Experience with Industrial Gas Turbines
Used in a 3 by 15,000-hp Gas Compressor Station

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The first three units of the improved industrial 15,000-hp gas generator GT35 were taken into commercial operation during 1970 in a gas compressor station for the Nederlandse Gasunie in Wieringermeer, the Netherlands. This paper gives a description of the equipment and deals with the experience from workshop tests, commissioning and commercial operation.


Copies will be available until January 1, 1973.
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NATURAL GAS TRANSMISSION SYSTEM

The construction of the transmission system from the natural gas fields in the northeast of the Netherlands was started in 1964 and today covers the whole of the country up to the borders of Germany, Belgium, and France where, in the export station, the transmission system of foreign customers are connected to the Dutch grid, Fig. 1. The main transmission system is designed for 67 bars pressure with a demand for 50 bars for export and 40 bars for the distribution networks, and the field pressure was sufficient for the gas transportation during the first five years. A study was made to establish the best way of increasing the system's capacity. This study included a computer simulation of the gas transmission system. An expansion can either be made by parallel pipelines or by increasing the gas velocity in the existing lines by compressor stations at certain distances, 60 to 90 km, and the study revealed that a combination of these two methods was the best solution. The first extension included four compressor stations. This paper will deal with one of these, the Wieringermeer station, which is a base load compressor station in the Ijsselmeer transmission line from Groningen to the areas of Amsterdam, the Hague, and Rotterdam.1

WIERINGERMEER COMpressor STATION

The Wieringermeer Compressor Station is located in a polder west of Ijsselmeer, and the station is planned for five compressor units, Fig. 2. A first step with three units was officially handed over on Nov. 27, 1970 and was immediately taken into operation.

Fig. 2 Compressor building with air intakes and oil coolers.

Fig. 3 Interior of compressor building.

from, the gas turbines. The building itself has no windows, and each turbine is surrounded by an acoustic hood to give acceptable noise level for the maintenance personnel.

The air filters are of the inertial type, and the chimneys have been provided with flaps, which close at a set time after stopping of the unit to prevent draught through the unit at standby and to prevent rainwater from entering the exhaust duct (Fig. 5).

The control building, some 300 m (1000 ft) from the compressor building, houses the control equipment, batteries, a 750-kw gas turbine driven standby set, air compressors, and office space.

Within the station area are buildings for fuel gas pressure regulating valves and metering, a fire station, and a 10-kv substation.

The present station increases the gas line capacity from $1.2 \times 10^6$ to $1.7 \times 10^6$ cu m/hr with a pressure ratio of 1.23 with two units in parallel. Two units in series give a maximum pressure ratio of 1.5. The set points are given from the Gasunie Dispatch Center at Groningen, and the station is planned for fully automatic unmanned operation.

GAS COMPRESSOR UNIT

The gas compressor unit consists of a 15,000-hp industrial gas generator, a two-stage, 5500-rpm power turbine, and a single-stage radial gas compressor. The gas generator and the power turbine are mounted on a special frame and delivered as one unit.

The gas generator is the redesigned GT35 of the twin-spool type, Fig. 6.

The ten-stage, LP compressor is driven by a two-stage turbine and the ten-stage, HP compressor, by a single-stage turbine. Shafts are coaxial, and bearings are of the tilting pad type for both axial and radial loadings. The seven combustion chambers are designed to give low thermal loading. The primary zone is lined with fin-cooled austenitic steel plates.

Starting is carried out by blowing compressed air through the engine from the LP compressor intake provided with an inlet casing with flaps which are closed during the starting cycle. Compressed air for the air injector is stored in a receiver at a pressure of 50 bars (715 psi). A pressure-reducing valve reduces the pressure to 12 bars (170 psi) before the injector.

The power turbine, designed for a nominal speed of 5500 rpm, has two disks flexibly mounted together as an overhang on the shaft, which is supported by two tilting pad radial bearings. The casing and stator blade rings are of the unsplit design, but rings and disks can easily be dismantled on site when the gas generator is removed.

The inlet guidevane is adjustable for trimming the flow capacity during test. The adjustment can be performed during a one-day stop.

The power turbine is connected to the gas compressor via a flexible tooth coupling.

The gas compressor is a conventional single-stage radial compressor using lubricating oil as seal oil for shaft sealing. The seal oil system has a gravity tank for emergency use and regulating valves to keep the proper ratio of gas to seal oil pressure during operation.

AUXILIARY SYSTEM

Safety precautions have dictated the design of the auxiliary systems. Explosionproof electric connection boxes and cubicles are used in the gas compressor building. Gas driven emergency pumps replace d-c motors, an extensive fire-fighting system with gas, smoke, and heat detectors has been installed, and all equipment, which can initiate fire, have been moved to the remotely located control building.

The lubricating oil system is designed for a nonflammable phosphate ester oil, which is used for the lubrication of all bearings, as well as for sealing of the gas compressor. Both the a-c driven oil pump and the gas driven emergency oil pump are duplicated for maximum availability of the system. The filters are of the full flow duplex type, making it possible to shift during operation. A small part of the oil flow is passed through a Fuller's earth-type filter.

The fuel gas system uses gas taken from the main line. The gas is cleaned in scrubbers, and the pressure is reduced to 15 bars (215 psi) before entering the governing valve.

Natural gas, at a pressure of 7 bars (100 psi), is also used for the ignition burners.

The governing oil system works with a pressure of 25 bars (355 psi). The system is split in two circuits, one for the overspeed trip device directly acting on the gas shutoff valve and one circuit for the operation of the governing valve.

The compressed air system is used for starting of the gas generator, operation of the chimney flaps, cleaning of the compressors, and for air supply to the ignition burners. The compressed air is stored in two receivers at a pressure of 50 bars (715 psi) and is then reduced to suitable pressure for the different types of use.

The cleaning system uses compressed air to force the cleaning agent into the LP compressor. To achieve good cleaning of the compressors, two types of cleaning agents are used — carbonblast and a chemical fluid. The agents are stored in two receivers and can be used either during operation of the unit or during blowing with a cold unit.

CONTROL EQUIPMENT

As the compressor station is intended for unmanned operation, controlled from the command center in Groningen about 70 miles away, the units are equipped with fully automatic control systems installed in 12 cubicles which are delivered completely wired and tested (Fig. 7).

Two units have identical systems. The third unit, which is the reserve unit, has a different valve arrangement, and, therefore, in some respects, a different control system.

The control system involves the following parts:

1. A sequencing system for fully automatic
start and stopping of the unit, including operation of all unit valves

2 A supervising system for giving alarms of certain conditions and shutting down the units on serious malfunctions

3 Measuring systems for turbine and compressor parameters

4 Turbine governing system

5 Compressor surge control system

A short description will be given of the different systems.

The sequencing system is built up with electromechanical relays of different types together with external equipment, such as motor starters, solenoid valves, temperature-, pressure-, level-, and limit-switches, and solid-state logic circuits involved in the measuring and governing systems, etc.

The supervising system separates faults of three different orders:

1 Order faults are serious malfunctions and trip the unit. Manual resetting is required for restart.

2 Order faults are, for example, faults in the starting sequence, which trip the unit, but resetting is automatically done when the fault disappears.

3 Order faults only give alarm. The common annunciation system indicates which fault was the first to come up.

The controls involve measurement of relevant turbine and compressor parameters, such as speed, temperature, and vibration. For measuring and supervision of the gas generator exhaust temperature, a new system was designed which measures the individual temperatures after each flame tube and compares them to each other and to the average temperature. Alarm and trip are given on certain temperature differences.

The thermocouples are placed downstream of the compressor turbines, and experience has shown that at certain loads, there is one step shift between the flame-tube position and the corresponding measurement. However, the indication of different temperature in any one flame tube is very distinct.

The turbine governing system is electrohydraulic with an electronic part for measuring and signal processing and a hydraulic servo. The electronic part is built up on printed circuit cards with integrated circuits and discreet components. Each circuit card comprises one function, e.g., acceleration control, speed control, etc.

The main control parameter is gas compressor speed, the setpoint of which can be adjusted either by means of an Increase-Decrease switch in the local control panel or can be given from the remote control. When the compressor station is finally completed, a computer will provide the speed set point from measurements of gas flow and pressure.

The surge control to prevent surging of the gas compressor operates a control valve in a bypass line between the compressor discharge line and the main suction line. The purpose of the valve is to take care of the gas flow during starting up before the discharge non-return valve opens and also to open if the operating conditions are approaching the surge line. The valve is pneumatically operated upon orders from an electronic controller, which forms a part of the electronic turbine governor. Contrary to the turbine governor, the surge control does not use a feedback from the valve, but no stability problems occur.

The starting sequence, which is automatically performed by the sequencing system, comprises the following main steps.

1 Prestart check: When everything is clear for start, a lamp is lighted.

2 Test of lubricating oil pumps thereafter...
the lubricating oil system is put into service. Start of LP rotor turning gear and filling of seal oil tank.

3 First pressurizing of the gas compressor casing.

4 At about half the nominal compressor casing pressure, the pressurizing is interrupted and the start sequence for the gas generator is continued with ignition and injection of starting air.

5 After acceleration to idle speed, Fig. 8, pressurizing of the compressor casing continues. At full pressure, the main suction and discharge valves open, and acceleration continues to PT 3000 rpm.

6 Loading: If the load command is remotely given, automatic loading to preset compressor speed will take place. In local mode, increasing of compressor speed has to be done manually by means of an Increase-Decrease switch.

The starting sequence is schematically shown in Fig. 9.

AUXILIARY POWER SUPPLY

Normally, the station is supplied from the commercial grid via a 10-kv transformer. On failure of the grid voltage, the 750-kv gas turbine driven standby generator is automatically started. Some essential loads, such as control system, main valves, etc., are fed with uninterrupted voltage from an "essential bus," connected to a "No break set," a rotating converter fed from large batteries.

For uninterrupted operation of the compressor units in the period between a power supply failure and the standby generator in service, the lubrication of the units is maintained by the gas driven lubricating and seal oil pumps for up to eight minutes, whereafter the units are shut down if there is still no power supply from the standby generator.

WORKSHOP TESTS

As both the gas generator and the power turbine were redesigned to a considerable extent, an extensive workshop test program was performed. The complete power train for all three units was tested against a water brake up to maximum output, and one gas generator was in addition tested against two fixed nozzles with slightly different areas.

The purpose of the test was to check the performance of the unit at different speeds on the power turbine, to determine the efficiency of individual components, and to check the mechanical behavior of the unit. A special stress and temperature measurement was carried out on the turbine blades and disks.

As much as possible of the auxiliary equipment was on test, and this also included the cubicles with the control system. As no natural gas was available at the test stand, the tests were performed on diesel oil which required replacement of burners and fuel manifolds.

The results of the tests showed that the flow capacities of the turbines compared with the predicted capacities were not fully achieved. The LP turbine was 7 percent and the power turbine was 9 percent to low. As the flow capacities of the HP and the power turbine can be adjusted, the best choice of turbine matching was to keep the LP turbine as it was, changing the HP turbine to -7 percent and the power turbine to nominal.

After these adjustments, the tested output was 7 percent higher and the specific heat consumption 2 percent lower than predicted, Fig. 10. Future gas generators will be matched to nominal flow capacities, which will give further gain in performance.

The gas compressors were manufactured by a Dutch company under a license agreement and were tested separately before the delivery to the site.

**Erection — Trimming — Commissioning**

The overall design of the station was made by the customer, who handed over the detailed engineering to a consultant specialist on gas pumping.

The compressor building was gradually completed step by step after erection of the largest machine parts, which had to be erected before the walls and the roof could be completed. This procedure caused some trouble in keeping the erection area clean enough for such precision work as alignment and erection of governing valves, shut-off valves, etc. It was also found that some components and some of the prefabricated piping were not sufficiently cleaned or protected for transportation and outdoor storage. This caused problems during trimming and commissioning in spite of a very careful flushing of respective systems.

Due to the fire regulations, the erection of all three units had to be finished before the gas came on to the station, and the testing of all three machines was carried on at the same time. Erection took little more than two months, testing and commissioning one and a half months.

In the electrical testing, the opening and closing of the explosionproof boxes and cubicles were, besides walking the rather long distance to the control building, the most time-consuming work. An intercom system with ear protections proved to be very useful.

**Operation**

The units were put into operation as soon as possible with two units in continuous operation during weekdays. Operating experience during the first operational season for two of the units has been fully satisfactory, while the third unit has suffered from two accidents, giving low availability as can be seen from Table 1.

The first accident to No. III unit happened after two months of operation when a conical bolt in the expansion joint between the LP shaft and the second disk in the LP turbine broke due to low cycle fatigue. The expansion joint is shown in Fig. 11 where the modification to a more flexible conical bolt has been indicated.

Unfortunately, the broken bolt found its way out to the gas path where it caused extensive damage to the blading in the power turbine. The unit was repaired and back in service in less than one month, and the other units have been modified in conjunction with planned outages.

The second forced outage was caused by a slowly increasing vibration amplitude measured on the gas generator. The unit was taken to the workshop and disassembled. Inspection revealed that the unit had suffered from quite severe corrosion on all lubricating oil-wetted surfaces and that the clearances for the two bearings which support the LP shaft inside the hollow HP shaft were a little too big. Apart from the damage to the bearings, the unit was in extremely good condition. The supplier of the nonflammable oil has now recommended a corrosion inhibitor to be added to the oil, and this necessitates disconnection of the Fuller's earth-type filters until a protective layer has been built up on all surfaces. The unit is now back in service, and the other two units have been
Table 1 Operating Statistics, October 1970 - July 1971

<table>
<thead>
<tr>
<th>Unit no.</th>
<th>I</th>
<th>II</th>
<th>III</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours of operation</td>
<td>1151</td>
<td>1297</td>
<td>1075</td>
</tr>
<tr>
<td>Number of starts</td>
<td>85</td>
<td>107</td>
<td>88</td>
</tr>
<tr>
<td>Installed hours</td>
<td>6570</td>
<td>6540</td>
<td>6642</td>
</tr>
<tr>
<td>Availability, percent</td>
<td>91.8</td>
<td>93.0</td>
<td>61.2</td>
</tr>
<tr>
<td>Reliability, percent</td>
<td>99.8</td>
<td>99.9</td>
<td>63.1</td>
</tr>
<tr>
<td>Use factor, percent</td>
<td>17.5</td>
<td>19.8</td>
<td>16.2</td>
</tr>
</tbody>
</table>

These figures include the trimming and commissioning periods.

The first hundred hours of operation revealed that compressor contamination was developing faster than expected. Inspection of the blading showed that they were oil-wetted and that the airborne dust in this polder area adhered to the oil-wetted surface. The oil emanated from the outlet from the oil vapor fan being located too close to the air intake. The oil vapor outlet was ducted to the chimney via a flame arrester, and this cured this problem.

The contamination of the compressors, however, revealed that the margin to the surge line for the LP compressor was not ample enough, and a few compressor surgings occurred during prolonged running at low idle for operation of the gas valves. The gas generator was provided with flanges at the design stage for bleed valves in the compressor intermediate casing, but these have never been utilized, as running in this speed band never occurs in an electrical power plant. All three units will now be provided with automatically operated bleed valves.

An initial hot section inspection after 1000 hr of operation has been performed on all three units, and the hot parts were in excellent condition. No signs of burning or carbon buildup were found, and the hot section inspections are now scheduled for every 3000 hr.

Although no definite noise measurements have been made with all units in operation, the impressions taken to suppress the noise have been successful. The acoustic hood over the gas generator reduces the noise level in the machine room to a level where almost normal conversation can be carried on.

CONCLUSION

The adaptation of the GT35 gas generator to a new application for gas compressor drive has been successful. The operating experience has been good but includes some teething troubles which have now been cured in all units.

The complete gas compressor plant has met all the requirements stated in the specification and will, no doubt, be a valuable contribution to the gas transmission extension in the Netherlands.

Fig. 11 Expansion joint with conical bolt