## 1. Introduction

Gas turbines in combined cycle plants face a more and more rough operation with daily starts and stops and power varying depending on renewables production capacities. On the other hand, the technology must still improve to challenge the highest efficiencies possible with very low emissions.

Technology risks are more and more often controlled by remote condition monitoring, as there is only two scores of people employed on site on a 3 shifts basis. When a risk appears on the remote condition monitoring screens, the first demand made is to have a look on the incriminated piece of hardware: a borescope inspection. Delays to stop, cool down the gas turbine, secure the rotating parts and the borescope operator path to the borescope holes take one full day, which means that a borescope inspection demand a prolonged week-end stop with an unavailability penalty. This seems quite too long when thinking to today's robotised technologies.

## 2. Project structure:

It is proposed to estimate what will be the cost of an automated borescope inspection which can be done within three to four hours after stopping the gas turbine, rotor secured and casings still hot. Such a delay makes possible an overnight stop inspection and gains many days on decision making. For that a research programme has to be launched with:

- ❑ Review the safety rules for stopping the gas turbine and borescope inspections.
- ❑ Design of a remote operated borescoping system located in the enclosure.
- ❑ Development of higher temperature borescope design and interface it to the condition monitoring.
- ❑ Analysis of borescope pictures with reference to former pictures for deterioration detection and growth.
- ❑ Manufacture and tests of such systems on two or three gas turbines (or steam turbines).

## 3. The state-of-the-art and beyond:

The main steps of a borescope inspection could be :

- Press the stop button

From GER 3658d : *Normal shutdown is initiated by the operator and is reversible until the breaker is opened and the turbine operating speed falls below 95%. The shutdown sequence begins with automatic unloading of the unit. The main generator breaker is opened by the reverse power relay at about 5% negative power, which drives the gas turbine fuel flow to a minimum value sufficient to maintain flame, but not turbine speed. The gas turbine then decelerates to about 40% to 25% speed, where fuel is completely shut off. As before, the purpose of this "fired shutdown" sequence is to reduce the thermal fatigue duty imposed on the hot gas path parts.*
*After fuel is shut off, the gas turbine coasts down to a point where the rotor turning system can be effective. The rotor should be turned periodically to prevent bowing from uneven cooldown, which would cause vibration on subsequent startups. Turning of the rotor for cooldown or maintenance is accomplished by a ratcheting mechanism on the smaller gas turbines, or by operation of a conventional turning gear on some larger gas turbines. Normal cooldown periods vary from five hours on the smaller turbines to as much as 48 hours on some of the larger units. Cool down sequences may be interrupted at any point for a restart if desired.*

- Cool down the rotor (5 to 48 hours). A typical gas turbine stop sequence is shown in annex 1.
- Open the enclosure doors when Gas turbine inner temperature is bellow 60 °C.
- Secure the gas turbine.
- Scafold the place to access to the desired endoscopic locations.
- Unbolt and gain access to the inner parts of the gas turbine.
- Position the borescope and make photos of parts. Recommendations to do borescope inspections on a GE LM 2500 are in annex 2.
- Report the findings.
- Rebolt and unscafold.
- Check every thing is in the right order and close the enclosure door.
- Restart.

Today a borescope inspection is conducted by a technician who must access to the borescope hole on the casing. Safety instructions demand that:

1. Not to open the enclosure doors when the gas turbine is hot as it might rapidly cools down the compressor casing endangering the compressor blades which might then rub or be compressed.

2. Not to access to the hot casings for men without wearing with adequate equipment if casing temperatures are over 40 °C.

First question coming to that point is how long does it take to cool down the gas turbine and what is the criteria not to be exceeded to avoid rotor bending? Is there any other issues when stopping the engine?

Second question is how a robot can access to the borescope hole :

1. Could we have something which is always in place?
2. Can the environment (surrounding) be adapted and how much?
3. Should the robots be completely autonomous or tele-operated?
4. What are the temperatures in the enclosure when the GT is operating?
5. What is the geometry, the path the robotics has to follow?

For the project, it is felt that a specific engine type and borescope port locations should be selected. The participants agree to design the system around the TBD (EDF proposal might be Alstom GT13E2 combustor and turbine to be confirmed). Exemples of typical damage tracking should be available.

Borescope manufacturers propose solutions to inspect at high temperatures depending on the size of the access holes in the casing and the one of the borescope. On a gas turbine access diameter is around ten millimeters just a few millimeters over borescope diameter. From ITC's Web site they have developedoptics which can sustain 170 °C. What are the best available technologies in that field ?

Finally, as the borescope pictures are taken fully automated, it seems to be efficient to collect them in the plant monitoring system and develop comparative analysis of the last picture to the preceding ones in order to show if any degradation develops. Information technology have already been developed for other problems but will have to be further adapted to borescoping images constrains.

3D or broad spectrum imaging is not the priority of the project but the enhancements they can bring could be assessed.

## 4. Project justification:

Annex 3 shows the gains advertised by Siemens on a test to do hot borescoping. This practice is not validated by this manufacturer.

Overnight borescoping will save many troubles and keep running some plants especially when power is needed. This has a strong impact on availability and flexibility of plants.

If borescope inspections can be made more quickly, they can be done more often and a newly detected defect might be followed by weekly/monthly borescope inspections with automated picture treatment and condition monitoring storage.

If a cheap system is developed, many gas turbines and steam turbines might be permanently equipped which means quite a strong market for endoscope and robot system manufacturers.

## 5. Research and Demonstration Tasks

Here are proposed seven tasks in order to show the possible improvements with the help of a prototype system :

1. **<u>Automated borescopic inspection process</u>** :

    a. Collect and check for security rules

b. Insert borescope inspection into gas turbine stop process
c. Check for when to borescope, how long, when to again cool down the rotor ...

2. **Robotics requirements** :

    a. Location and details to be monitored
    b. Borescope port location and design
    c. Inner details of enclosure
    d. Robotics location when not in use
    e. Robotics path and mouvements
    f. Degree of tele-operation

3. **Borescope design** :

    a. From task 1 & 2 define cooling system and time of stay at X °C temperature.
    b. Define optical system
    c. Agree on image output format with task 5

4. **Robotics design** : from requirements delivered by task 2

5. **Collect image, store and analyse** :

    a. Standard image processing
    b. Assessment of 3D and broad spectrum images gains

6. **Specimen manufacture and rig tests** :

7. **Prototype system manufacture and test** (on a gas turbine in cold conditions then in hot conditions)

## 6. Duration and budget:

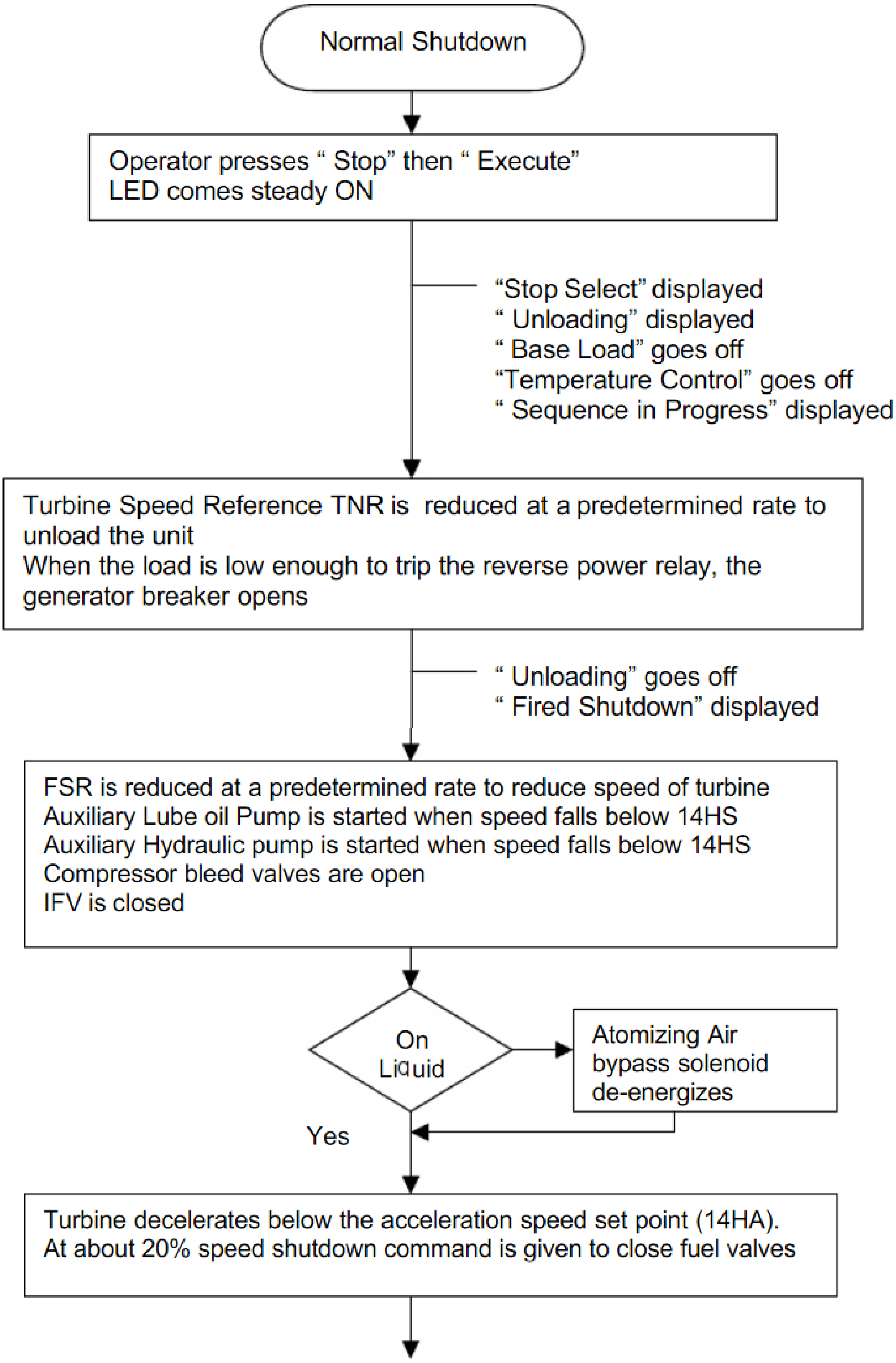
This is a first draw of a tentative plan for the project which could last almost 3 years.

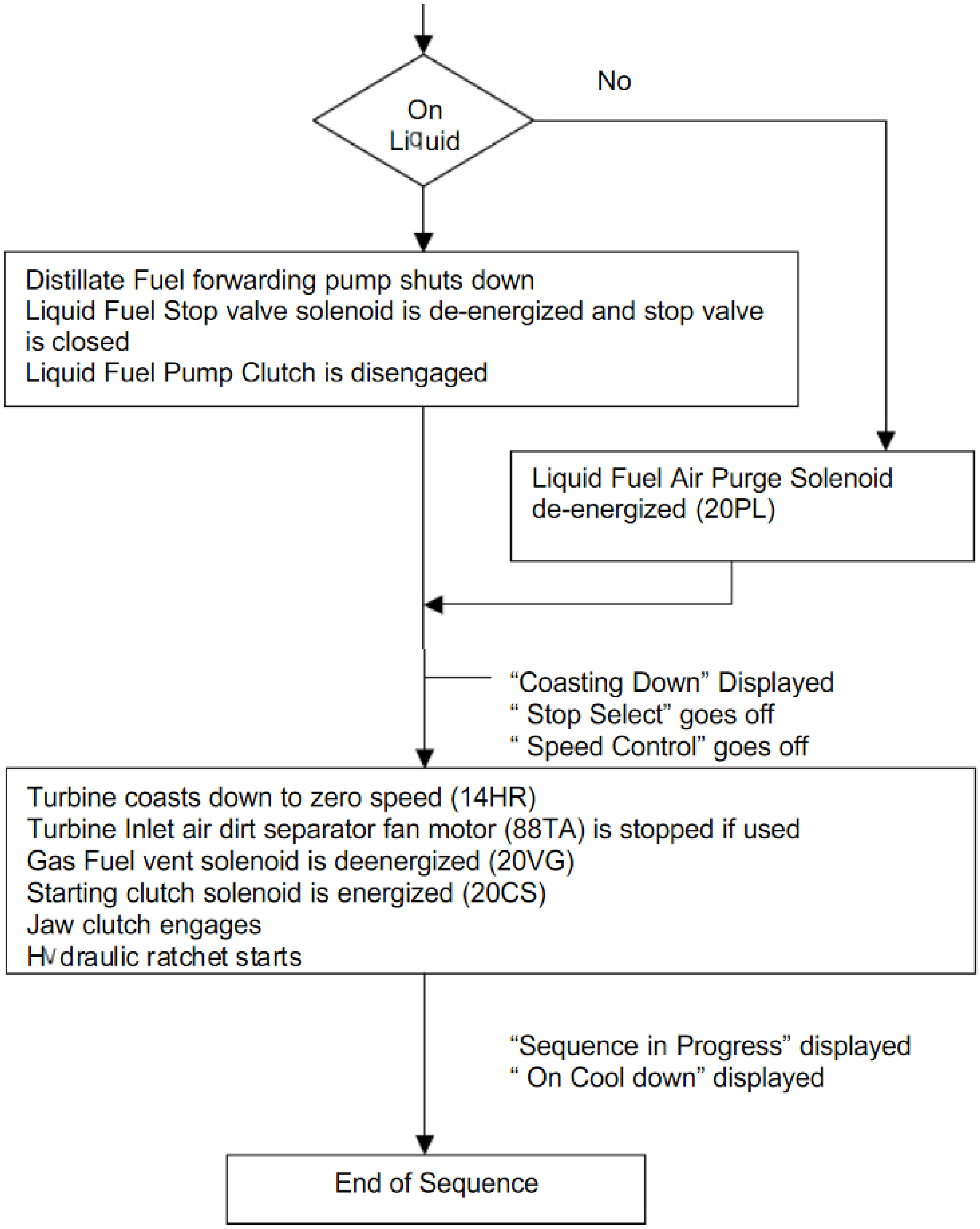
| Task N° | Trim 1 | Trim 2 | Trim 3 | Trim 4 | Trim 5 | Trim 6 | Trim 7 | Trim 8 | Trim 9 | Trim 10 | Trim 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 process | | | | | | | | | | | |
| 2 requirements | | | | | | | | | | | |
| 3 borescope | | | | | | | | | | | |
| 4 robot design | | | | | | | | | | | |
| 5 image process | | | | | | | | | | | |
| 6 rig test | | | | | | | | | | | |
| 7 prototype | | | | | | | | | | | |

## 7. Ideal Consortium

It should be a common programme in between some operators, OEM and second source provider and borescope manufacturers. University will participate to bring the research and technology developments which are necessary to get to the target especially on robotics and image processing.

## ANNEX 1 : stop sequence 6FA




On Liquid
No
Distillate Fuel forwarding pump shuts down
Liquid Fuel Stop valve solenoid is de-energized and stop valve is closed
Liquid Fuel Pump Clutch is disengaged
Liquid Fuel Air Purge Solenoid de-energized (20PL)
"Coasting Down" Displayed
" Stop Select" goes off
" Speed Control" goes off
Turbine coasts down to zero speed (14HR)
Turbine Inlet air dirt separator fan motor (88TA) is stopped if used
Gas Fuel vent solenoid is deenergized (20VG)
Starting clutch solenoid is energized (20CS)
Jaw clutch engages
Hydraulic ratchet starts
"Sequence in Progress" displayed
" On Cool down" displayed
End of Sequence

# ANNEX 2 : Borescope instructions on a LM2500

From http://members.shaw.ca/planet-e-tech/preview_gt_maint.pdf

**BORESCOPE INSPECTIONS**

Borescope inspection requirements and procedures are found on the maintenance requirement card (MRC). These cards contain all the basic information necessary to conduct an inspection. Included on the MRCs are the serviceability limits and a list of conditions that require an inspection. Borescope inspections are usually performed semiannually or when the engine has been operated beyond the allowable limits listed on the MRC.

The following section discusses the borescope procedures used to inspect the LM2500 GTE. The inspection procedures and the knowledge gained from damage evaluation may also be applied to the borescope inspection of the Allison 501-K17 GTE.

**GENERAL INSPECTION PROCEDURES**

It is a good engineering practice to review the machinery history of an engine before you conduct an inspection. Various component improvement programs will eventually affect all engines in service. A rebuilt or modified engine may contain improved parts that differ from the original. An example of this is the first-stage compressor midspan damper that may have its original coating, an improved coating, or a carboloy shoe welded on at the midspan damper interface. If you review the machinery history, you will discover the status of those parts that have been changed or modified. Assuming that the engine history is normal and FOD is not suspected, you should be aware of the following factors when conducting a borescope inspection:

- Know your equipment.
- Locate all inspection areas and ports.
- Establish internal reference points.
- Scan the inspection area thoroughly orderly manner.
- Note any inconsistencies.
- Evaluate the inconsistencies.
- Report your conclusions.

**GEOMETRIC ORIENTATION OF THE ENGINE**

To communicate information about an engine inspection, you must establish a geometric frame of reference for the engine assembly. A language for describing the physical damage is also necessary.

When the probe is in the inspection hole, it is not unusual for you to lose your sense of direction. On the Wolf borescope, the large plastic disk just beneath the eyepiece has an index mark that shows the direction the probe object window is facing. You can feel and see this mark. Another reference you can use to detect the direction the object window is facing is the light cable attachment. On the Wolf and Eder probes, the viewing window is 90 degrees clockwise from the light cable, as shown in figure 2-4. In the future, borescoping equipment may have changes incorporated that significantly improve the inspection equipment. Newer models may incorporate a swiveling light cable that allows the cable to hang down regardless of the viewing direction. You must read the manufacturer's instruction manual before you can successfully use the equipment. Figure 2-5 is an example of how the engine and borescope geometry work together. It shows you how the borescope appears when looking forward and aft from the right side of the engine or from the left side of the engine.

**BORESCOPE PORTS**

Table 2-2 is a description of the ports and the areas that you can see from each borescope port.
Figure 2-7 shows the locations of the different borescope ports on the ge LM2500 gas turbine.

**Compressor**

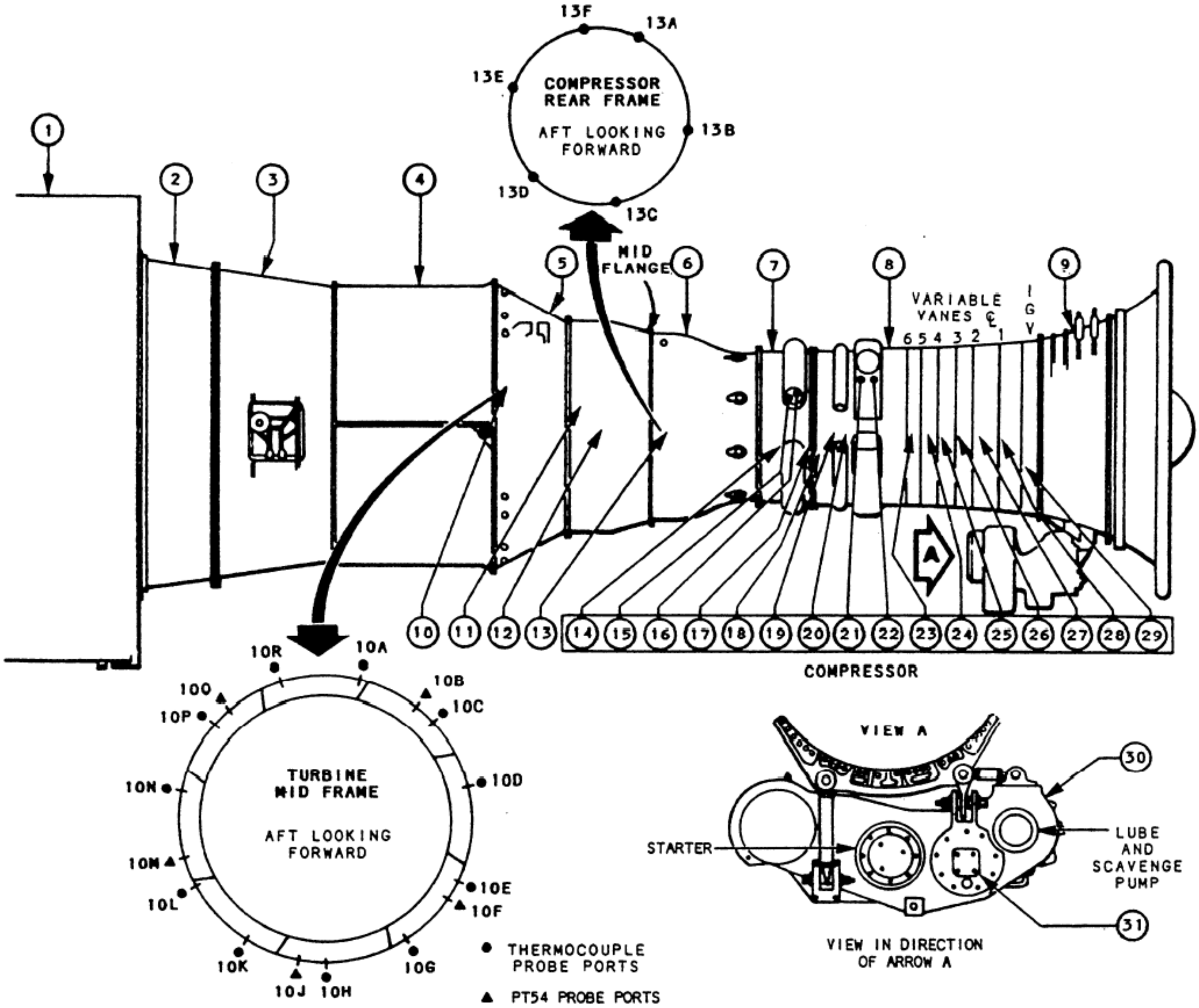
Fifteen borescope inspection ports are in the compressor near the 3 o'clock split line. A port is located at every compressor stator stage. These vane ports start at the IGVs and work aft in the same direction as the airflow (except for stage 8, which is internally blocked). Stator stages 9 and 13 borescope ports require you to remove piping interferences.

Table 2-2.—Area Visible From Borescope Inspection Ports

| PORT IDENTIFICATION | PART/AREA ACCESSIBLE FOR INSPECTION |
|---|---|
| 29 | Two Inlet Guide Vane Airfoils |
| 28 | Stages 1 and 2 Compressor Rotor Blades and two Stage 1 Stator Vane Airfoils |
| 27 | Stages 2 and 3 Compressor Rotor Blades and two Stage 2 Stator Vane Airfoils |
| 26 | Stages 3 and 4 Compressor Rotor Blades and two Stage 3 Stator Vane Airfoils |
| 25 | Stages 4 and 5 Compressor Rotor Blades and two Stage 4 Stator Vane Airfoils |
| 24 | Stages 5 and 6 Compressor Rotor Blades and two Stage 5 Stator Vane Airfoils |
| 23 | Stages 6 and 7 Compressor Rotor Blades and two Stage 6 Stator Vane Airfoils |
| 22 | Stages 7 and 8 Compressor Rotor Blades and two Stage 7 Stator Vane Airfoils |
| 21 | (Blocked) |
| 20 | Stages 9 and 10 Compressor Rotor Blades and two Stage 9 Stator Vane Airfoils |
| 19 | Stages 10 and 11 Compressor Rotor Blades and two Stage 10 Stator Vane Airfoils |
| 18 | Stages 11 and 12 Compressor Rotor Blades and two Stage 11 Stator Vane Airfoils |
| 17 | Stages 12 and 13 Compressor Rotor Blades and two Stage 12 Stator Vane Airfoils |
| 16 | Stages 13 and 14 Compressor Rotor Blades and two Stage 13 Stator Vane Airfoils |
| 15 | Stages 14 and 15 Compressor Rotor Blades and two Stage 14 Stator Vane Airfoils |
| 14 | Stages 15 and 16 Compressor Rotor Blades and two Stage 15 Stator Vane Airfoils |
| 13 | Combustor, Fuel Nozzles, and Stage 1 HP Turbine Nozzle |
| 12 | Stage 1 HP Turbine Rotor Blades and two Stage 1 HP Turbine Nozzle Airfoils |
| *11 | Stages 1 and 2 HP Turbine Rotor Blades and two Stage 2 HP Turbine Nozzle Airfoils |
| 10 | Stage 2 HP Turbine Rotor Blades, Stage 1 LP Turbine Blades and Vanes, Turbine Mid-Frame Liner, and $T_{5.4}$ Thermocouple Probes |

**Combustor and HP Turbine**

Aft of the right-hand side compressor ports are six circumferentially positioned ports, just forward of the mid-flange of the compressor rear frame. From these ports you can inspect the combustor, the stage 1 HP turbine nozzle assembly, and a few fuel nozzles. Near the aft flange of the compressor rear frame on the right-hand side of the engine are two HP turbine stator ports that you can use for viewing the air-cooled turbine blades. The $P_{t5.4}$ pressure probe harness adjacent to the after flange of the turbine mid-frame is located aft of the stage land 2 turbine ports. Five pressure probes are located circumferentially around the turbine mid-frame at the inlet to the LP turbine. All five probes (fig. 2-8) extend radially into the gas path and can be removed to inspect the LP turbine inlet and the HP turbine exhaust.




1. Exhaust Duct
2. Outer Cone
3. Turbine Rear Frame
4. Turbine Case
5. Turbine Mid Frame
6. Compressor Rear Frame
7. Rear Compressor Casing
8. Front Compressor Casing
9. Compressor Front Frame
10. Turbine Mid Frame Ports
11. Compressor Rear Frame Port
12. Compressor Rear Frame Port
13. Compressor Rear Frame Port
14. Stage 15 port
15. Stage 14 port
16. Stage 13 port
17. Stage 12 port
18. Stage 11 port
19. Stage 10 port
20. Stage 9 port
21. Stage 8 port
22. Stage 7 port
23. Stage 6 port
24. Stage 5 port
25. Stage 4 port
26. Stage 3 port
27. Stage 2 port
28. Stage 1 port
29. Stage 0 port
30. Transfer Gearbox
31. Drive Pad Cover Plate

Figure 2-7.—Borescope inspection ports.

**INDEXING AND ROTATING THE ENGINE**.

You can rotate the engine by using a socket wrench pad with an 18-inch long 3/4-inch drive extension. You attach the 3/4-inch drive extension after you remove the cover plate on the aft face, right-hand side of the accessory gearbox, next to the lube and scavenge pump accessory gearbox. When you are inspecting through the forward-most borescope ports, there is not enough space for both you and the person turning the engine to work. This requires you to do the turning yourself or to have the turner rotate the engine from the other location on the accessory gearbox. You can find the alternate drive pad for manual engine turning on the forward face, left-hand side of the accessory gearbox.

Detailed procedures are provided for indexing and rotating the engine on the MRC. Zero reference for the compressor and HP turbine stages is established by use of the locking lug blades. Establishing the zero reference ensures a complete inspection for each stage. It also provides you an immediate circumferential reference point for distress reporting for each stage. You should not concentrate on counting the blades. Instead, concentrate on the specific condition of each airfoil as it passes. The forward and aft drive pads have different drive ratios to the main rotor shaft. You may find it advantageous to use a torque multiplier to slow down and maintain better control over the main rotor speed.

Depending on the manual drive setup, you will be able to establish how many full arcs of the ratchet wrench are required to move the main rotor one full revolution. For example, when you are using the forward pad, a 344-degree revolution of the input drive equals 360 degrees on the main rotor.

## ANNEX 3 : Exemple of a first try to reduce inspection time yet not in usual practice

# Borescope Reduces Time for Gas Turbine Inspections

07/01/2003

### Section 1.01 Borescope Reduces Time for Gas Turbine Inspections

By Douglas J. Smith, IEng
Senior Editor

SIEMENS WESTINGHOUSE has developed a patented high temperature borescope for the inspection of hot parts in gas turbines. The high temperature borescope can visually inspect, measure and photograph a turbine's hot path at temperatures up to 1,000 F, thus allowing inspection to begin as soon as four hours after turbine shutdown. Older borescopes cannot be used until the turbine has cooled to 150 F. As a result it can take up to 24 hours after shutdown before inspections can start.

The lightweight borescope was designed and developed to reduce outage time and enhance unit availability. A thin-wall aluminum tube allows cool air to be pumped through the tube to a camera positioned at the end of the probe. The telescoping tube can be extended from 41-126 inches. If an inspection finds damage the camera takes digital photographs for immediate analysis and evaluation by the engineers. Access for the borescope to the hot sections is gained through removable pilot nozzles. With the borescope, inspection of different parts of a gas turbine's hot sections can be performed in as little as 15 minutes. According to Siemens Westinghouse the borescope and its camera can be used worldwide and adapted for a wide variety of gas turbines.

### Section 1.02 Lakeland Electric Completes Inspection in Two Days

At Lakeland Electric's McIntosh power plant in Florida, Siemens Westinghouse used the high temperature borescope for scheduled maintenance inspection of the transition between the combustor and the first stage blading of the gas turbine. Inspection of the transition was completed in two days. The unit was removed from service on a Friday and was back online on Sunday.

After a four-hour cool-down period, and a safety check of the unit, the pilot nozzles were removed and the probe inserted. The inspection team performed the inspection at a turbine temperature estimated at 1,000 F. If discrepancies were identified, photographs would have been taken and transmitted to engineering within ten minutes.

According to Tim Bachand, Engineering Manger, Energy Supply, Lakeland Electric, using the hot borescope for inspecting the transition saved the plant approximately twelve hours of outage time. By reducing the outage time, the plant is able to save a minimum of $4,500 an hour from lost generating revenue. On a particularly hot day the savings could triple, says Bachand.

http://www.power-eng.com/articles/print/volume-107/issue-7/field-notes/shborescope-reduces-time-for-gas-turbine-inspections.html