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MAAG

HIGH EFFICIENCY TURBOGEARS FOR GAS TURBINES

ABSTRACT

A new type of gear, running in a partial vacuum, is placed into operation in three power stations for the first time after extended testing of function on the test bed. The basis of the High Efficiency Turbogear (HET®) Technology will be explained in a short outline including special aspects of design and construction. The new gear technology and its integration into the control circuit of a gas turbine train will be discussed including technical details of the vacuum control system. The calculated saving from the reduction of power losses has been verified by measurements at a power station.

NOMENCLATURE

HET	HET® High Efficiency Turbogear, i.e. the system of increasing the efficiency of a power plant by reducing gearbox losses
HKW	"Heizkraftwerk" - cogeneration power plant
kW	kilowatt
kWh_{el}	generated electrical power per hour in kilowatts
MW	megawatt
rotors	pinion and wheel (rotating parts of a gear)
v'	pitch line velocity (m/s)

INTRODUCTION

Within the effort to improve the efficiency of high speed gas turbine trains, attention is given to each component of the equipment. Thus, an improvement of the efficiency of gas turbine driven turbogears was developed into a marketable commodity showing remarkable reduction of fuel consumption and CO_2-emission in case of constant power output. The power losses could be reduced by more than 45 per cent compared to a conventional turbogear.

It is well known that losses in turbogears can be reduced by an optimization of two components:

- bearings
- toothing.

The improvement of bearing design concerning loss reduction is continuously ongoing. However, the reduction of toothing losses which make up a great part of the total gear losses are for the first time being reduced by the generation of a partial vacuum around the toothing. The basic idea is not really new but it could not be transferred into practice until a technical solution for maintaining a vacuum without impairing the oil draining system was found. This technology is now called High Efficiency Turbogear (HET®).

Along with several constructive details which allow to produce a partial vacuum, a complex vacuum control system was developed to integrate this new technology into the gas turbine protective control unit. It must assure that there is no restriction in availability for the gas turbine train including an automatic switch over to conventional operational mode in the case that any trouble concerning the vacuum system occurs. Beside this automatic safety system it should in any case and at any time be possible for the customer to switch manually between vacuum and conventional mode.

Finally, the HET gearbox is also designed to fit in already existing gas turbine trains to minimize costs of system modifications.

Principle

The focus of the HET-Technology is a reduction of gearbox losses.

Gearbox losses have their origin in toothing and bearings because of both friction and aerodynamic effects. These power losses result in the heating up of the lube oil and the gear itself and have to be carried off as heat.

Figure 1 gives an overview of the origin of relative power losses for a typical high-speed gear with a power of more than 30 MW. The relation shown in this figure is based on practical experience and can vary according to the specific gear design within a range of 5 per cent. For gears with a pitch line velocity of 150 m/s and more 80 per cent of the losses in toothing originating from the gear mesh and the rotation of the rotors are caused by aerodynamic effects known as "churning" and "windage" (as shown in Figure 2). A detailed explanation of aerodynamic toothing losses is given in a VGB publication [1].

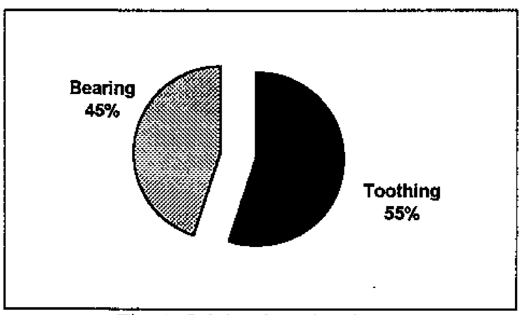

Fig. 1: Origin of gearbox losses

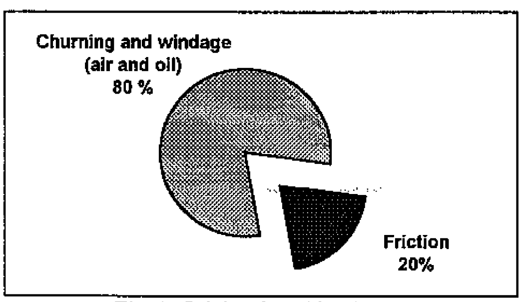

Fig. 2: Origin of toothing losses

Based on this information the approach of reducing gearbox losses is logical: the sources of power losses have to be optimized. With stress on the toothing, the aerodynamic toothing losses can be reduced by

- evacuating as much air as possible to reduce the effects of windage and churning
- reducing the oil flow to the gear mesh to the minimum required for sufficient lubrication and cooling.

To reduce the bearing losses new bearings (special tilting pad types) with very low oil consumption have been designed. This allows a minimization of the oil consumption at a given circumferential bearing speed.

Constructive Details

The pioneering solution for a considerable reduction in gearbox losses is to run the rotors under vacuum. The detailed design, for which MAAG has a patent, is explained in Figure 3.

The HET gearbox has in addition to the main casing (2) an inner casing (4) which encloses the rotors (1). From the so created interior space (5) the air and also most of the lube oil can be removed by a combined oil and air pump (6). The shafts are airtighted by special sealings (7). With this design a vacuum level of about 85 per cent can be reached when the HET gearbox is running in the vacuum mode. The bearings (3) are separated from the interior space. Consequently, there is no oil flow from the bearings into the vacuum area.

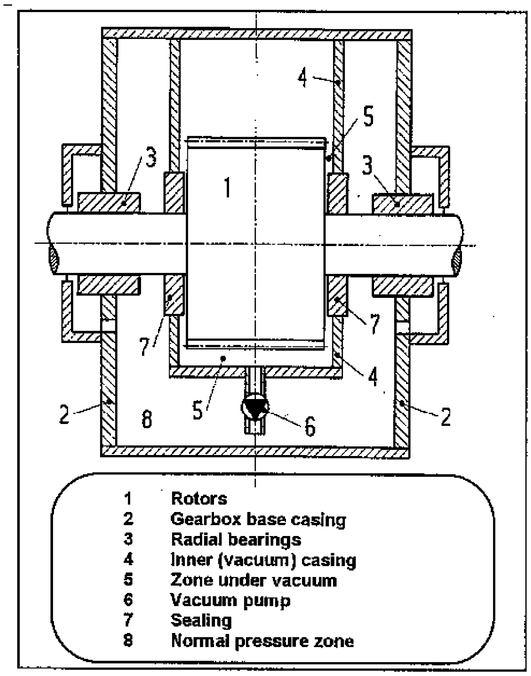

Fig. 3: Patented MAAG HET® gear design

INTEGRATION OF THE HET GEARBOX INTO THE GAS TURBINE TRAIN

The integration of the HET-Technology into the gas turbine shaft train requires reliability as well as easy maintenance. Thus, the following demands were made on the HET-Technology before it started operation in a power station for the first time:

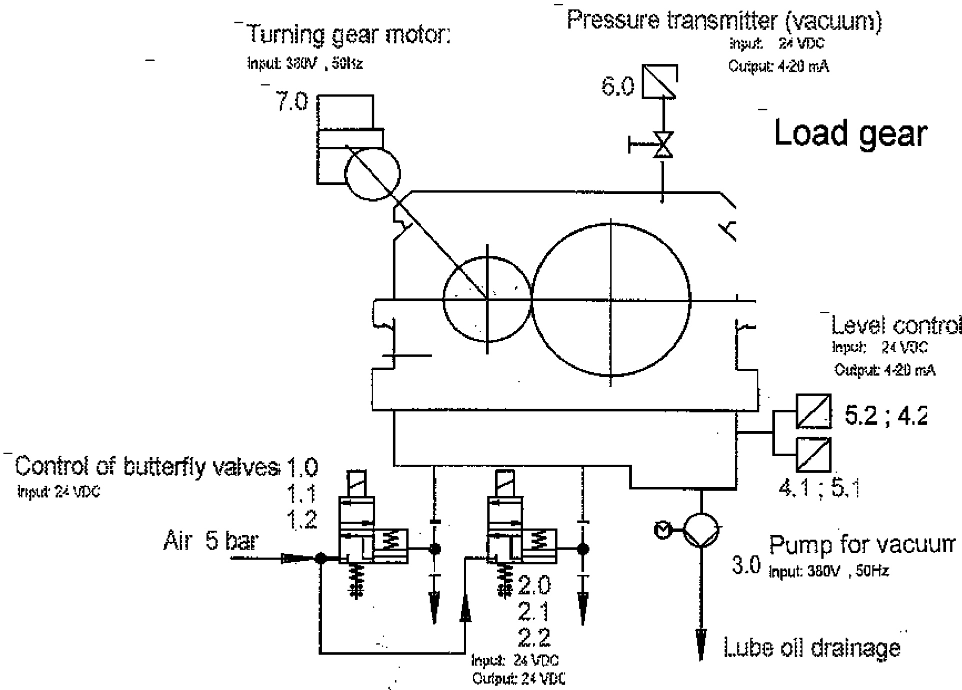

Fig. 4: HET Vacuum Control Logic

- Guaranteed operation in two modes alternatively, vacuum as well as conventional, without any restrictions on life time operation and maintenance
- Ability to switch over between vacuum and conventional mode without any interruption of the operating mode of the gas turbine
- Endurance test of new components such as the vacuum pump
- Elaboration of a vacuum control logic to guarantee trouble free operation of the gas turbine
- Testing of the vacuum control logic.

Vacuum Control Logic

The new HET-Technology was taken into use on condition that both operating modes, vacuum mode as well as conventional mode, can be switched over without any limitation on operation of the gas turbine. The HET-Technology is controlled by a redundant oil level detection. If the oil level exceeds a defined limit further operation remains possible in conventional mode taking into account higher gear losses, only. The protection equipment can basically be explained according to Figure 4.

Vacuum is generated in the inner casing of the gear by means of a vacuum pump (3.0) which removes the mixture of oil and air. The oil-level is controlled by a redundant oil level detection (4.1/4.2/5.1/5.2). This control unit initiates a switch over from vacuum to conventional mode if a defined level is reached. Trip of the gas turbine is released in case of a further, unexpected increase up to a second oil level. After release of the trip, the rotor speed is reduced to an uncritical level in the event of a further oil level increase up to the contact point between the oil and rotating gearing.

Each swing check valve (1.0/2.0) is equipped with two proximity switches (1.1/1.2/2.1/2.2) with redundant design of each swing check valve.

As explained above a switch over from vacuum to conventional mode is actuated by an unexpected increase of the oil level. At the same time it is also possible to switch over between both modes manually.

The pump can be changed within two hours during continues operation in conventional mode without any interuption of the plant.

System availability and reliability

Apart from the inner casing and the operation under a vacuum condition, the design of a HET gearbox is based on well proved technology.

The rotors and toothing are designed based on the same MAAG know-how that is applied also to conventional applications. Specifically, the longitudinal modifications that are performed on the toothing is manufactured with the same precision. The reliability of the toothing is therefore given and proved in practical experience. Furthermore, there is no difference in dimension and construction of the main gearbox casing. Also the centre distance of a HET gearbox normally corresponds with that of a conventional gear with the same rated power. These two constructional details allow an easy retrofit of conventional gearboxes already in operating power plants.

The availability of the HET gearbox consequently depends only on the ability to maintain the vacuum in the inner casing. This is ensured by a specific protective control system (as described above) and by using only reliable and well-tested components. In addition it is possible to run the HET gearbox both on conventional and vacuum mode. Therefore the availability of the HET gearbox in view of its prime function (driving a generator e.g.) is at least as high as for a conventional gear.

FIRST OPERATING EXPERIENCES

The proof of the new HET-Technology is for the first time given in three power plants:

- Neckarwerke Stuttgart AG's HKW 2, Altbach/Deizisau in Germany
- SK Power Company's thermal power station at Hillerød in Denmark
- Stadtwerke Hannover Linden.

In these plants a MAAG HET gearbox type GD is combined to a Siemens (KWU) gas turbine V64.3 at Hillerød and to a gas turbine V64.3A at Altbach/ Deizisau and Stadtwerke Hannover with cumulated operating hours of more than 14'000 at the time of writing this article. The availability of the HET-Technology in these three plants is 100 %, i.e. there was no shut down due to a defective vacuum system or the HET-Technology/gearbox themselves.

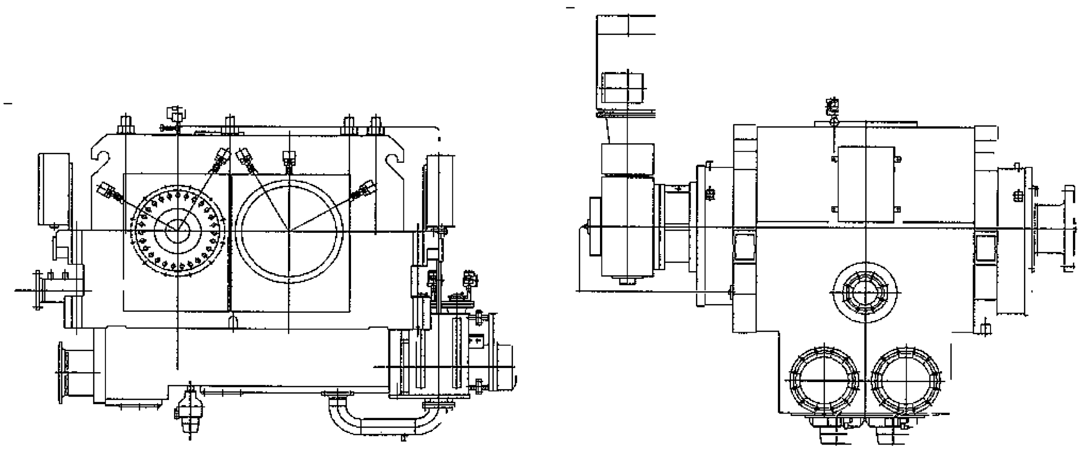

Fig. 5: HET gearbox

Review of the HET-Technology

Although the design of the rotors and the bearings is based on long-time technical experience the operating in a vacuum mode required an adaptation of some parameters and a new control and safety system.

Before introducing the HET-Technology in the market, a back-to-back test with 70 000 kW gears was performed. The arrangement of this test has also been published in a VGB publication [1]. This test gave first indications to verify the design under full and partial load. But all these results were based on test conditions and not on a real operating condition.

For the design review it was therefore important to compare the data from the practical experience of the HET-Technology with the theoretical design approach. The information based on three HET gearboxes with cumulated operating hours of more than 14'000 proves the basic design and the reliability of the HET-Technology. But it also shows the possibility to optimize the system. In consequence, two major improvements were made:

- It was known that the thermal deformation in operating in a vacuum mode would be different. This deformation was considered in the longitudinal modification and proved in praxis. In addition, the absence of air circulation causes a partial hot spot in the gap of the toothing . The degree of this heating could only be defined in the operating process. It is now controlled by optimizing the cooling of this area.
- The second improvement was made by optimizing the protective control system. This was done both in redesigning the arrangement of the instruments and in defining new requirements for the vacuum system.

Determination of the Gear Power Losses

Acceptance test measurements will be carried out at the test bed of the gear manufacturer. The gear power losses are determined under no-load conditions by means of a torque meter. Another 2.5 kW power consumption of the vacuum pump has to be added to these power losses to come to an accurate valuation of the HET-Technology.

For conventional gears, the power losses under load conditions will normally be calculated only. Based on the measured power losses during the no-load test run the expected power losses on full-load condition will be determined by using a ratio which is based on long-term experience of MAAG.

Due to lack of comparative figures, the determination of the power losses for a HET gearbox running in vacuum mode at nominal operating conditions is based on a back-to-back configuration [1]. Although the calculation for HET gearboxes follows in principle the same rule as described for the conventional gears, a different ratio has to be used and a correction for the bearing losses has to be made because of the vacuum system and the fact that the relation between toothing losses and bearing losses is changing.

In order to verify these theoretical calculations, additional acceptance test measurements were carried out at the Altbach/Deizisau power station to confirm gear losses under real load conditions.

The first measurement was carried out on the test bed. It significantly confirms the importance of gear power losses generated by the toothing, especially by churning and windage as it is described above. These toothing losses can be reduced if the vacuum mode is switched on.

The acceptance test measurement of the new HKW 2 parallel-powered combined cycle power station at Altbach/ Deizisau confirmed the loss reduction of the HET-Technology under load conditions. The gear losses measured at the power station correlate with a deviation of maximum 5 per cent with the predicted losses which had been determined based on test measurements at the manufacturer's test bed under no-load conditions.

In addition, a power saving was also determined for the High Efficiency Turbogear running in conventional mode. This can be explained by the optimization of both the gearing oil cooling system, which was developed in preparation for the HET-Technology, and the bearings, i.e. the power loss of a HET gearbox running in conventional mode is always lower than for a conventional gearbox.

The profit which can be achieved if the gear is running under vacuum mode is based on individual aspects of each customer and therefore it cannot be given in general.

CONCLUSION

The new technology of High Efficiency Turbogears successfully started operation in three power stations for the first time. This new technology of gears, running in partial vacuum (vacuum level of the inner casing about 85 %), was developed from first test runs at the gear manufacturer's test bed to the reliable operation in a 65 MW gas turbine train including all requirements for a safe operation of the gas turbine train.

First experiences confirmed the trouble-free operation in two modes, vacuum and conventional with a system availability of 100 per cent.

Power loss measurements of the gear were carried out under no-load and load conditions. In addition to the usual determination of power losses at the manufacturer's facility, the power losses were measured at the power station also. Thus, the design of the new HET-Technology could be affirmed in efficiency improvement and operation experience implemented in the control and safety circuit of a gas turbine train.