Experience Gained in Operation of the GTS Finnjet Gas Turbines and Improvements in Ship’s Fuel Economy

This paper briefly describes the use of gas turbines of the GTS Finnjet, matters concerned with maintenance and repair as a result of four years’ experience (45,000 engine hours) in service, using light distillate fuel. The research and modifications required for changeover to blended residual fuel oils in gas turbines are then reviewed, as well as the first experiences (4,000 engine hours) in using the blended fuel oils during the summer of 1981. Finally we describe how the fuel economy was further improved by installing a diesel-electric machinery on the car deck to be used for manoeuvring and low season journeys.

INTRODUCTION

The gts Finnjet is a 30.5 knot gas turbine powered car and passenger ferry, ordered from Wärtsilä Helsinki shipyard at the end of 1973 by Enso-Gutzeit Oy, parent company of Oy Finnlines Ltd. The Finnjet has been designed for the Finnlines Baltic Route between Helsinki and Travemünde and entered service in May 1977.

Several different types of vessel and propulsion machinery were examined for this 600 nautical mile route during the design phase between 1969 and 1973. The most advantageous alternative was seen to be a fast, high capacity vessel which could be used very efficiently (departure every day at the same time, max. 1,560 passengers and 400 cars on board, 22 hours journey and two hours turnaround).

As main propulsion units aero-derived gas turbines (Pratt & Whitney type FT4C-1D) were chosen, mainly because of their small size, lightness and ease of shore based maintenance. Diesel machinery was not considered possible because the additional weight would consume an additional 6,600 kW. Moreover, that kind of installation would have been impracticable in a car ferry with a continuous car deck.

GAS TURBINE MAINTENANCE

There are no stated intervals for overhaul of the gas turbines. Repairs are carried out as required by engine condition.

The gas generator is constructed from easily exchangeable modules so that repair times are the shortest possible, and the best utilisation is attained.
The ship normally has four engines available for use, two installed and two spares. On account of the changeover to heavier fuel oil we had procured a fifth engine for operations in summer 1981.

Changing of engines at sea can be carried out if necessary in about two hours, during which time the vessel's speed is decreased by about six knots, and the effect on the ship's schedule is about 20 minutes in deep water. However, normally the engine changes are carried out in shallow water near Travemünde, and the effect on ship's schedule is only a few minutes.

If the engine inspection, maintenance, or fault repair lasts more than two hours, the engine is exchanged and the removed engine left in Helsinki for renovation.

WORKSHOP

The engine is taken into the Finnlines workshop, where it is dismantled sufficiently to remove the module or part to be repaired. After cleaning, inspection and repair the engine is reassembled using exchange modules and spare parts as required. A complete module exchange operation takes about 70 man hours.

Those removed parts and modules which we do not repair ourselves are sent to subcontractors to be refurbished. For example, high-pressure compressors and high- and low-pressure turbine modules are repaired at Helsinki in the Finnair engine overhaul shop.


Table 1

<table>
<thead>
<tr>
<th>Gas turbine Serial No.</th>
<th>Total time</th>
<th>Free turbine Serial No.</th>
<th>Total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>686 663</td>
<td>17,456</td>
<td>SB 600 549</td>
<td>21,211</td>
</tr>
<tr>
<td>686 664</td>
<td>13,012</td>
<td>BB 600 584</td>
<td>20,293</td>
</tr>
<tr>
<td>686 656</td>
<td>9,876</td>
<td>BB 600 030</td>
<td>3,547</td>
</tr>
<tr>
<td>686 561</td>
<td>2,639</td>
<td>BB 600 484</td>
<td>0</td>
</tr>
<tr>
<td>686 566</td>
<td>2,086</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TOTAL: 45,051</td>
<td>TOTAL: 45,051</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

An economical TBR of 3,000 hours for the gas turbines was established due to wear in the high-pressure compressor 9th stage midspan shrouds and low-pressure turbine 3rd stage blade notches.

As a result of this wear the blades become loose, which leads to higher wear rates. If not replaced for refurbishment, additional operation would increase the eventual scrap rate.

The engine manufacturer, United Technologies, is presently engaged in a program in connection with these problems, and modified 9th and 3rd stage blades are currently in service evaluation with Finnlines.

After four years in service the performance of the gas turbines was still quite satisfactory, as can be verified from figure 1. TT7 had increased 1.2 per cent, corresponding about 7°C at base load.

![Fig. 1 Deterioration of performance (eng. 686 664) during 4 years using distillate fuel.](image)

The free turbines have stood up to use as expected. The port unit has been exchanged once because of excessive wear in the No. 7 bearing outer race.

During the four years there had been 48 engine changes and four free turbine changes. There were in all 18 scheduled repair changes and 12 unscheduled repairs; changes as a result of heavy fuel oil testing numbered 6 and convenience changes 12. (See table 2.)

OTHER SHIP'S MACHINERY

Reduction gearbox:

In 1978 a large crack was found in the bull wheel between the hub and the tooth ring at the weld, and the bull wheel had to be replaced. Further, we found a tooth crack in the port side 2nd stage pinion and two cracks in the same stage on the starboard side.

Rudders:

As a result of faulty design the rudders eroded rapidly from the beginning. The cause was that the shaft bracket was set at a wrong angle which led to rudder cavities. Thereafter only small annual repairs were found necessary.

Automatic control:

No particular problems were found and the equipment worked rather well, only normal service being required.

Fuel control:

The Hamilton Standard electronic fuel control unit developed a few small faults each year which were repaired on board. During the whole period factory service was only required on one occasion.

FUEL OILS

In the first phase light fuel oil was used in gas turbines, the auxiliary diesels and the steam boilers. It was decided in 1979 that from the summer of 1981 washed blended fuel oil would be used in the gas tur-
Table 2

UNSCHEDULED REMOVALS AS A RESULT OF FAULTS IN GAS TURBINES

<table>
<thead>
<tr>
<th>Reason for removal</th>
<th>Fault</th>
<th>Part total time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Excessive spread of exhaust gas temperature</td>
<td>Microbic growth in fuel tank and clogging of filters in fuel nozzles</td>
<td>545</td>
</tr>
<tr>
<td>2. Blades damaged by loose part from inlet case</td>
<td>Piece broke off inlet case guide vane and was drawn into engine</td>
<td>2,352</td>
</tr>
<tr>
<td>3. Cracks in high pressure compressor 9th stage midspan shrouds</td>
<td>Blade manufacturing fault</td>
<td>530</td>
</tr>
<tr>
<td>4. As in 3 above</td>
<td>As in 3 above</td>
<td>496</td>
</tr>
<tr>
<td>5. Vibration in high pressure compressor</td>
<td>No. 2 thrust bearing failure</td>
<td>2,956</td>
</tr>
<tr>
<td>6. As in 5 above</td>
<td>No. 2 thrust bearing failure in same engine</td>
<td>858</td>
</tr>
<tr>
<td>7. As in 5 and 6 above</td>
<td>Fatigue failure in 11th stage blade root</td>
<td>3,200</td>
</tr>
<tr>
<td>8. Metallic chips in oil filter</td>
<td>Bearing failure in oil scavenge pump</td>
<td>14,503</td>
</tr>
<tr>
<td>9. External oil leak</td>
<td>Fatigue failure in oil pipe</td>
<td>7,339</td>
</tr>
<tr>
<td>10. Excessive oil consumption</td>
<td>Damaged oil pipe, No. 6 bearing</td>
<td>9,668</td>
</tr>
<tr>
<td>11. Excessive oil leak</td>
<td>Damaged carbon seal of 4 1/2 bearing. NA</td>
<td></td>
</tr>
<tr>
<td>12. Weak noise in low pressure compressor</td>
<td>Counterweight edge broke loose</td>
<td>15,660</td>
</tr>
</tbody>
</table>

The blended fuel oil used is a mixture of 20 - 30% light distillate and 70 - 80% of residual fuel with a viscosity of 230 cst/50°C. The alkaline metal salts will be removed from the residual fuel component at the Neste Oy Naantali refinery, using an electrostatic fuel washing system so that sodium and potassium content in the fuel is less than 0.6 mg/kg. The viscosity of the final blended fuel oil is below 50 cst/50°C.

The washed blended fuel oil is used in the gas turbines at cruising speed. Consumption is about 300 tons per day. Light fuel oil is used in gas turbines only for starting, manoeuvring, and stopping.

**FUEL SYSTEM**

At base load the temperature of the blended fuel oil is 100°C, the viscosity 8 cst, and pressure 48 bar in the fuel manifold inlet (Fig. 2).

Two boilers supply steam for fuel heating. Finnjet takes in heavy blended fuel oil at the Helsinki terminal, where there is a bunker station comprising 2 x 10,000 m³ heavy oil underground tank and a 1,000 m³ light oil tank.

Fuel bunkering takes one hour 20 minutes, and in summertime about 650 m³ is taken on board every other day.

**HEAVY FUEL OIL RESEARCH**

Research into the use of heavy oil in Finnjet gas turbines was begun about five years ago. We examined several different applications and systems but did not find one which we could have applied directly. We spe-
Table 3

<table>
<thead>
<tr>
<th>GTS FINNJET FUEL SPECIFICATIONS</th>
<th>ORIGINAL LIGHT DISTILLATE USED FOR GAS TURBINES</th>
<th>WASHEO BLENDED FUEL OIL USED FOR GAS TURBINES AT CRUISING SPEEDS</th>
<th>RESIDUAL FUEL OIL WILL BE USED FOR MAIN AND AUXILIARY DIESELS AND BOILERS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specification Test method</td>
<td>Specification Test method</td>
<td>Specification Test method</td>
</tr>
<tr>
<td>Sulphur, % wt</td>
<td>&lt;0.80 DIN 51 409</td>
<td>&lt;3.0 DIN 51400</td>
<td>&lt;3.4 DIN 51400</td>
</tr>
<tr>
<td>Distillation, °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 %</td>
<td>204 - 215 ASTM D 86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>90 %</td>
<td>282</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Flash point, F - M, °C</td>
<td>&gt; 56 ASTDM 93</td>
<td>&gt;60 ASTM D 93</td>
<td>&gt;56 ASTM D 93</td>
</tr>
<tr>
<td>Gravity, kg/m³</td>
<td>0.83 - 0.86 ASTM D 1298</td>
<td>&lt;0.93 ASTM D 1298</td>
<td></td>
</tr>
<tr>
<td>Viscosity, mm²/s</td>
<td>3.0 - 1.5 ASTM D 445</td>
<td>&lt;50 ASTM D 445</td>
<td>&lt;233 ASTM D 445</td>
</tr>
<tr>
<td>20 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>50 °C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cloud point, °C</td>
<td>&lt; 2 ASTMD 2500</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pour point, °C</td>
<td>&lt; 0 ASTM D 97</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carbon residue, Rams-bottom, %</td>
<td>&lt; 0.25 ASTM D 524</td>
<td>&lt;6.0 ASTM D 189</td>
<td></td>
</tr>
<tr>
<td>dist. residue, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conradson, %</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net heat comb., MJ/kg</td>
<td>41.9 ASTM D 240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sediment, mg/l</td>
<td>&lt; 10 ASTM D 2776</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Free water, mg/l + vol.</td>
<td>&lt; 60 ASTM D 3240</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water + Sediment, % vol.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ash, % wt</td>
<td>&lt; 15 ASTM D 482</td>
<td>&lt;400 EN 7</td>
<td>&lt;0.2 EN 7</td>
</tr>
<tr>
<td>mg/kg V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Metals, mg/kg Na + K</td>
<td>&lt; 0.2 IP 286/72</td>
<td>&lt;70 ASTM D 2788</td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>&lt; 0.6 ASTM STP 531</td>
<td>&lt;0.6 ASTM D 2788</td>
<td></td>
</tr>
<tr>
<td>Pb</td>
<td>&lt; 0.5 IP 224</td>
<td>&lt;5.0 (modified)</td>
<td></td>
</tr>
</tbody>
</table>

Cified the fuel requirements in collaboration with United Technologies, the engine manufacturer, and the fuel supplier (Neste Oy) on the basis of results obtained from the manufacturers' heavy fuel oil test engine and also Seatrain container vessel operations using blended fuel oil in similar gas turbines.

Subsequently problems connected with combustion, hot corrosion and build-up of ash deposits had to be solved. In our research, we enlisted the aid of a number of experts and laboratory establishments, and additionally carried out about 50 test runs on board over a two year period.

COMBUSTION

This kind of gas turbine was not designed specifically for use with heavy fuel oil, there was a risk that the combustion chambers would be too short and the flames would reach the turbine.

By improving the fuel atomisation, combustion time and flame length could be shortened and risks reduced.

In the Seatrain gas turbines, satisfactory results were obtained by adding water to the fuel, which, with the aid of a homogenizer, emulsifies with the water at high pressure (200 bar). With water thoroughly mixed in the oil droplets when heat is added in the combustion chamber, a so-called micro-explosion takes place, as a result of which the fuel droplet size diminishes greatly and the combustion time shortens.

In our case the procurement of a homogenizer and construction of a working system might have proved relatively expensive, as there was no proof of it being absolutely necessary. Also, there was some evidence of the water reacting adversely with some of the Mg-additives, causing deterioration of the additive compound and subsequent fuel nozzle clogging.

Using a different approach to improving atomisation, a new design of nozzles was used in the manufacturers' heavy fuel test gas turbine; atomisation being improved by the use of high pressure air (200 bar). These air-boost nozzles have been under test thus far for about 1,000 hours, and according to the manufacturer have been successful. Since the nozzles and asso-
cated systems are in the prototype stage, delivery would have been too long for us to consider. The fuel nozzles currently in general use have never been used extensively with heavy fuel oil but in the makers' opinion combustion and engine operation should be satisfactory providing that close control of the fuel and the necessary on board systems was maintained. Based on this, we decided to experiment with the original fuel nozzles. If the result had not proved satisfactory, we would have had to adopt either the homogenizer or air boost nozzle system.

The experiment succeeded and the experience gained thus far indicates that the original equipment combustion system can handle the blended fuel oil.

**HOT CORROSION**

In order to avoid hot corrosion, the melting point of turbine materials and ash deposits must be higher than the gas temperature (Fig. 3).

![Fig. 3 FT4C-1D turbine temperature profile at base load by UTI](image)

When using residual oils, hot corrosion will be caused by vanadium in the fuel (in addition to sodium and potassium salts). Based on other experiments it is known that vanadium corrosion can be completely prevented by using magnesium additive.

\[ V_4O_5 + MgO \rightarrow Mg_3(VO_4)_2 \]

The ash melting point of the resulting compound is then so elevated that there is no corrosion risk. The required amount of magnesium depends upon the vanadium content in the fuel. In the ideal situation a complete chemical reaction is achieved when the weight ratio of Mg/V is 0.72. From experimental results it is known that there is no corrosion of vanadium when Mg/V ratio is greater than 3.0. (Ref. Design and Technology of 80's, General Electric European Gas Turbine Seminar 1980.)

At this ratio, however, the build-up of deposits on the turbine parts would be so rapid that it would seriously impair the efficiency of the gas turbine. In lowering the ratio Mg/V to 2.0 the build-up rate is acceptable. The composition of the deposits is similar to that occurring when the ratio Mg/V was 3.0. In both cases the amount of corrosive compounds present (water soluble vanadates) was insignificant. During the summer we accidentally used a blended fuel oil (V = 65 p.p.m.) for 94 hours at a 1:1 Mg/V ratio. The mistake was a result of the oil supplier giving incorrect information as to the vanadium content. In the analysis of the deposits it was confirmed that the water solubility at this ratio was essentially worse than at 2:1 ratio. However, the quantity of corrosion caused by the water soluble vanadates was so small that a visual inspection only showed some slight traces of damage to the coating of turbine blades and vanes.

This confirms that using a 2:1 Mg/V ratio provides a sufficient safety margin in terms of vanadium corrosion.

**MAGNESIUM ADDITIVES**

The more generally used magnesium additives are Mg-sulphate (water soluble), Mg-sulphonate (oil soluble), and Mg-oxide or Mg-hydroxide (in suspension). The end result is similar whichever form of Mg additive is used in the fuel, but the nature of the existing fuel system imposes certain other requirements. For example, Mg-oxide causes blocking of depth-type filters and additionally leads to erosion of the fuel nozzles.

We chose the oil-soluble Mg additive (Kontol K 1-16), because it is simple to use and it should not have caused difficulties in other parts of the fuel system. The use of this additive, however, caused blockage of the fuel filters (Fig. 2, item 13) in less than 20 hours. After the additive had been cleaned by using 10 micron filtration, the fuel filter exchange interval was increased to about 60 hours.

Laboratory analysis showed that 60% of the material causing fuel filter problems was magnesium carbonate. According to the manufacturer of the additive the Mg-carbonate was created by the high temperature (128°C) of the steam heating coils in the additive tank on board.

The difficulties could be eliminated by using hot water (60°C) instead of steam for additive heating.

**GAS TURBINE MATERIALS AND COATINGS**

High hot corrosion resistance of base materials and coatings is one of the most important requirements in using residual oils. The materials and coatings mainly in use are:

| Table 4 |
| --- | --- |
| **BASE MATERIALS** | **COATINGS** |
| 1st blade | Inco - 792 |
| 2nd blade | Inco - 738 |
| 3rd blade | Inco - 738 |
| 1st vane | Mar-M-509 |
| 2nd vane | Mar-M-509 |
| 3rd vane | Inco - 738 |

**SALT REMOVAL**

Sodium negates the effectiveness of magnesium treatment.

\[ V_2O_5 + NaCl \rightarrow Na VO_3 + MgO \]

According to the manufacturers' research, sodium accelerates hot corrosion in accordance with the graph in Fig. 4.
United Technologies' recommendations for the maximum salt content allowed in the combustion reaction should be less than 1.0 p.p.m.

When the sodium content in the fuel is 0.6 p.p.m., only 0.05 p.p.m. is allowed in the suction air. The three stage demisters installed in Finnjet have kept the air salt content below this limit.

The salt content of blended fuels is 20 - 30 p.p.m. before washing. The separation process for removing salt from the fuel should have been technically acceptable for use on board ship, but the salt content specification was so stringent that the capacity of an on board washing system may not have been sufficient to maintain the specification limit.

In considering the investment and operational risks the savings achieved were not sufficiently large, so that we decided to carry out salt removal on shore.

**DEPOSITS**

The use of magnesium additives resulted in build-up of deposits on the turbine blades and vanes. This decreases turbine efficiency by about 4% during one journey.

In order to maintain the required power, fuel flow had to be increased accordingly, resulting in the exhaust gas temperature (TT7) approaching the maximum recommended value.

For this reason the build-up of deposit layers must be kept to a minimum and the efficiency restored to its former level by cleaning the turbine in port after each journey.

The deposit is mainly composed of magnesium sulphate (water soluble), the sinter point of which is so low that it bonds to the blade and vane surfaces.

In Fig. 5 there is a x 5,000 magnification of the 1st stage nozzle guide vane trailing edge, the sample being taken close to the blade material. The sintering can be verified from the necking between molecules.

In Fig. 6 the same sample is analysed using an ISI Mini-SEM-PGT 1000 X-Ray analyser. The vanadium content in the sample is particularly small although the vanadium content in the fuel oil was 43 p.p.m.

On the leading edge and concave surface of the 1st stage turbine nozzle guide vane there is a hard deposit which when dry is very difficult to remove. On the rear surface is a soft, loose, slightly greasy-feeling layer. The cooling holes in the vanes will remain open despite of deposit formation.

On the 1st stage turbine rotor blade leading edge and front side is an even thicker, very hard and dense layer. During running, part of the deposit will break free from the leading edge. The rear surface has a similar soft thin layer to that of the nozzle guide vane.

The deposition build-up on the 2nd and 3rd stage turbine blades and vanes occurs in a similar manner but at a much slower rate.
The following graphs (the best linear fit of experimental points) show the main trend of the deposition rate with different fuels (Fig. 7).

![Graph showing deposition rate with different fuels]  
**Fig. 7** Increase of exhaust gas temperature (TT7) using different kinds of fuels and additive/V ratios

The cut-off curve shows how the silicon additive affected the deposition rate. The best result was obtained when Si/V = 1.0 and Mg/V = 3.5. In using silicon the deposit was no longer water soluble and it was very difficult to remove from the surface of turbine parts.

When vanadium content in the fuel was increased from 43 p.p.m. to 70 p.p.m., the deposit formation was slightly slowed down. Deposition built-up rate is followed from the performance monitoring graphs (Fig. 8).

![Graph showing deterioration of engine performance during one journey using blended fuel oil]  
**Fig. 8** Deterioration of engine performance during one journey using blended fuel oil

Illustrated is a typical run using residual blended fuel (V = 70 p.p.m.). The exhaust gas temperature rises steeply at the beginning, then levels off to the end of the run. The N1 graph shows the low-pressure rotor and N2 the high-pressure rotor decrease in rotational speed. The fuel flow (FF) rises steadily and is at the end of the run about 6 litres/minute higher than at the beginning.

Following the water wash, the engine performance is restored to 99.90%.

Other problems caused by deposits

Test runs (450 hours) were carried out during the winter using the GG4C-1 gas turbine. At the beginning of the summer when we began to use the uprated GG4C-1D version turbines, two new problems arose:

1. Immediate turbine reacceleration after large power reductions could not be achieved because of the dirty turbine. After an idle running period of 1 - 3 minutes, operation returned to normal for the time being. There is a critical area just above the idle running speed where the engine will stall if it is accelerated too strongly. The electrical fuel control unit, which has a built-in acceleration schedule to prevent stalling, takes into account rotor speed (N2), exhaust gas temperature (TT7), and outside air temperature (OAT). The relationship of these parameters changes in a dirty engine, and the acceleration schedule does not allow engine acceleration without the idle running pause to allow cooling.

   In order to eliminate this delay the acceleration schedule was readjusted closer to the critical stalling area. This procedure improved the situation but the results were not entirely satisfactory and created a further problem in that the engine began to stall at the acceleration stage (as we had feared). This problem can be solved by accelerating the engine slowly in the critical area. In practice this is carried out by accelerating from idle speed using the gas turbine speed control until the critical area has been passed through, the propeller speed control then taking over, this being the normal manoeuvring mode.

2. The compressors of the GG4C-1D engines stalled strongly also during deceleration. The stalling was eliminated by readjusting the bleed valves which are sited between the high and low stage compressors.

**WATER WASH**

Deposits are automatically washed away in each port. Washing time is 20 minutes per engine.

During the washing procedure the free turbine is rotated by a geared motor, since without rotation only part of the rotor blades would be cleaned, thus causing excessive vibration at start up.

![Diagram showing location of high and low pressure water wash nozzles and drain pipes]  
**Fig. 9** Location of high and low pressure water wash nozzles and drain pipes
1. Washing in port is begun by cooling down the engine using the starter motor to rotate the engine.
2. During the cooling phase, two high pressure water wash nozzles are installed.
3. A high pressure piston pump and nozzles are used to jet a flat fan-shaped spray between two nozzle guide vanes and into the 1st stage rotor blades. The water pressure is 375 bar, temperature 60°C, and flow rate 140 litres/minute per nozzle.
4. Simultaneously the low compressor inlet is sprayed with hot water at a pressure of 5 bar and a rate of 120 litres/minute and the combustion chamber sprayed at 250 litres/minute. Detergents are used in cleaning the compressors.

Water wash will restore the engine performance close to clean engine condition. However, some of the deposits cannot be removed, and the engine performance will be gradually deteriorated as can be verified from the monitoring parameters shown in Fig. 10.

Table 5

<table>
<thead>
<tr>
<th>Gas Turbine Serial No.</th>
<th>Total Time</th>
<th>Total Time with BFO</th>
<th>Free Turbine Serial No.</th>
<th>Total Time</th>
<th>Total Time with BFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>686 663</td>
<td>18,375</td>
<td>919</td>
<td>SB 600 549</td>
<td>23,398</td>
<td>2,187</td>
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<td>686 664</td>
<td>13,752</td>
<td>740</td>
<td>BB 600 548</td>
<td>22,494</td>
<td>2,201</td>
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<td>686 656</td>
<td>9,970</td>
<td>94</td>
<td>BB 600 030</td>
<td>3,547</td>
<td>0</td>
</tr>
<tr>
<td>686 561</td>
<td>4,032</td>
<td>1,393</td>
<td>SB 600 484</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>686 566</td>
<td>3,310</td>
<td>1,242</td>
<td></td>
<td>TOTAL:  49,439</td>
<td>4,388</td>
</tr>
</tbody>
</table>

**MODIFICATIONS AND INVESTMENTS**

1. At the Finnjet bunker station a new recirculating fuel heating system and increased pumping capacity have been constructed.
2. On board Finnjet new tank arrangements have been made, more efficient heat exchangers and fuel filters procured, and a Mg-additive system and water wash system installed.
3. Two bosses have been welded in through the gas turbine combustion outer case to carry the high pressure nozzles during the water wash operation. Seven low pressure water nozzles have been permanently installed in the diffuser case. An enlarged drain pipe was fitted to the bottom of the free turbine exhaust elbow.
4. A spare gas turbine was purchased and the spare parts stock doubled.

**SUMMARY**

1. On the basis of our experience during the summer (over 4,000 engine hours) we are able to confirm that operation with blended fuel oils fulfilled our expectations, in other words, the reliability of the ship was maintained and profitability improved at a lower fuel outlay.
2. The period between engine exchanges is now reduced to 300 - 600 hours, the main problem being cleaning of the turbine 1st stage nozzle guide vanes because deposits cannot be entirely removed with the present washing system. Thus the efficiency of the turbine will gradually diminish. For this reason it is economically feasible to dismantle the turbines and clean them with high pressure wash at least every 4 weeks. Last summer we carried out 12 engine exchanges and the longest period between removals was 740 hours or 5 weeks.
3. In addition to turbine cleaning in our workshop, maintenance work was increased due to fuel nozzle cleanings and combustion chamber repairs. The fuel nozzle had to be cleaned every 700 hours because of the magnesium additive coking problem (see under Magnesium additives). Blockages in the fuel nozzles caused burning damages on combustion chamber walls which had to be patch repaired more often than before.
4. The oil soluble magnesium additives prevent vanadium corrosion at a ratio of Mg/V = 2.0.
5. The three stage demisters keep the suction air salt content below the allowable limit (0.05 p.p.m.).

6. The fuel system operated quite satisfactorily, except that the Mg-additive coking problem caused blocking of doublex fuel filters so rapidly that the filters had to be cleaned twice a day. After the coking problem had been solved, the situation improved considerably. In order to get reasonable service time for the fuel filters, we intend to double the filter capacity before next summer.

7. Based on the experience gained so far the maximum increase of expenditures for the year 1982 is predicted below in Table 6.

**Table 6**

<table>
<thead>
<tr>
<th>Cost factors</th>
<th>Increased expenditure</th>
<th>USD/BFO ton</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel heating</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Mg-additive</td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>GG-maintenance</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>GG-leasing</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>GG-spare parts</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td><strong>Totally:</strong></td>
<td></td>
<td><strong>16</strong></td>
</tr>
</tbody>
</table>

The fuel consumption has increased about 2.8% due to lower heat value of blended fuel oil, and about 2% due to turbine fouling. The desalting of residual fuel at refinery costs about USD 35/BFO ton. The blend used today consists of 23% distillate and 77% residual fuel. Based on the November 1981 prices (distillate USD 319/ton and residual USD 185/ton) the savings per ton of blended fuel oil were about USD 65.

**DIESELS FOR WINTER TRAFFIC**

The use of diesel-electric machinery is intended to improve Finnjet fuel economy during the low season when speed and power requirements are at their lowest. Under these conditions the gas turbines are at their least efficient. When high speed is required, gas turbines still offer the economical alternative because of their compact size and low weight; this is of particular importance on a passenger vessel, and for this reason the gas turbines will continue to be employed during the busy season when a voyage time of 22.5 hours has to be maintained. The new power plant will comprise two diesel-electric engines with an output of 5,700 kW each. These will be coupled to generators of 6,500 kVA capacity of 800 r.p.m. These generator sets will be placed in two separate engine rooms to be built into the aft part of the car deck. The generators will drive two propeller motors which will be placed in the turbine rooms. The propeller motors will be coupled to the original reduction gears via a SSS-type clutch and an additional two-wheel reduction gear. The generators and propeller motors will be water cooled. When using the diesel engines the vessel speed will be about 18.3 knots, and the crossing time between Helsinki and Travemünde will be about 36 hours.

The use of heavy fuel, to be burnt in the new, medium-speed diesel engines, together with their low specific fuel consumption compared with the low efficiency utilisation of the gas turbines, will improve Finnjet fuel economy markedly during the low season. Fuel consumption on a 36-hour one-way voyage, using the diesel engines, will drop by about 50%, although over the year the fuel saving achieved through the use of the diesel engines will only be about 15%.

**Fig. 11** General arrangement of the Finnjet diesel-electrical machinery
GTS FINNJET - TECHNICAL DETAILS

Main dimensions:

- Length, o.a.: 212.3 m
- Length, W.L.: 200.0 m
- Breadth: 25.4 m
- Draught: 6.5 m
- Draught at propeller: 7.2 m
- Depth to the 4th deck: 14.8 m
- Depth to the 7th deck: 23.2 m
- Displacement: abt. 16,500 m³
- Gross tonnage: abt. 65,000 m³
- Net tonnage: abt. 32,500 m³
- Gross tonnage: (24,605 register tons)
- Net tonnage: (10,786 register tons)
- Speed: 30.5 knots
- Deadweight: 2,825 tons

Passenger cabin spaces:

- A-cabin, 2 + 2 berths: 2 m² 156 cabins
- B-cabin, 2 berths: 8 m² 312 cabins
- C-cabin, 4 berths: 4 m² 74 cabins
- Lounge chairs: 268
- Passenger capacity: 1,650

Cargo capacity:

- Free height on car deck: 4.4 m
- Free breadth at bow ramp: 4.5 m
- Free breadth at stern ramp: 5.0 m

Cargo alternative A:

- Lorries: 34
- Buses: 4
- Cars: 140

Cargo alternative B:

- Lorries: 23
- Buses: 5
- Cars: 225

Cargo alternative C:

- Cars: 400

Propulsion machinery

- 2 gas turbines, Pratt & Whitney FT4C-1DLF
- Output: 2 x 27.5 MW (2 x 37,500 hp)
- Rate of revolution: 63.3 m⁻¹ (3,800 r.p.m.)
- Fuel consumption: 274 kg/MWh (200 g/hph)

- 2 reduction gears, Lohmann & Stoltterfoht GUY 7733, 2-step, equipped with 2 disen-gaging couplings
- Reduction ratio: 22.245 : 1

- 2 controllable pitch propellors, KMW 179 s 1/4
- Diameter: 5.0 m
- Rate of revolution: 2.85 s⁻¹ (171 r.p.m.)

Computer control of the gas turbine and measuring and alarm equipment by AEG Schiffbau
CONCLUSIONS

Development of passenger traffic

Finnlines formerly had two vessels in service on this route, and in 1976 the two ships together carried 73,000 passengers.

Finnjet has carried 817,000 passengers during the last four years, and for example in 1979 the number of passengers was 237,000 and additionally 30,300 vehicles were carried. In summertime about 75% of the travellers are from Central Europe.

The ship operated at a capacity of 75% in 1980, and in the summer of 1981 an about 85% utilisation of the ship’s capacity was reached. This corresponds to an average of 1,200 passengers per departure.

Gas turbines

The experience gained in operating gas turbines over the last four years has been quite satisfactory and completely fulfilled our expectations from the operational reliability and maintenance aspects. However, we are not satisfied with the high fuel costs incurred in operating at low speeds during off season so that the use of light distillate in the gas turbines has not been economical.

Fuel economy

The only real problem that we have encountered with Finnjet has been the fuel economy. To improve this aspect of operation, the less expensive blended fuel oils have been used since the beginning of summer 1981. Also the ship's schedules were reorganised in accordance with overall expenditure so that the number of journeys has been reduced by 44. Thus in 1982 about 220 one-way journeys will be made.

When the diesel engines ordered for off season operation are installed in the autumn of 1981, the CODEOG Finnjet (combined diesel or gas turbine) will be equipped to keep pace with the changes in passenger traffic requirements as well as possible.