Retrofit of steam turbine with fixed speed induction motor and variable planetary gear

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Synopsis

Recent developments in hydrodynamic-variable planetary gear technology using the principle of “Power-Splitting” have allowed its use as an effective drive for compressors. A standard induction motor used as the driver. An economic solution is the variable planetary gear drive with a high efficiency and reliability.

Biography

Ulf Sjöemar is Manager of the Mechanical Group and responsible for rotating machinery at Scanraff refinery in Lysekil Sweden. Scanraff is partly owned by Preem Petroleum AB, which is a major Swedish oil company. He was allocated as Machinery Specialist for the extension of Preem Refinery in Gothenburg Sweden 1995 to 1997. Mr. Sjöemar was graduated from the Chalmers University of Technology in Gothenburg 1973 with Master of Science in Mechanical Engineering and has over twenty years experience of rotating machinery.

Georg Wahl is the General Manager of Engineering in the Variable Speed Drive Group at Voith Turbo Power Transmission in Crailsheim, Germany. He has 32 years of experience in development, manufacturing, testing and field service of hydrodynamic variable speed drives. Mr. Wahl is responsible for design and development of variable speed drives with torque converter, hydraulic coupling, including gears, also for high speed application. He graduated from Fachhochschule Augsburg Germany in 1961 with a Dipl.-Ing. (FH).

Wolfgang Sautter is the Project Manager in the Variable Speed Drive Group at Voith Turbo Power Transmission in Crailsheim, Germany. He joined Voith in 1990 and has gathered experience in engineering, project management, application engineering, marketing and sales. From October 1996 to October 1997 Wolfgang Sautter worked in the Variable Speed Drive Group at Voith Transmissions in York, Pennsylvania. He graduated from Berufsakademie Heidenheim, Germany with a Dipl.-Ing. (BA).

David Pell is the Manager of Application Engineering and Sales in the Variable Speed Drive Group at Voith Transmissions in York, Pennsylvania. He has 15 years of experience in applying Voith variable speed drive technology to various rotating equipment. Prior to joining Voith in 1982, David Pell worked for Ingersoll Rand Reciprocating Compressor Division in India. He graduated from the University of Madras, India in 1977 with a Master’s Degree in Chemical Engineering.

Abstract

The retrofit of a speed-controlled compressor drive is presented. The steam turbine used previously is replaced by an induction motor with constant speed and a variable planetary gear. To justify the project there are several points considered based on a pay back period below two years. Two different electric motor driving system are evaluated. A variable frequency drive and a constant speed induction motor driving through a variable planetary gear drive. Total cost comparison made the selection for the variable planetary gear. This drive consists of a planetary gear and a hydrodynamic torque converter in the "power-split" branch. It has a regulating range of 70 - 105 % and high efficiency. The drive allows the compressor to operate within its required speed range. A torsional vibration analysis is presented along with a brief description of the design. Manufacturing installation and a successfully commissioning carried out in two days is presented.
Introduction

In May 1995, the Preem refinery (former OK refinery) in Gothenburg Sweden decided to replace a steam turbine driving a compressor (Figure 1) by a new driving system. Originally the compressor was installed in 1965 and revamped in 1991.

Plant requirements

Justification of the project

The project was justified based on a pay back on invested money below two years:

- The turbine is restricted in power. With the new driving system there is a possibility to keep a high compressor flow and a high ratio between circulating gas and naphtha feed for most gas compositions giving a slower coke build up in the catalyst. This means that the number of unit shut downs for regeneration of the catalyst can be reduced from twice per year to once per year for a period of one week. The higher power of the new driving system will also give the possibility for a faster regeneration, when the compressor is used to circulate a nitrogen/air gas mixture for reduction of coke.
- Reduced energy cost with an electric motor drive. The cost for electricity in Sweden is rather low for big consumers (about 3.25 cent/kWh). As the electrical supply is very reliable there is no need for a steam turbine for availability reason.
- As the production of high pressure steam by the boilers is reduced the national environmental fee for NOx emission is also reduced.
- The refinery steam balance is improved.

The compressor is installed in a gasoline producing reformer unit in the refinery. Figure 2 shows the circuit diagram.

The compressor is circulating gas (mainly hydrogen) through heat exchangers, heaters, reactors, coolers and separators in a closed loop. The reformer gas circuit is fed by naphtha after the compressor. The naphtha is then heated, transformed to high octane gasoline by a catalytic reaction in the reactors, cooled and separated as a outgoing product before the compressor.

This process uses only one compressor. There is no spare compressor so a stop of the compressor will shut down the whole reformer unit and also downstream process units with a loss of production and a great economical impact. This means that the compressor system should have 100% availability between the main turnarounds, which occur every four years.

Fig. 1: Old installation

Fig. 2: Schematic process description
The refinery circulating cooling water system, which is highly loaded during summer time giving cooling problem, is unloaded by 9 to 12 MW as the turbine condenser is not needed. This will also make it possible to add the new gas oil desulphination unit to the existing cooling water system without modifications.

The maintenance cost for the new compressor electric motor driving system will be lower than for the old (30 years) turbine (with auxiliaries) driving system.

The old high maintenance demanding lube oil system can be exchanged with new integrated lube oil system of the variable planetary gear.

To be able to fulfil the different operating cases ranging from light high hydrogen content gas to almost pure nitrogen gas the compressor have to be speed controlled.

**Selection of equipment**

Two different electric motor driven system were evaluated. One with a frequency controlled induction motor with a gearbox and one with a constant speed two pole induction motor driving through a variable planetary gear.

The evaluation can be summarised as follows:

- The frequency controlled motor had a slightly better efficiency than the variable planetary gear.

- The frequency controlled motor had a lower noise emission than the variable planetary gear. The variable planetary gear required an additional noise hood.

- A new lube oil system was required with the frequency controlled motor. The variable planetary gear has an integrated lube oil system.

- The frequency controlled motor has a risk for producing torsional shaft vibration and harmonics in the electric system, despite predictive calculations.

- A spare rotor assembly was bought for the variable planetary gear as this was a long lead item.

When above factors were considered and transformed to an economical value the total cost (investment/operation/maintenance) for the variable planetary gear was lower by app. 9% when compared with the frequency controlled motor. As the commissioning and start up period for the new driving system was very short there was no time to solve unforeseen problems like shaft torsion vibrations.

Based on this the final selection was made in favour of the variable planetary gear. Figure 3. The retrofit project was handled by Dresser Rand, Le Havre France as the main contractor.

**Variable Speed Drive**

**Analysis of the system data**

The contractor responsible for the retrofit, analysed the required pressure and flow data of the process (Figure 4) and converted it to power versus speed data of the compressor (Figure 5).

![Fig. 4: Pressure vs. Flow](image)

![Fig. 5: Power vs. Speed](image)
Three cases had to be fulfilled:

- Rated case, higher content of nitrogen (N2), normal power demand
- Light gas case, higher content of nitrogen (N2), lower power demand
- Regeneration with nitrogen (N2) with low air content, highest power demand

The final design data for the compressor are:

- Rated power: 4400 kW
- Output speed: 10450 rpm/9952 rpm
- Speed control range: down to 6600 rpm
- Operating mode: 100% continuous

and for the Motor:

- Rated Power: 5000 kW
- Input speed: 2987 rpm

**Variable planetary gear design**

For this power and speed data, a drive was selected consisting of a constant speed induction motor and a variable planetary gear. The variable planetary gear include a variable planetary gear and a hydrodynamic torque converter operating to the "power-split" principle (Figure 6).

**Principle of operation**

The main shaft is connected via a connection coupling to the induction motor shaft. The sun wheel of the planetary gear is connected to the compressor shaft via a connection coupling. As shown in Figure 7. Approximately 75% of the power is transmitted directly from the main motor to the compressor via the planetary gear with the high efficiency of app. 98%. Only app. 25% of the power is branched from the main shaft through a variable speed torque converter to the planet carrier. The torque converter has an efficiency up to 89%. The total efficiency of the variable planetary gear can be up to 95.5%

Figure 8 shows the function of a planetary gear when the branched power is superimposed through the planet carrier. The ring gear (annulus) is running with constant speed of the induction motor. If the speed of the

![Fig. 6: Principle of operation](image)

![Fig. 7: Planetary gear; principle of power split](image)

![Fig. 8: Planetary gear](image)
There are no torsional vibration excitations from the induction motor and not from the variable planetary gear drive during operation.

Only for switching on and failures in the electric supply system torsional vibration excitations can occur. According to the engineering standard VDI 3840 [5], for an induction motor the following excitation cases have to be considered:

- Switching on
- Momentary re-switching
- Prolonged re-switching
- Three pole terminal short circuit
- Two pole terminal short circuit

The excitation cases are shown in Figure 11.

The torsional calculation for the whole drive train was made by the contractor Dresser Le Havre France, for switching on the motor, two pole terminal short circuit and three pole terminal short circuit. As an example, the calculation for the three pole terminal short circuit is shown in Figure 12.

The upper diagram shows the excitation torque in the air gap of the motor. The other diagrams show the corresponding torque in the shafts. This torque results in stresses in the shafts and has to be compared with the allowable strength.

As a result of the torsional calculation the stiffness of the spacer in the diaphragm coupling between the motor and the variable planetary gear was defined.
Manufacturing

Figure 13 shows the schedule from date of order through delivery. The delivery time was 10 months. Some of the special features of this order are as follows:

- Input motor speed of 3000 RPM
- Shaft driven oil pumps
- Oil supply for motor and compressor
- Base frame for main motor and drive
- Customised instrument panel
- Customised planetary gear

Figure 14 shows the variable planetary gear drive on a skid which was designed as a common support also for the main motor. The skid is designed for low resonance frequencies. The lubrication system is an integral part of the variable planetary gear with shaft driven pumps. Lubrication is provided to the compressor and the main machine. The oil tank is flanged on the bottom of the variable planetary gear.

The test run was carried out as functional test with part load at the manufacturing facility. Here the oil flow and pressures were set, temperatures and vibration measured. No string test with the compressor was carried out.

Fig. 12: Torque response at three pole terminal short circuit
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Fig. 13: Manufacturing schedule for the drive

Fig. 14: The drive is ready for shipment
Installation

Figure 15 shows the location selected for the new drive train which is alongside the existing installation. A new platform was constructed on pillars to support the drive train.

As the compressor shut down period was only three weeks, preparations were made to move the compressor to a new foundation close to the original position but on a lower elevation.

The main equipment were delivered within ten month and installed on the new foundation while the compressor was still in operation. All process/utility piping were installed using a compressor dummy. During the shut down in May 1996 the compressor was moved to the new foundation and all the piping were finally connected.

Start up of the drive train

During start up, the compressor power consumption is reduced as shown in figure 16. It also shows the operating envelope for the compressor and the characteristic torque curves of the torque converter at various guide vane position.

Experience

As January 1999 the compressor has been in continuous operation for more than 22000 hours. The variable planetary gear has provided the necessary and accurate speed control with no problems. Vibrations have been below the specified limits. Bearing temperatures have been within the normal operating range. The only maintenance performed since June 1996 is the replacement of the lube oil filter inserts.

Conclusion

This retrofit has been in continuous operation since June 1996 and has fulfilled the requirements established by the customer:

- Increased gas flow
- Reduced regeneration period
- Reduced environmental fee
- Reduced maintenance cost
- Meet required schedule
- No torsional excitation
- Operation within the required speed and power range
- Simple reliable and efficient solution

It have been able to confirm that the justification of the project was right and there have been no major problem.
Bibliography


