year	Gear Type MAAG	Power kW	Speeds rpm
Stadtwerke Düsseldorf	Steam Turbine	Generator	1959	GS-150	43750	2988/1000
Bayernwerke Aschaffenburg	Steam Turbine	Generator	1961	GS-175	62500	2998/1000
STW-Bremen I	Steam Turbine	Generator	1961	GS-175	62500	2998/1000
STW-Bremen II	Steam Turbine	Generator	1962	GS-175	62500	2998/1000
STW-Bremen III	Steam Turbine	Generator	1969	GS-150	36765	2988/1000
VKR-Datteln I	Steam Turbine	Generator	1962	GS-175	62500	2998/1000
VKR-Datteln II	Steam Turbine	Generator	1962	GS-175	62500	2998/1000
VKR-Datteln III	Steam Turbine	Generator	1968	GS-150	36765	2988/1000
STW-Düsseldorf	Steam Turbine	Generator	1976	NHY-140	42500	3018/1000
VKR-Datteln	Steam Turbine	Generator	1992	G-100	40000	2976/1000
VKR-Datteln	Steam Turbine	Generator	1993	G-100	40000	2976/1000
VKR-Kirchmöser	Steam Turbine	Generator	1994	G-125	65000	3000/1000
VKR-Kirchmöser	Gas Turbine	Generator	1994	GX-160	65000	5415/1000
VKR-Kirchmöser	Gas Turbine	Generator	1994	GX-160	65000	5415/1000

Table 1: German Railway Power Plants

## 2. KIRCHMOESER PLANT

The plant Kirchmoeser is located in Germany and will start to generate power for the German Railways by the end of 1994. Responsible for erection and operation is VKR Veba Kraftwerke Ruhr.

It is a combined cycle plant consisting of two Siemens type V64.3 gas turbines and one Siemens steam turbine for the gas turbines waste heat recovery. Each of the three turbines delivers around 65 MW power which is transformed by the Siemens generators into electricity. The speed of the gas turbines is 5415 rpm and the steam turbine runs at 3000 rpm. Therefore, the Maag G-125 gearbox design for the steam turbine is different from the two Maag GX-160 gearboxes for the gas turbines. Both gas turbine trains have only one axial bearing in the gas turbine itself. The single helical gearboxes are equipped with thrust collars and rigidly connected to the turbines and the generators. There is no axial bearing in these gearboxes and the rotors are axially free to take any specified thermal expansions. On the steam turbine train, there are two axial bearings:

One is located on the bullgear of the gearbox and represents the axial fixpoint of the generator; the other axial bearing is in the steam turbine itself and the helix hand of the gearbox single helical pinion is chosen such that the toothing thrust acts against the turbine thrust and helps to reduce the load on the turbine axial bearing. With this arrangement again, any thermal expansion of the whole train can be compensated within the single helical toothing which is axially free.

Figure 1 shows the general machinery arrangement at Kirchmoeser plant. It should be noted that the bullgears of the gearboxes are hollow and long quill shafts are going right through these hollow gearshafts in order to save total train length and machinery hall space. The long quillshafts between gears and generators of around 5000 mm length are necessary in order to minimize the influence of fluctuant torques on the gear mesh. Even with this arrangement, the gears had to be designed to withstand a short circuit torque of eight to ten times the nominal torque.

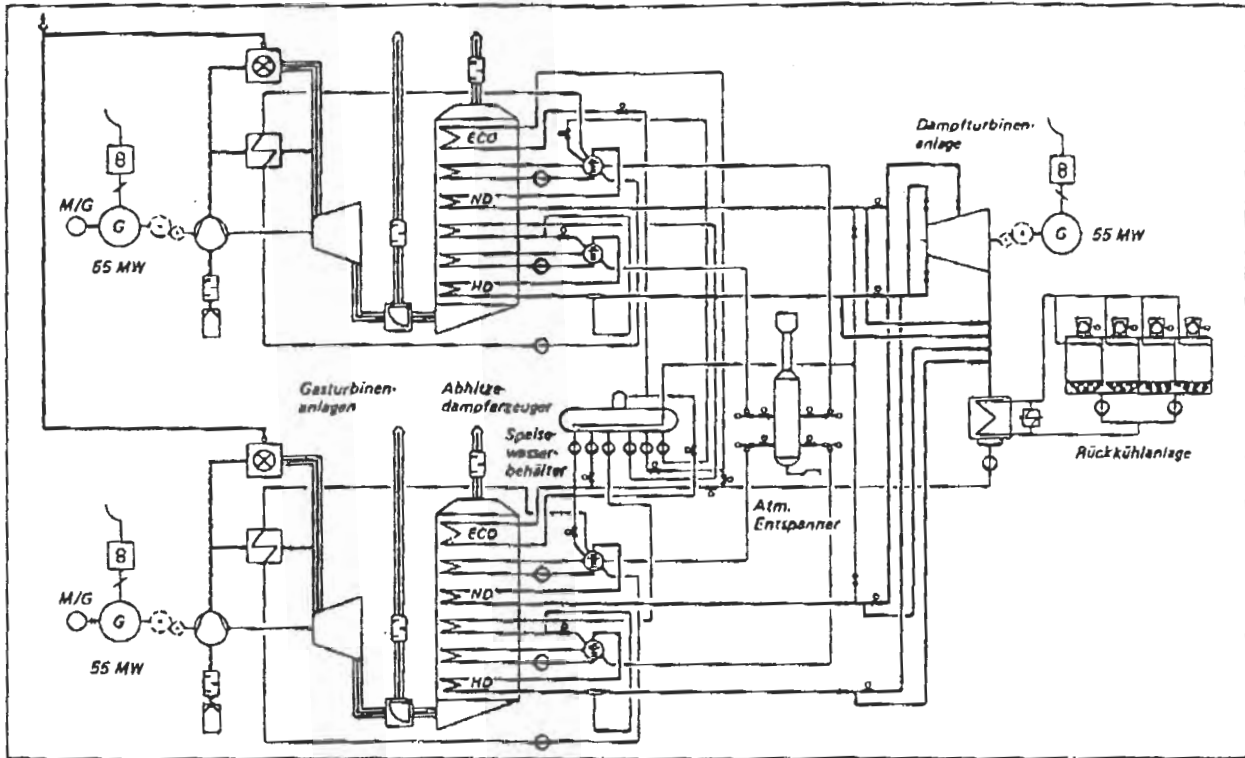


Figure 1: Kirchmoeser Plant Machinery Arrangement

### 3. GEARBOX DESIGN

#### 3.1 Gear Concept

The two different gearboxes are designed according the same design principles and differ only with respect to dimensions of the individual components.

Following design principles have been applied:

- The gearwheels are surface hardened in order to limit the enormous dimensions. Pinions are carburized and case hardened, bullgears are nitrided or carburized and case hardened. The hardness values are min. 58 RC for the case hardening steel and min. 650 HV for the nitriding steel.
- Each quillshaft is made from especially high tensile steel to cope with the enormous 10 times short circuit torque.
- Radial bearings are of the two or four lobe type. One radial bearing on the pinion shaft is designed as an adjustable bearing which means that the gearmesh can be adjusted easily in the field, if necessary.

- The gearbox casing is a welded design. All radial bearings are located directly in the very thick and stiff main side plates of the casing. There are no bearing caps; the upper casing has side plates of the same strength as the lower casing. With this design of two fabricated, very stiff upper and lower casings bolted together by high strength bolts which are tightened by means of hydraulic tools, the radial bearings are fixed between these two casing parts. Since the four casing feet are an integral part of the thick side plates, too, this is a very rigid construction with a shortest possible way for the reaction forces to be led from the bearings to the foundation.
- The gears have a single helical involute toothing, ground with highest precision and the necessary profile and longitudinal modifications.

Cross sections of the gearboxes are shown in [Figure 2](#) and [Figure 3](#).

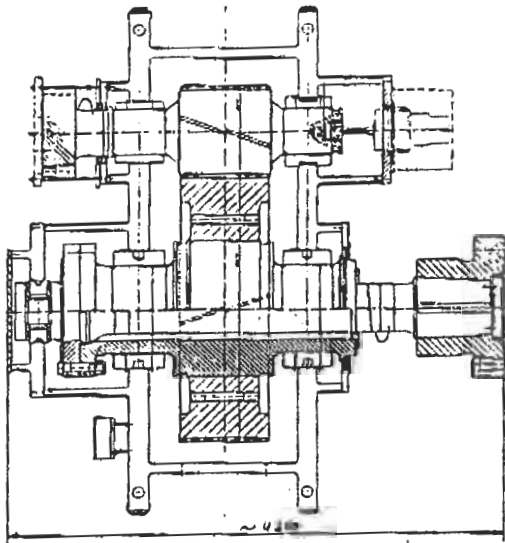


Figure 2: G-125 Gear Cross Section

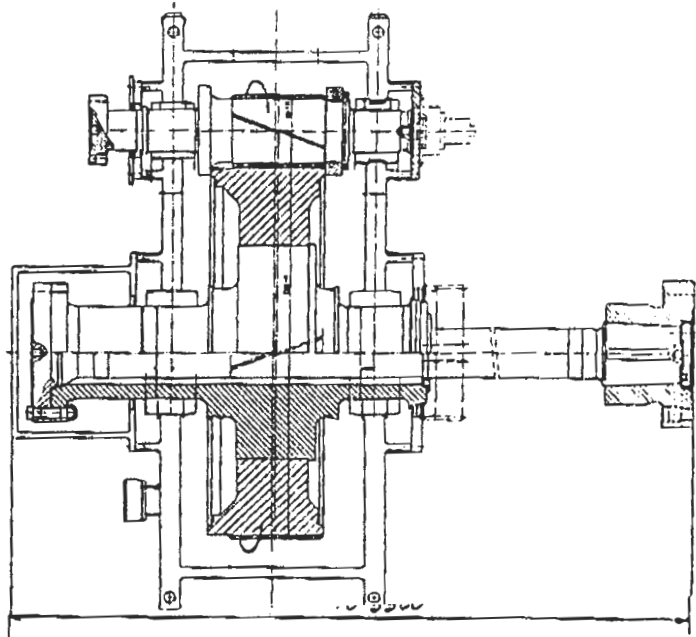


Figure 3: GX-160 Gear Cross Section

It should be noted that some of the technical key data of these gears are outstanding. The G-125 gearbox is the high speed gear with the highest circumferential load in the toothing that we have ever built. A tangential load of 635500 N will be transmitted at a speed of more than 100 m/s! Furthermore, the gears had to be designed to withstand short circuit torques of eight to ten times nominal torque which will explain the huge dimensions of shafts, flanges and bolts.

**Table 2** lists some engineering data of the two gearboxes.

Gear Type	G-125	GX-160
Power kW	65000	65000
Speeds rpm	3021/1000	5415/1000
Pitch Line Velocity m/s	102,3	137,9
Tangential Load N	635522	471371
Diameter Bullgear mm	1976,8	2651,8
Center Distance mm	1300	1560
Overtorque Capacity	10-times	8-times
Weight Bullgear kg	21873	36000
Weight Gearbox kg	47000	63100

**Table 2: Engineering Data**

### 3.2 Toothings and Bearings

It is our general philosophy to have hardened, ground and single helical toothing in our gears. Hardening and grinding of gearwheel teeth is nowadays state of the art for high speed gears and there is no useful alternative. The grinding is necessary to reach the required accuracy after hardening distortions; for the described gears we have ground the toothing with a quality grade of ISO 1..2. Without hardening, it would not have been possible to keep the dimensions and weight of the big GX-160 bullgear within the limits of capacity of gear manufacturing machines.

In fact, the most important problem to resolve was the design of the big bullgears. For case hardening, there are given limits for weight and diameter of the workpieces around 15000 kg and 2800 mm. The bullgear had to be designed as a shrunk-on massive body which resulted in a weight considerably higher than 15000 kg. For this reason, we decided to make them from a special nitriding steel and make use of the nitriding hardening technique.

Today, the process of nitriding, applied to the right material, results in a hardening layer thickness similar to that of the carburizing process and the heat distortions are considerably less. In our opinion, these two hardening techniques are equivalent for big gearwheels.

The involutes of the teeth are ground after hardening with modifications on profile and over the face width. With these modifications, mechanical and thermal deformations of the individual tooth and the pinion as a slender body are compensated in a way that under full speed full load condition, the tooth bearing pattern will be 100 % over the profile and the face width.

**Table 3** lists some engineering data of the toothings. The calculations have been done according to ISO 6336 standard.

Gear Type	G-125	GX-160
Normal Module mm	13.1	11.6
Normal Pressure Angle deg	20	20
Number of Teeth	48 / 145	41 / 222
Gear Ratio	3,02	5,42
Helix Angle deg	10	10
Pitch Diameter mm	664 / 1953	486 / 2633
Gearing Quality	ISO Q2	ISO Q2

**Table 3: Toothing Data**

All radial bearings are of the hydrodynamic type, lined with white metal. They are entirely designed and manufactured by Maag because besides the toothing, an essential part of gearing Know-how is the bearing design which we want to keep under our responsibility. The bearing design is based on the multiple surface principle which guarantees a good dynamic behaviour and stability. **Table 4** shows some important engineering data of the radial bearings.

The axial bearing in the G-125 gearbox is a conventional tilting pad bearing design with directed pressurized lubrication. Every bearing is equipped with at least two temperature sensors, embedded in the hottest load zone as close as possible to the white metal layer.

The adjustable radial bearing on the pinion rests on four individual shoes which can be adjusted in height. With this simple arrangement it will be possible to readjust the tooth contact in the plant during alignment and for compensation of possible changes in foundation after some time of operation.

Gear Type	Bearing Dimensions mm		Specific Loads N/mm <sup>2</sup>		Circumferential Speeds m/s	
	Pinion	Wheel	Pinion	Wheel	Pinion	Wheel
G-125	ø 335 x 335	ø 650 x 350	3,12	2,15	51	34
GX-160	ø 300 x 300	ø 650 x 350	2,77	1,85	85	34

Table 4: Bearing Data

#### 4. NO LOAD TEST RUN RESULTS

Test runs without load but full speed have been carried out at our testbed facilities. For all gears, overspeed testing at 105% and 110 % speed has been included. The testbed arrangement, see [Figure 4.5](#) has been similar to the actual plant machinery layout. A 1500 KW motor (DC) has been installed to drive the gears instead of the turbines.

The low speed quill shafts had a third independent bearing on the output flanges which simulated the first radial bearing of the (non existing) generators. The speed of the electric motor was increased to test pinion speed by means of an auxiliary gearbox. Between this auxiliary gearbox and the test gear, a torquemeter has been installed to measure the actual test gear losses.

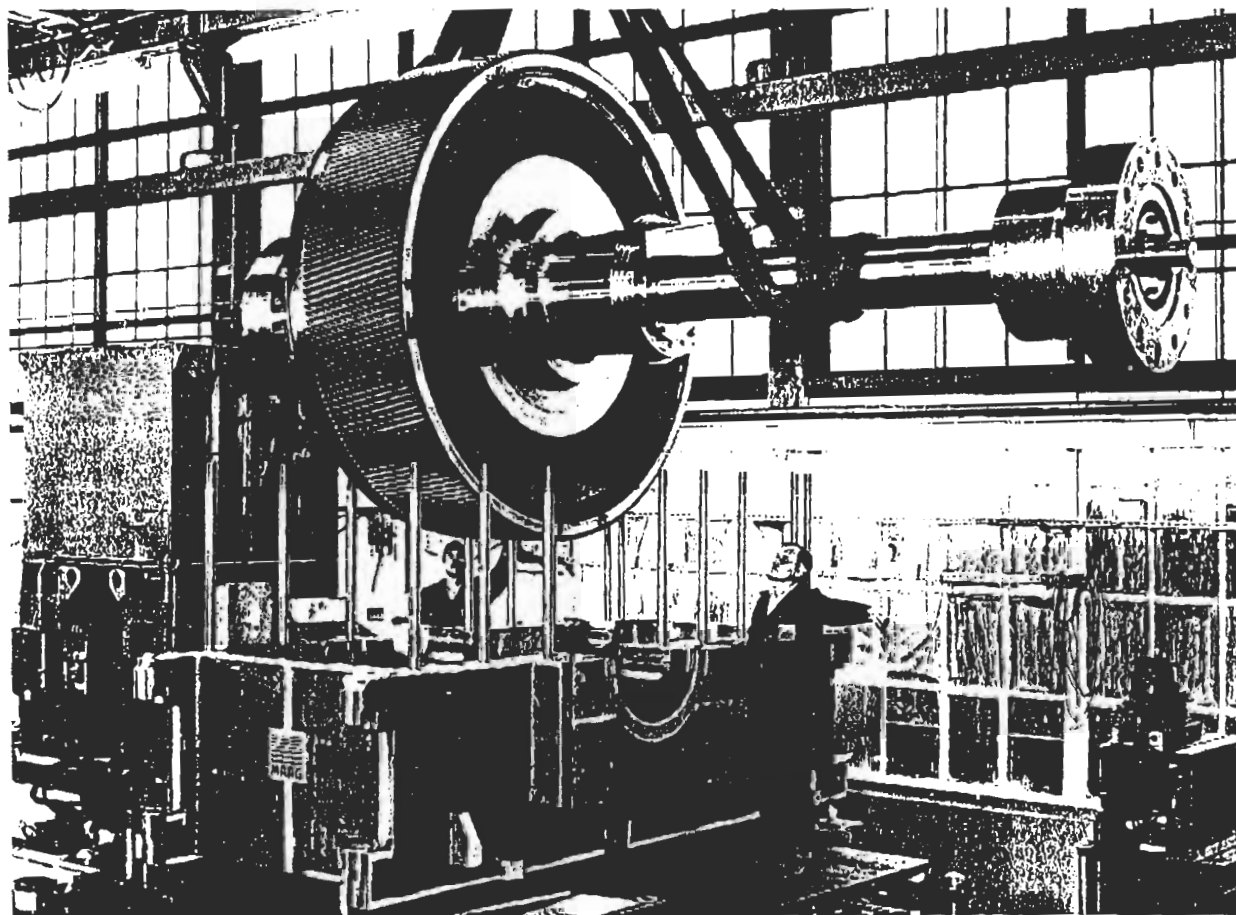


Figure 4: GX-160 Gear Assembly

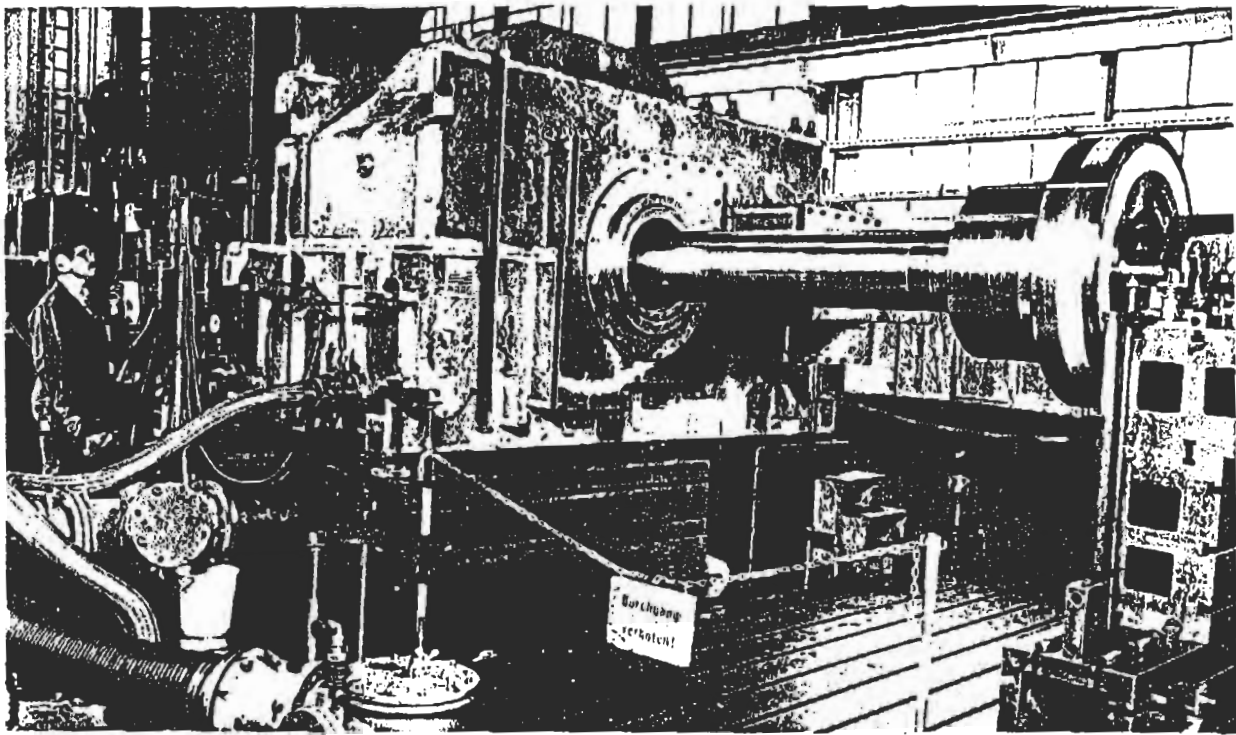


Figure 5: G-125 Gear on Testbed

The relevant gear data, such as oil consumption, losses, temperatures, pressures, vibrations and speeds have been continuously recorded during the test runs. Some of these data are listed in Table 5. It should be noted that these data have been recorded at no load.

Under full load, we expect to have around slightly more losses, 10% more oil consumption due to the eccentric rotor positions in the bearings under load and about 20° C higher temperatures in the bearings.

Gear Type	Pinion Speed rpm	Gear Losses kW	Oil Consumption l/min.	Oil Temperature In / Out; °C	Max. Bearing Temperature °C	Max. Vibration $\mu\text{m}$	Noise Level at 1m dBA
G-125	3032	496	965	37 / 54	60	19	85
GX-160	5415	1140	1430	37 / 59	68	15	86

Table 5: No Load Test Run Data

## 5. CONCLUSIONS

Maag has thirty years of experience in designing gears for railway power generation. These gears are exceptional because high power is combined with a relatively low speed which must, however, still be related to "high speed" gears. The 1000 rpm output speed at 65 MW leads to huge gear components which are nevertheless exposed to run with pitch line velocities of up to 140 m/s. This means that all the important aspects for the design of high speed gears, such as heat distortions, necessary manufacturing accuracies, balancing and so on have to be considered on really big workpieces. These are the real difficulties in designing such gears!

Some specific design principles have been explained in this paper, and some test run results are shown. The limits to manufacture these gears are given by the capabilities of heat treatment facilities, balancing and gear grinding machines. Weight and dimensions of the bullgear must be kept within reasonable limits to meet the given restrictions. Experience, based on a step by step approach becomes an important factor for a successful design.