Gas Turbines as Prime Movers for High Pressure Water Injection

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INTRODUCTION

In 1960 an extensive study was conducted by Gulf Oil Corporation personnel concerning the economics of and the equipment to be used for the construction of the Goldsmith (5600') Field High Pressure Water Injection Station in Ector County, Texas. The volumes and pressures had previously been established, and the station was designed and constructed to meet these requirements. After several months of investigation, gas turbines and centrifugal pumps were selected. The purpose of this paper is to discuss and summarize the initial installation, subsequent modifications, and almost five years of operation of the plant and turbines.

INSTALLATION

In April 1961, three gas turbine engines were installed as prime movers to drive centrifugal pumps for a water injection station. They are variable speed, two-shaft engines with eight-stage rotary axial-flow compressors and are equipped for natural gas fuel. Figure 1 is a cutaway view of a typical gas turbine engine showing the component parts.

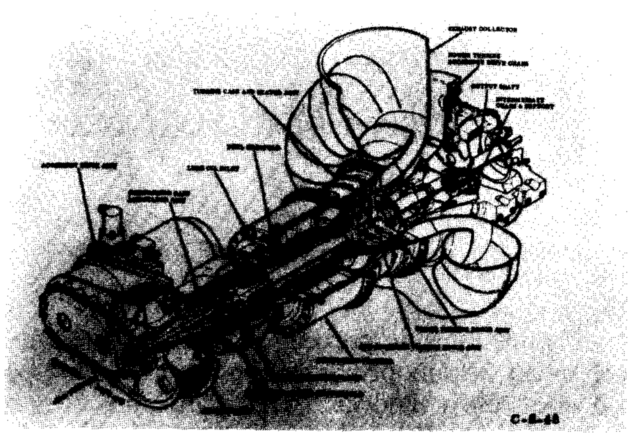

Fig. 1 - Cutaway View of a Two-Shaft Gas Turbine

The combustion chamber is basically a cylindrical doughnut-shaped assembly and is designed for axial flow operation. Although the gas producer turbine and power turbine rotors are contained in a single case, each rotates on a separate shaft. The gas producer turbine rotor consists of a two-stage drive that motivates the compressor rotor. The power turbine rotor consists of a single-stage drive that rotates the output shaft of the engine. Speed reduction gears are mounted inside the output housing of the gas turbine and have the necessary ratio to reduce the maximum turbine shaft output speed from 22,300 RPM to 3870 RPM. These engines are rated at 1000 brake horsepower at the station site elevation of 3140 ft above sea level and at an ambient inlet air temperature of 73°F. The total weight of each engine and attached accessories is approximately 1500 lbs.

In the original installation the turbines were driving six-stage, horizontal, split case, double volute, centrifugal pumps which were rated at 33,500 BWPD at 1200 psi pressure at a maximum speed of 3870 RPM. The pump cases were designed to withstand 2000 psi working pressure.

The Goldsmith Station is essentially an outdoor installation with only the controls being housed in a small building. Figure 2 shows a general view of the station. A small cubicle is built around each turbine to provide some protection from the elements and reduce the noise level. The cubicle can be seen in Fig. 3. Figure 3 also shows the combination air filter-cooler which is provided for each engine. The air is filtered by means of a screen which rotates through an oil sump and is cooled by an air evaporative type cooler. Also, the air-to-oil radiator assembly can be seen on the side of the cubicle, which provided cooling for the lube oil. The turbines and pumps have been unitized and mounted on oil field type skids. The engine [redacted] voir is contained in this sub-base. The foundation for these turbines and pumps consists of a reinforced concrete slab approximately 18-in. thick. The skids are bolted to the slabs.

Fig. 2 - View of Gulf's Goldsmith (5600') Water Injection Station

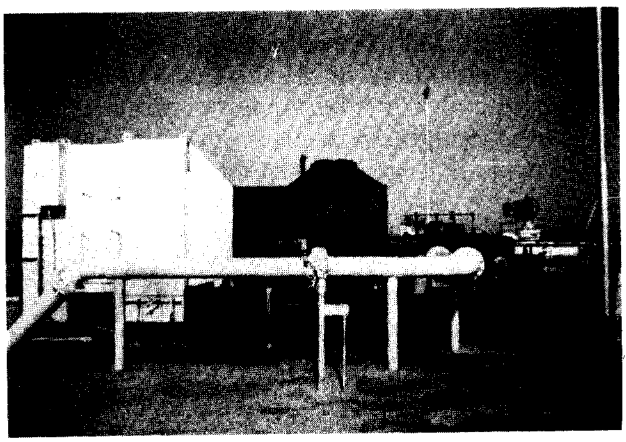

Fig. 3 - View of Single Unit Showing Air Filter-Cooler, Turbine, and Centrifugal Pump

Provisions have been made for future expansion by installation of additional units to charge the suctions of the existing pumps by a series arrangement of pumps and turbines to obtain discharge pressures of 2000 psi.

An electric motor-driven centrifugal pump station which is completely automated and unattended, delivers water some 38 miles to the Goldsmith 5600' Injection Station. The 5600' Station is also completely automated and unattended. The two stations are linked together by means of a telemetering signal which is transmitted by use of telephone lines.

Figure 4 shows the telemeter receiver, recorder, and transmitter. This instrument receives a signal of the water level in two 5000 bbl tanks which float on the line and are installed at the highest elevation on the water supply line. The water level is recorded on an 8-day chart so that a record is maintained. If the level in the tank falls below a pre-set safe operating level, a signal is transmitted to the station controller instrument and a shutdown is accomplished automatically. When the tanks reach a pre-set operating level, a start-up signal is transmitted to the station controller and automatic restarts are programmed. A run or no-run signal is transmitted to a 24-hour monitoring station in the District Office; and when shutdowns occur, operating personnel can be notified.

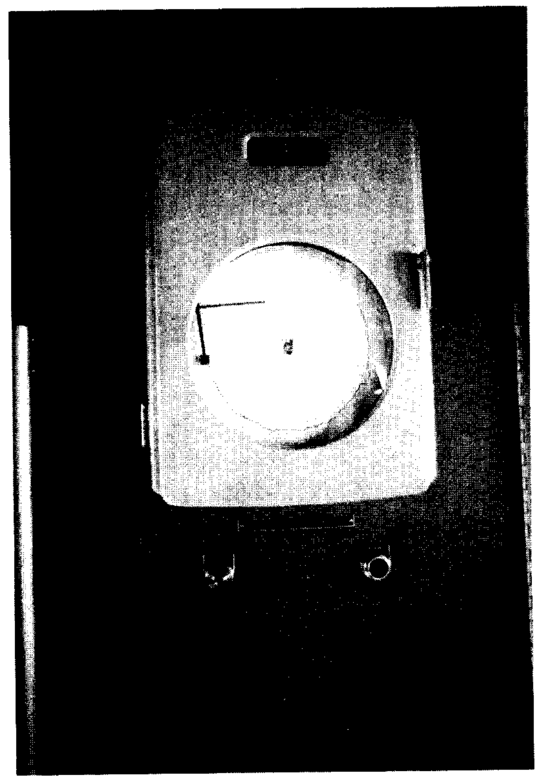

Fig. 4 - Telemeter Receiver, Transmitter, and Recorder

Figure 5 is a portion of the station control panel which provides the normal start-up and shut-down devices. This panel provides a schematic drawing of the sequence of flow throughout the station. The panel also includes safety shut-down devices such as low suction and discharge pressure, high pump case temperature, and turbine safety shutdowns. Safety shut-down light indicators are provided to assist in trouble shooting.

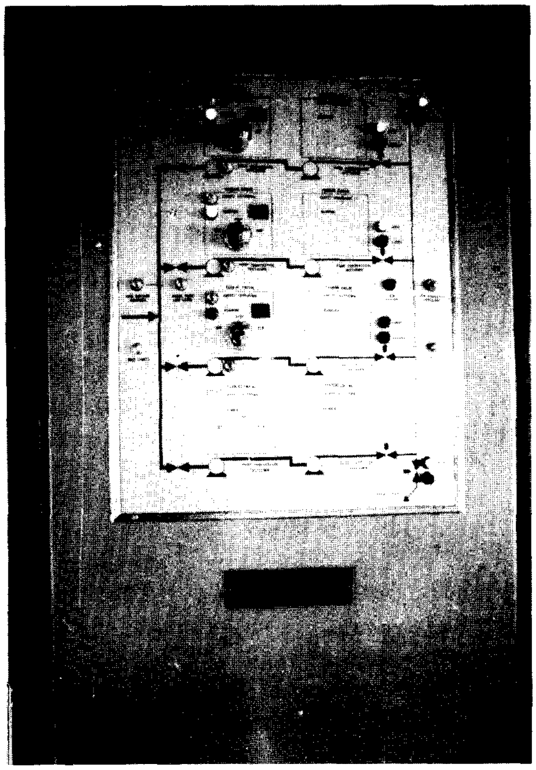

Fig. 5 - Station Controls with Schematic Drawing

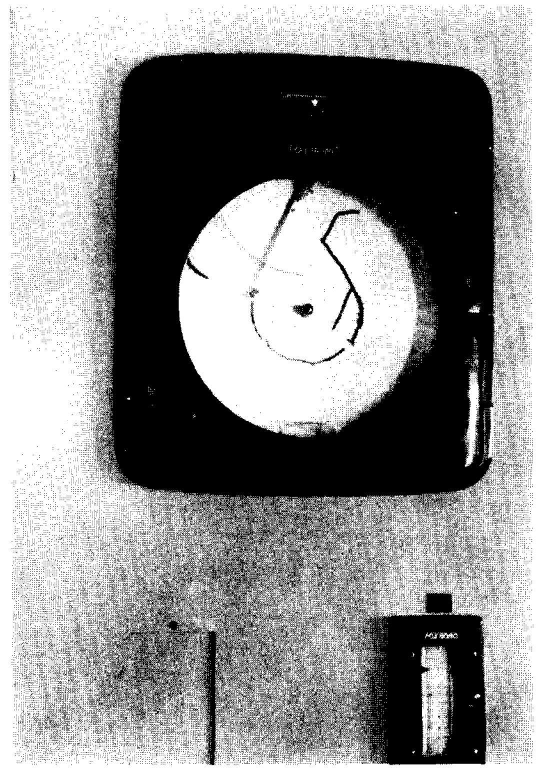

Fig. 6 - Station Master Controller Recorder and Individual Turbine Controller

Figure 6 is a photograph of the station master controller-recorder and individual turbine controllers. These instruments are pneumatically operated using instrument air provided by the compressor of the gas turbine. For example, if 90,000 BWPD is the required volume, the master controller pointer would then be set at this amount. One turbine would receive the signal to start, and run up to maximum speed, which is 22,300 RPM. If the volume being pumped by the first pump was not equal to 90,000 BPD, then a second turbine would receive the start signal. When indicated flow reached 90,000 BPD total, the master controller would, by pneumatic output signal, seek to divide the flow between the two pumps which were on the line. This is accomplished by the individual controllers receiving the same signal from the master controller and then transmitting the same signal to the diaphragm operated governor on the gas turbines.

Figure 7 is a photograph of the turbine control panel. This panel provides circuitry for the safety shutdown of the gas turbines, such as low oil pressure, excessive vibration, high oil temperature, excessive exhaust temperature, engine over speed, failure to start (after three attempts), and low gas pressure. A malfunction indicator light is provided for each safety shutdown device to assist in trouble shooting. A dual tachometer is provided in this panel to indicate the per cent speed of both turbine and pump. This is arranged by means of a toggle switch. Also, an exhaust temperature indicator is provided in the panel.

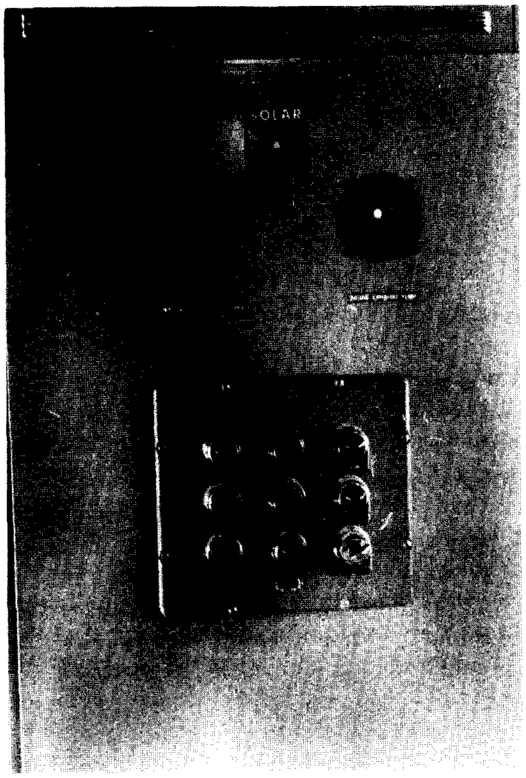

Fig. 7 - Turbine Control Panel With Safety Shut-Down Indicator Lights

The gas turbines were installed in conjunction with the station construction, and their cost cannot be separated from the total station cost. A fourth turbine and pump have been ordered, and it is estimated that the station cost will be approximately $138.00 per installed horsepower. This cost figure compares favorably with other types of centrifugal pump installations.

Gas turbines had been used to power generators and centrifugal pumps, etc., in other types of service; but this was one of the first industrial uses of American manufactured gas turbine engines in the 1000 HP range. The use of gas turbines for prime movers in high pressure water floods was relatively new at the time of this installation. The basic concept has proven to be sound, and the knowledge gained from this installation will be beneficial in the design of future plants.

MODIFICATIONS

Several modifications of the auxiliary equipment on the turbine have been made since initial installation. The air-to-oil radiator type heat exchanger, which can be seen in Fig. 3, require some modification. The oil was being cooled by a jack shaft-driven fan radiator arrangement. The shaft extended the width of the engine cubicle and was supported by three bearings. Numerous jack shaft bearing failures occurred in the first few months of operation. A hydraulic drive was installed to turn the lube oil cooler fan. The rotation of the fan on the side of the cubicle caused excessive vibration so the hydraulic system was replaced with a water-to-oil heat exchanger which is mounted on the outside of the cubicle next to the slab.

Excessive maintenance and repair cost resulted in a change from the original 24-volt starter-generator system to an air starter, which has given excellent service to date.

The prototype engine and gear box was built with output shaft speeds of 6000, 1800, and 1200 RPM. The pumps were designed to operate at a maximum speed of 3870 RPM. The pumps were to be operated using the 600 RPM output gear boxes until the turbine manufacturer could design and develop a new gear box for this particular application. The 3870 RPM gear box was put into operation; and after several gear box failures, a decision was made to exchange the 3870 RPM pumps for 6000 RPM pumps, which would match the already proven 6000 RPM gear box. These new pumps are three-stage, horizontal, split case, double volute, centrifugal. They are designed to deliver approximately 38,000 BWPD at 1200 psi discharge pressure when rotating at 6000 RPM's. The cases are also rated at 2000 psi working pressure, as were the six-stage pumps. Since installation of the 6000 RPM pumps in December 1964, most of this trouble was eliminated.

Since the above modifications have been made, maintenance and down time have been reduced. The gas producer section of the turbine has proven to be very reliable and rugged, although a bearing failure indicated a need for a change in the lubricating system. The combustion section also has proven to be trouble free.

CONTROLS

No major problems have developed in the design, installation, and operation of the automatic controls. Some of the advantages that make gas turbines adaptable to automation are:

(1) The turbine control panel requires only a simple "on" or "off" signal to initiate a start or stop.
(2) No warmup or cooling period is required when starting or stopping.
(3) The two-shaft design eliminates the requirement for a clutch and also allows complete flexibility in speed variation.
(4) Pneumatic instrument control air is provided from a take-off at the sixth stage of the turbine compressor; therefore, no separate air compressor is required.
(5) The turbine control system is operated from a 24-volt battery arrangement which allows operation to be independent of utility power.

FLEXIBILITY

The two-shaft turbine allows 100 per cent variation in speed. The original design of the station was based on individual pump requirements of 33,500 BWPD at 1200 psi with expected pump efficiencies of 80 per cent. The present three-stage pump offers practically the same pumping flexibility with slightly lower efficiencies and higher head characteristics. Current injection pressures are approximately 1000 psi, and each pump will discharge approximately 45,000 BWPD with an efficiency of 77 per cent.

FUEL CONSUMPTION

Fuel consumption at the 5600' Station is comparable to other types of gas engines in this type of service. Table 1 is a tabulation showing the actual fuel consumption data obtained on a single turbine-pump unit. The turbine from which this data was obtained had accumulated approximately 26,000 total operating hours and 2000 operating hours since engine overhaul. These tests were not made with laboratory precision instruments; therefore, minor errors may exist. The data is presented to give some indication of actual fuel consumption as compared with manufacturer's published figures. The data shown in Table 1 compares very favorably with those of the manufacturer.

COST OF MAINTENANCE AND REPAIRS

The first year the turbines were in operation, the manufacturer absorbed a large portion of the cost of the modifications and adjustments that have been discussed. Gulf also paid a portion of this cost in 1962 which amounted to approximately \$3700 in direct charges, or \$1.22 per installed horsepower-year. In 1963, the charges for direct labor (less superintendence) and replacement parts for repair and maintenance was \$10,976, or \$3.66 per installed horsepower-year. In 1964, the charges as mentioned above were \$17,070, or \$5.70 per installed horsepower-year; and in 1965 the charges were \$15,789, or \$5.25 per installed horsepower-year. Discounting the first year warranty, the average cost to operate these turbines over a three year period has been \$4.96 per installed horsepower-year. Based on this information, it appears that a figure of \$5.00 per installed horsepower-year can be expected. For the last three years (1963, 1964, and 1965), the three turbines have accumulated approximately 64,500 operating hours of a possible 78,840 hours for a station service-factor of .82.

CONCLUSION

As a result of Gulf's experience in the installation and operation of gas turbines as prime movers for high pressure water injection stations, the following conclusions can be reported:

(1) Installation of these gas turbines and unitization with centrifugal pumps can be made with very little difficulty. Only a fraction of the foundation is required for this installation as compared with other installations of this type using heavier equipment. Vibration of equipment and piping is practically eliminated.

(2) The cost to construct the station compares favorably with other stations utilizing different types of prime movers.

(3) Gas turbines are easily automated for unattended operation.

(4) The use of two-shaft turbines with centrifugal pumps provide good flexibility and a wide range of economic operation.

(5) Several operating problems were experienced, but modifications have been made and the station is operating satisfactorily.

(6) Fuel consumption compares favorably with other types of gas engines.

(7) Maintenance and repair costs have been slightly higher than anticipated, but the overall operation is economically attractive.

TABLE 1

Test Data—Goldsmith (5600') Water

Injection Station

Run No.[1]	1	2	3	4
Time — Hour	9:30	10:05	10:30	10:45
Suction Press. — Psig	90	90	90	90
Discharge Press. — Psig	775	780	750	730
TDH — Feet[2]	1,580	1,590	1,520	1,500
Volume — BWPD[3]	47,000	49,000	41,000	37,000
Gear Box Off — Per cent[4]	98	98	98	98
Pump eff — Per Cent[5]	71	70	75	77
Brake Horsepower	790	840	625	545
Pump Speed — RPM	5550	5800	5240	4975
Power Turbine Speed — RPM	20,650	21,550	19,500	18,500
Ambient Temp. °F	46	49	49	50
Fuel Gas Volume — Cu. Ft./Hr.[6]	11,800	13,000	9,800	9,100
Fuel Consumption — Cu. Ft./Brake Horsepower-Hour	14.95	14.50	15.70	16.70

1. All runs made 1-14-66 (A.M.) on Unit No. 2.
2. Specific gravity of water—1.0.
3. Water measurement made with orifice meter.
4. Gear box efficiency assumed.
5. Pump efficiency by manufacturer's pump curve.
6. Fuel gas measurement made with orifice meter.