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The importance of magnetic forces on the performance of turbines and heat exchangers

Presented, on 29 / 09 / 2021, Infront of the committee:

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"

Success is not final; failure is not fatal: It is the courage to continue that counts."

-- Winston S. Churchill

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Roumaissa

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General Introduction

General Introduction

The hydrocarbon industry in today's world is undergoing a phenomenal evolution and is growing in size and importance; this is an inevitable consequence of the continuous increase in market demand, and the economic interests at stake.

To eject gas from the wells, due to a lack of pressure, natural gas must be reinjected into the wells. This lack of pressure has become a primary concern in order to increase the pressure of the deposit and maximize production.

The high power, smooth running and high performance of gas turbines make them one of the most popular means of driving mechanical loads.

The national company of transport and marketing of hydrocarbons (SONATRACH), which plays an important role in the national economy, is obliged to face this situation in order to satisfy its contracts and to consolidate its 14th place at the international level.

To this end, SONATRACH follows a strict policy, which avoids production stoppages as much as possible and obliges the maintenance department to adapt its strategy in order to ensure greater availability of equipment and a high and perfect performance, especially those in a critical position with respect to the production process, such as the gas turbines which are very widespread in the oil sector.

To reach these objectives many methods, researches and experiments are made among all this, the use of magnetic fields as a means of improving the quality of combustion has been carried out by scientists. Most researchers use permanent magnets or iron as the source of the magnetic field, the weakening of the magnetic field strength will decrease over time, otherwise the magnetic field generated from the wire winding in the core of the coil is an electric flow or colloquially called an electromagnet, its magnetic force does not decrease as long as there is electric current. Magnetic effects cause changes in fuel molecules from an aggregated state to a disaggregated state. by 40% and particles by 35%

In order to obtain the engineering degree, this thesis is the result of a practical internship at the production division of Rhourd el Baguel, Hassi Messouad. In this work we will study the impact of the magnetic field put in the combustion chamber on the efficiency of the MS5002C turbines.

Our dissertation is structured as follows: in the first part we proceed to the presentation of the place of training, generalities on the turbines and also we speak about magnetism. A second chapter is reserved for the detailed description of an MS5002C turbine. The third chapter contains the results of calculations after and before the installation of a magnetic induction coil in the combustion chamber, which will be interpreted later. We ended our thesis with a general conclusion.

Chapter I:

Generalities

1.1 Presentation of the internship site

1.1.1 Geographic location

The field of Rhourde El Baguel is located on the system of structures that border theprovince of Illizi and Ghadames to the west. Its surface is estimated at 164.05 km². RhourdeEl Baguel is part of the commune of El-Borma - Daïra Hassi Messaoud - Wilaya de Ouargla The geographical coordinates of REB are as follows:

X = 6° 54' 00" to 7° 01' 00" (Longitude East) Y = 31° 20' 00" to 31° 28' 00" (Latitude North).
With an average altitude of the field is 170.68 m.

The word Rhourde El Baguel means "Big Dune"; the field is located 90 km South-East of the city of Hassi Messaoud on the western edge of the Ghadames basin, and about 1000 km from Algiers.[1]

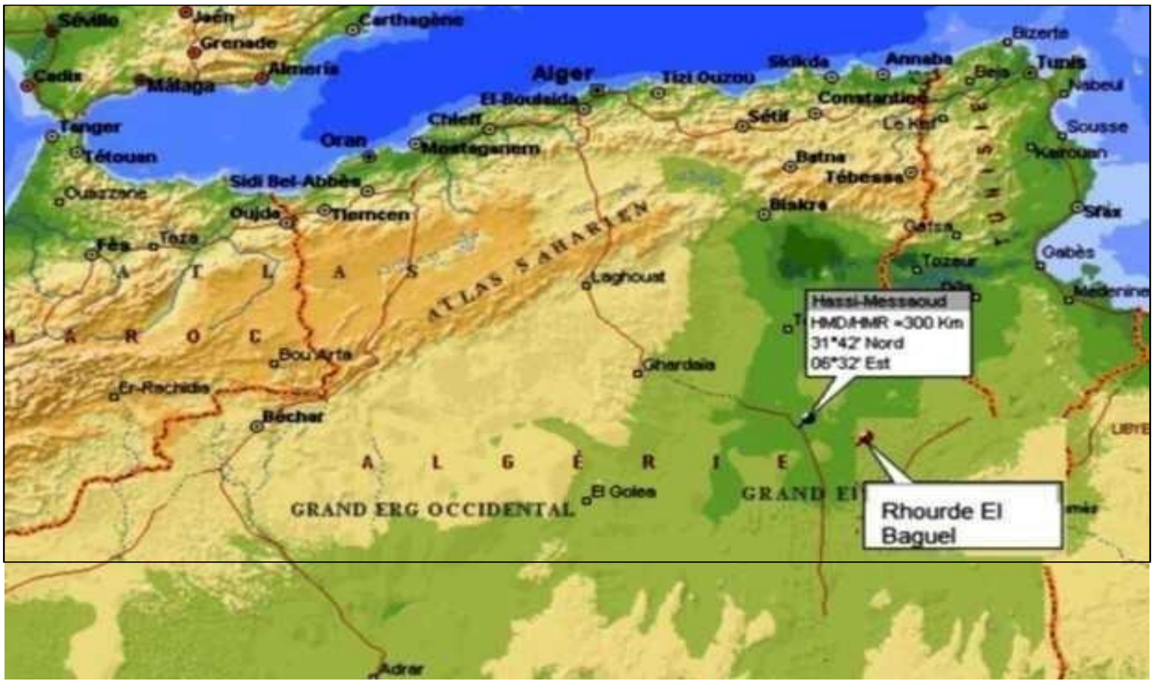

Fig 1.1: geographical situation of the region Rhourde EL BAGUEL.[1]

1.1.2 General description of the REB region

The REB region together with many wells, producing wells from which crude oil is produced. Gas injector wells with 18 million cubic meters of gas are rejected every day to maintain the pressure of the deposit. There are also useful water wells.

The oil from the wells is gathered by means of 3 manifolds (North, East and South), each with 3 operating systems each with 3 operating systems:

- High Pressure System (HP).
- Medium Pressure System (MP).
- Low Pressure System (LP).

In order to stabilize the oil and recover the gas, two operating centers have been set up

The CPF (Central Production Facilities) or phase A, and the TCF (Turbo Compression Facilities) or phase B. CPF and TCF are both crude and injection gas processing centers and are the heart of REB.

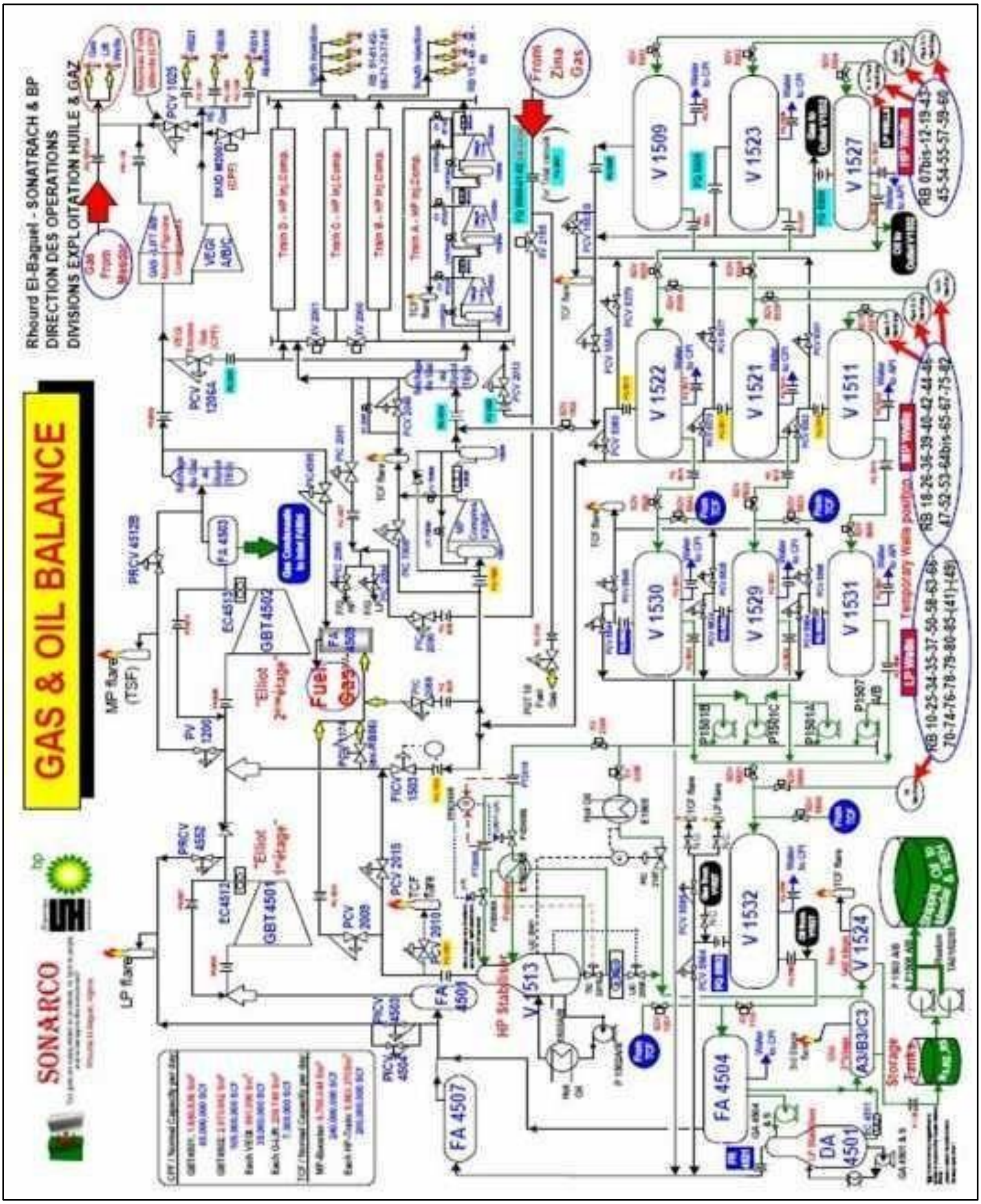

Fig 1.2: General view of the main component units of the CPF and TCF.[1]

1.1.3 The CPF center (Central Production Facilities):

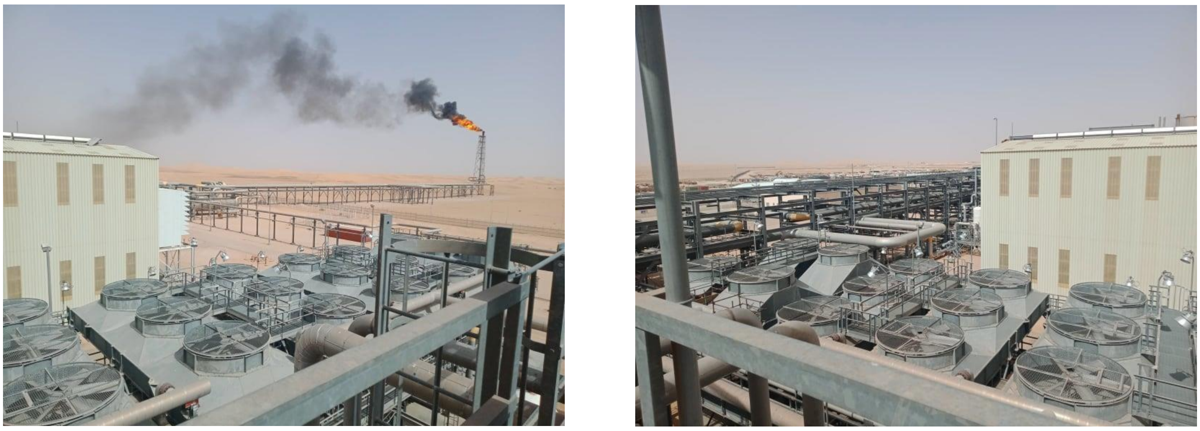

Fig 1.3: CPF REB [Photos taken during the training]

It consists of two sections: a processing section and an optimization section

1.1.3.1 Processing section

The crude processing section is composed of the following sections:

- HP, MP and LP separators.
- Water treatment unit EDR.
- Storage and shipping.
- Utilities section.
- API/CPI section

1.1.3.2 HP, MP and LP separators

The HP separators; receive the charge from the HP manifolds at a pressure of 30-35 bars and a temperature of 46°C and ensure the separation of crude and gas. The gas flow goes to TCF (TEG unit) to be dehydrated, compressed to 350 bar and then injected into the wells, while the crude flows to the MP1, V1511, V1521 and V1522 separators to be separated from the gas again; on the other hand, the separators also receive a load from the MP manifolds.

These separators are currently operating at a pressure of 14-17 bar and a temperature of 42°C. Part of the separated gas goes to TCF (MP compressor) and the other part goes to the suction tank of the GBT4502 compressor.

Then, the crude passes through the MP2 separators; V1529, V1530 and V1531, which are currently operating at 10-12 bars and a T° of 32°C, after which it joins the low pressure separator LP1532 and FA4504 operating at an average pressure of 3-4bars.

The gas from the MP2, LP and FA4504 separators is directed to the FA4507 drum.

1.1.3.3 Optimization unit

The optimization unit consists of two main sections:

- **The low pressure stabilization section**

The crude oil leaving the FA4504 drum is pumped by the GA4504 pump at 7 bars to the LP stabilization column (DA4501), which is composed of 18 trays, operates at 2 bars and ensures the separation of light gases from the crude oil in order to improve the vapour pressure of the crude oil (TVR). The reboiling of the charge at a temperature of 132°c is ensured by two EA4501&S reboilers operating in standby, the crude circulates on the calendar side and the hot oil on the tube side.

The stabilized crude, after being cooled in the EC4511 aero-coolers to a temperature of 40°C, will be sent to the V1524 separator to be cleaned of light ends and then sent to the storage tanks. The gas flow coming out of the DA4501 column head and the gas coming from the MP2 and V1532 separators feed the FA4507 drum. The gaseous part is sent to the 1st stage suction tank FA4501, while the condensates are recycled to FA4504.

Fig 1.4: BP stabilization section [photo taken during the training]

The gas from the FA4501 flask is sucked in at a pressure of 1.6 bar and compressed by means of a GBT4501 compressor to a pressure of 14 bar. After having been cooled down to 33°C in the EC4512, the effluent is collected in the FF4501 flask and sent to the FA4510 2nd stage suction flask.

The gaseous part, brought to a pressure of 14bars, is compressed by the GBT4502 compressor to 44bars, cooled and then collected in the FA4503 tank, the outgoing gas, after being dehydrated in the TEG dehydration unit, is sent to TCF. The condensate from FA4503 are sent to column DA4502, which has 36 trays, operates at 14 bar and ensures the separation of the light C1 and C2 at the top which enter the FA4510 flask, the condensates at the bottom are sent to column DA4501.

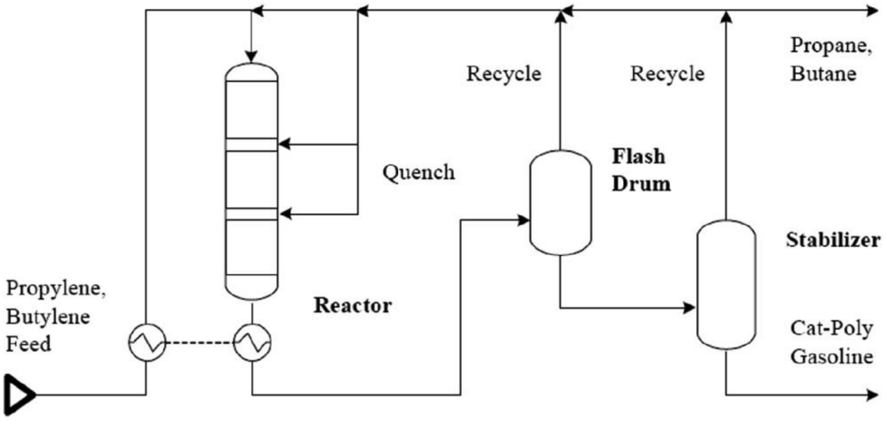

Fig 1.5: General view of the low pressure stabilization unit.

- **Tri ethylene glycol (TEG) dehydration unit**

The gas coming from the FA4503 flask is directed to the MV-1401-I separator to eliminate the condensates, then feeds the MV-1401-A contactor where the counter-current absorption takes place, the ascending effluent and the descending TEG, the absorption is done at a temperature of about 40°c, the wet TEG coming out of the bottom of the contactor is directed to the regeneration section, while the head gas of the contactor feeds the cyclone separator flask V-1404 where the recovery of the traces of TEG entrained in the gas is carried out, the head gas is sent to the VEGI compressors and gas lift while the TEG recovered at the bottom is sent to the TEG regeneration section.

- **The high pressure stabilization section**

The crude oil leaving the separators V1529, V1530 and V1531 is pumped to a pressure of 17bars, heated in the exchanger E1502, then fed to the HP stabilization column. The V1513 column has 20 trays and performs the same function as the DA4501 column, but the stabilization is done at a pressure of 17 bars.

The circulation of the reboil is done by pumps P1502A /B by exchanging heat in exchangers E1503 with the hot oil coming from the furnace F5001.

The stabilized crude, after being cooled in the aerosol E1501, goes to the V1524 drum to be separated from the light gases and then sent to the storage tanks, while the top gases are sent to FA4510 and the existing fuel gas network.

Fig 1.6: HP stabilization section [photo taken during the training]

1.1.4 The TCF center (Turbo Compressor Facility)

The purpose of this unit is to inject dry and compressed gas into the reservoir to increase the reservoir pressure to the miscibility pressure; this increase in reservoir pressure will increase the crude oil production.

The injected gas consists of:

- HP associated gas from the HP separators located in the crude processing unit.
- MP associated gas from the MP separators located in the crude processing unit.
- Excess gas from VEGI, this gas comes from the discharge of the GB 4502 compressor of the optimization unit after dehydration in the TEG unit of phase A.
- Gas imported from GR1, it is a dry gas with the specifications of sales gas.

1.1.4.1 Description of the unit

The gas injection unit consists of:

4 parallel turbocharger trains, each train consists of three compressors driven by a single turbine:

a) The KT2002A turbine drives the K2002A, K2003A, K2004A compressors.
b) KT2002B turbine drives K2002B, K2003B, K2004B compressors.

c) KT2002C turbine drives K2002C, K2003C, K2004C compressors.
d) KT2002D turbine drives K2002D, K2003D, K2004D compressors.

Medium pressure turbocharger train consisting of the KT2005 turbine driving the K2005 compressor; 4 gas dehydration trains at the TEG, these 4 trains are identical and parallel:

a) The M1403A train called A train.
b) The M1403B train called train B.
c) Train M1403C called train C.
d) The M1403D train called D train.

A line of 30 inches in diameter and 60 km long allows to import gas from the GR1 pipeline at the level of the station of ZINA. A distribution network that starts from the turbochargers delivery allows supplying the injector wells.

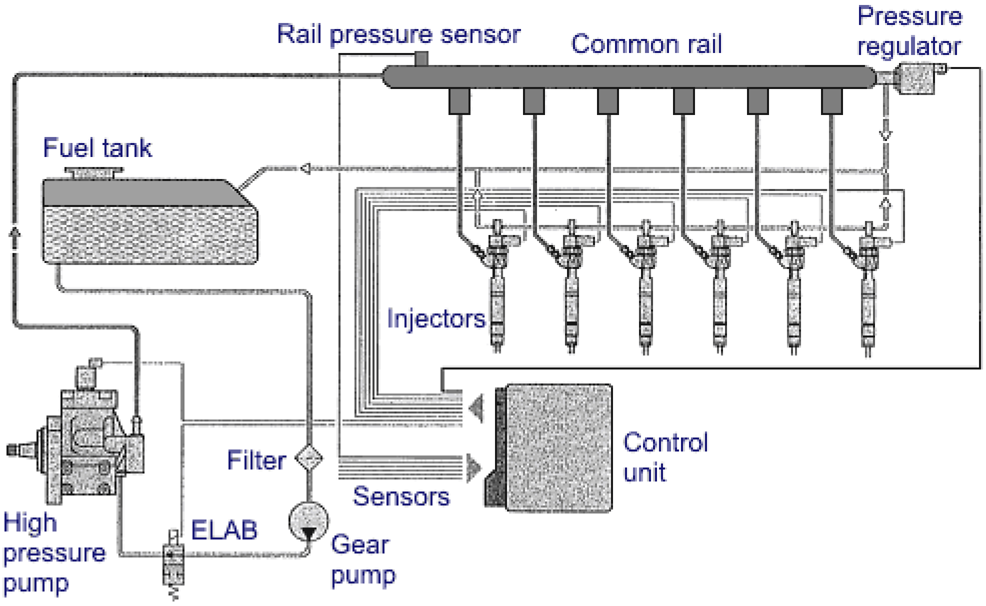

Fig 1.7: Simplified diagram of the gas injection unit [2]

1.1.4.2 Description of the process

The different gas supplies of the miscible gas injection unit are: MP gas, HP gas, import gas and excess gas from the VEGI station. The MP gas coming from the MP separators is first compressed by the MP turbocharger train (K2005-KT2005), this train with a capacity of 6,825,000 Sm3 per day raises the pressure of the MP gas from 15.2 bars to 33.4 bars, the gas thus compressed is cooled and then mixed with the HP gas coming from the HP separators of the crude oil treatment unit.

The mixture of the two gases feeds the dehydration trains at the TEG where it is cleaned of the water it contains, thus dehydrated, the associated gases (MP and HP) feed the inlet manifold of the turbocharger trains. The inlet manifold is equipped with valves in such a way that it

The low pressure section of the inlet manifold operates at 31 bar and can feed the D train or the D and C train simultaneously. The high pressure section of the inlet manifold operates at 31 bar up to 48 bars and is configured to supply trains A, B and C or just trains A and B. The opening of all the valves of the inlet manifold will allow to feed all the trains at the same suction pressure.

1.1.5 Organization of the Rhourde El Baguel field

The regional management of Rhourde el Baguel, is governed by the following organization chart:

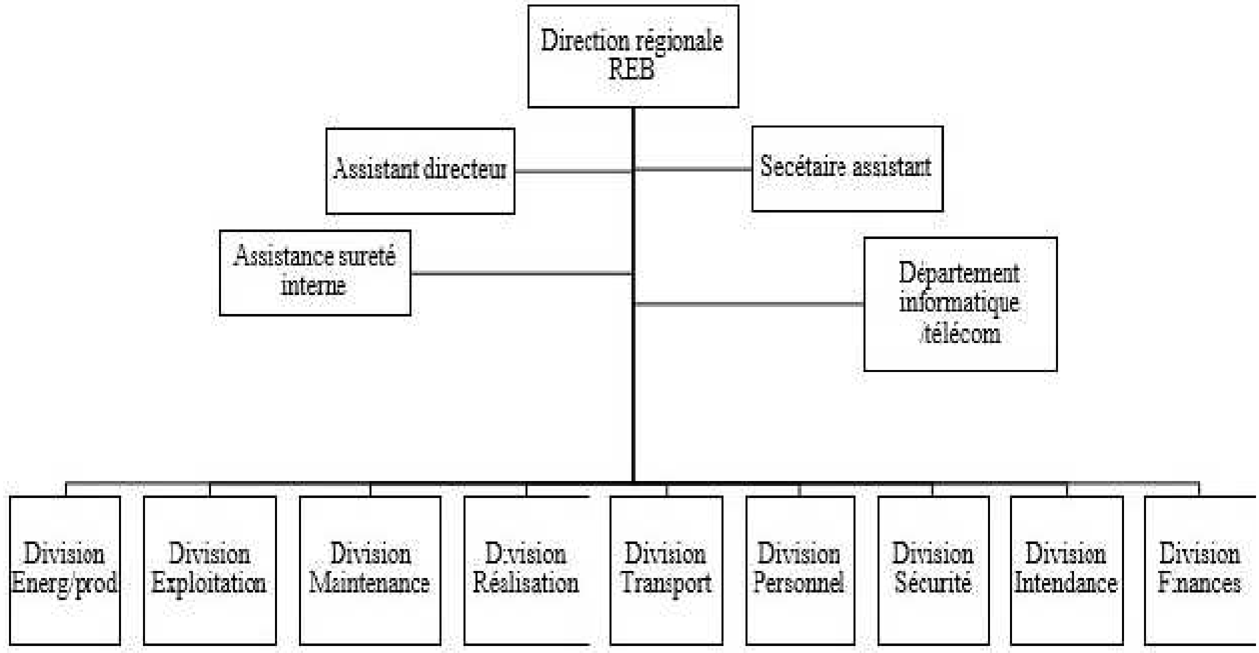

Fig 1.8: REB management organization chart [1]

1.1.5.1 Maintenance Division

The Maintenance Division is organized as follows:

- A Methods department
- A Mechanical department
- An Instrumentation department
- An Electricity department

1.1.5.2 Methods Department

This department's main purpose is the planning and monitoring of all operations and equipment management. The preventive maintenance schedule and the preparation of intervention plans are generated in this department.

The main tasks are: predictive scheduling of inspections, scheduling of PM and CM maintenance, verification and monitoring of stock, supervision of work and its rate of progress, procurement of spare parts. To accomplish these tasks, the method department uses a computer-assisted maintenance management system called MAXIMO and STOCKTAKING.

1.1.5.3 Mechanical department

This department is in charge of the maintenance and repair of all the equipment and static and rotating machines that are found in the production center, such as Heat exchangers, columns, ovens, gas turbines, pumps, compressors and motors...etc. This department works in collaboration with the method and planning department to ensure its task of maintaining the proper functioning of mechanical equipment as long as possible.

1.2 Generalities about the gas turbine

1.2.1 Introduction

The gas turbine is a rotary motion internal combustion engine, equipped with an air compressor and a combustion chamber capable of producing a fluid under pressure and at very high temperature.

This fluid, as it expands in the turbine stages, releases mechanical energy to drive a receiving machine. [2]

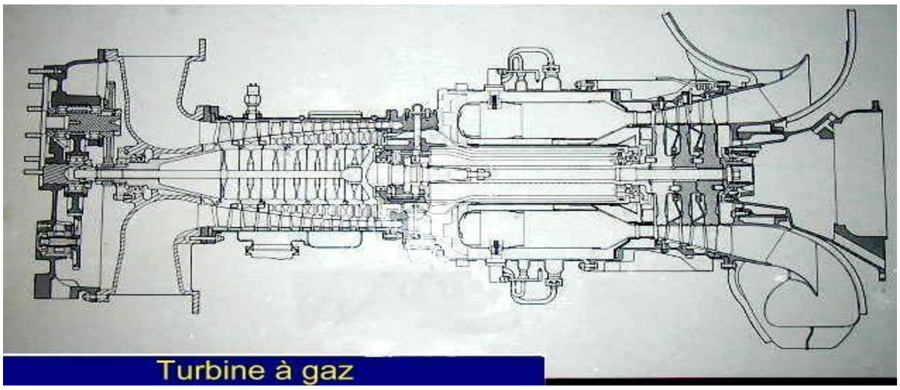

Fig 1.9: Representative diagram of the gas turbine [3]

1.2.2 Gas turbine composition

Axial compressor: The main function of the compressor is to compress atmospheric air to a higher pressure.

Combustion Chambers: Compressed air from the compressor is mixed with the fuel, and the mixture is ignited. The product of this combustion is a stream of hot gases at high pressure.

Turbine section: The hot gases at high pressure expand, producing work to drive the turbine compressor and the load.

1.2.3 Operating principle

The atmospheric air, sucked in by the axial compressor, is compressed and then delivered into the combustion chamber where the fuel is introduced; the desired mixture (compressed air and pressurized gas) is obtained.

A spark from a spark plug causes combustion. The heat produced in the combustion chamber and the energy released by the combustion product are directed to the first turbine wheel (HP) where this thermal energy is transformed into mechanical energy.

Part of the power developed by the turbine is used to drive the axial compressor (after it has been uncoupled from the engine, or launch turbine). The other part of the power developed is converted into usable energy, i.e. used to drive the receiving machine (gas compressor, in our case).

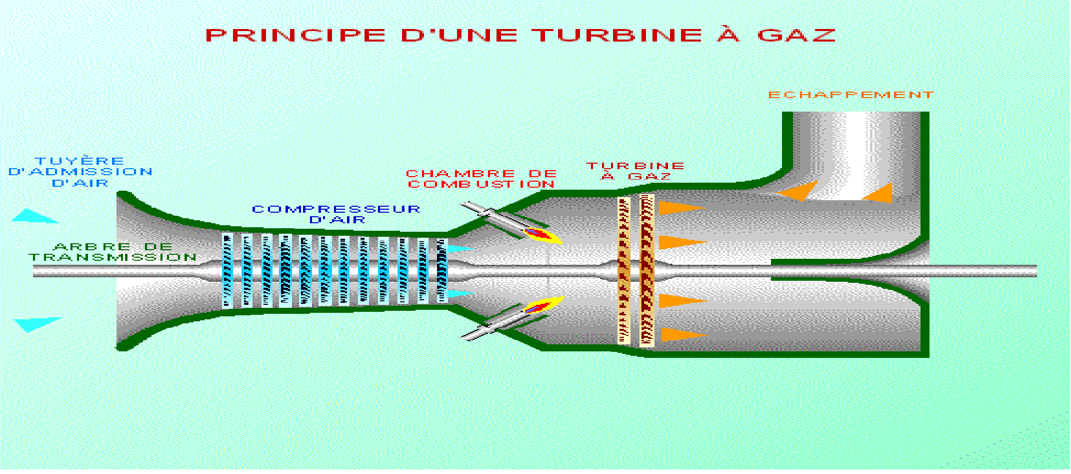

Fig. 1.10: Operating principle of a gas turbine [3]

1.2.4 Classification of gas turbines

a. *By construction mode:*

Gas turbines can be classified as follows:

The field of use of a gas turbine is a means of choosing the right type of machine. In industry, there are single-shaft turbines, also known as single-shaft turbines, which are generally used when a constant load is required (to drive electricity generators).

A second type includes two-shaft turbines (bi-shaft), which have the advantage of driving variable-load equipment (pumps, compressors, etc.). They are mainly composed of two parts, the first one ensures the autonomy of the turbine (TAG), the second one is linked to the load.

A third type can also be mentioned, they are the so-called aeronautical derived turbines, and they have a special design according to the field in which they are used. In this third type, the part which ensures the autonomy of the turbine still exists, and the energy still stored in the exhaust gases is used to generate thrust, by transforming this energy (thermal and pressure) into a kinetic energy of jet in a nozzle.

b. *By working mode:*

There are two types of turbines:

Action turbine: Where the thermal energy is completely transformed into kinetic energy in the director. The evolution of gases in the wheel is done without variation of static pressure $P1>P2=P3$.

Reaction turbine: Part of the thermal energy is transformed in the wheel into kinetic and mechanical energy. The evolution of gases in the impeller is done with a variation of static pressure $P1>P2>P3$. The reaction rate ε will characterize the percentage of total thermal energy.

With:

P1 : Gas pressure at the inlet of the director

P2 : Gas pressure at the outlet of the director

P3 : Gas pressure at the turbine wheel outlet

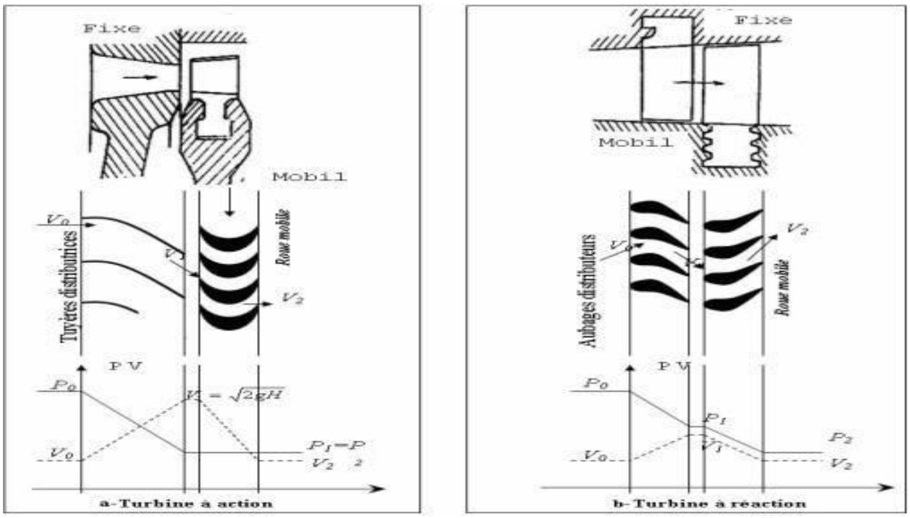

Fig. 1.11: Classification by work mode.

c. *By thermodynamic mode of operation:*

There are two thermodynamic cycles:

- Closed cycle gas turbine: In which the same fluid is taken back after each cycle.
- Open-cycle gas turbine: This is a turbine whose intake and exhaust are carried out directly into the atmosphere.

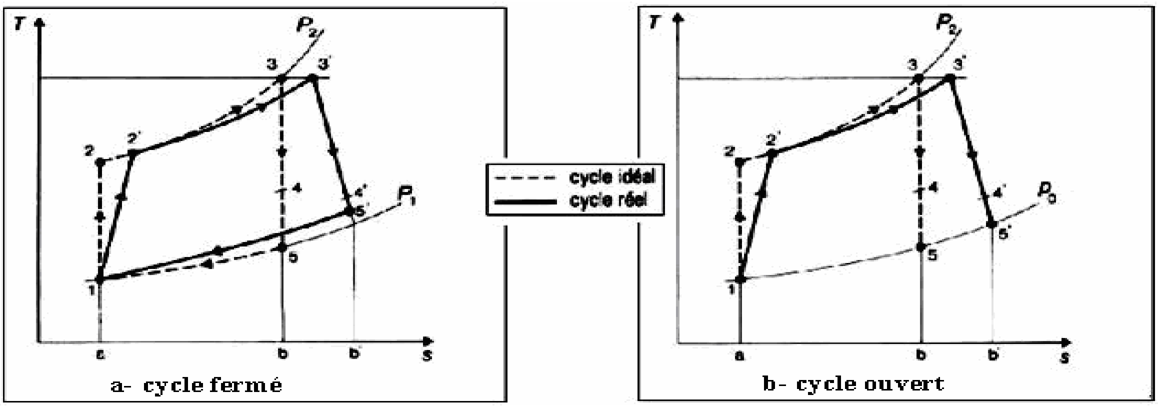

Fig. 1.12: Representation of closed and open cycle.

This type of turbine, which is the most widespread, is divided into two classes:

- Simple cycle turbine: It is a turbine using a single fluid for the production of mechanical energy, after the expansion the gases still having an energy potential are lost in the atmosphere through the exhaust.
- Regenerated cycle turbine: This is a turbine whose thermodynamic cycle involves several driving fluids in order to increase the efficiency of the installation.

Depending on the layout of the tree :

Another way of classifying gas turbines is according to the arrangement and number of shafts they can contain, for this purpose we find :

- Single shaft: Also called single shaft, this is a gas turbine in which the rotating components are mechanically coupled on a common shaft. It is generally used when a constant load operation is required (to drive electricity generators)
- Two shafts: It has the advantage of driving variable load equipment (pumps, compressors,...), it is composed of two parts, the first one ensures the autonomy of the gas generator turbine (TAG), the second one is linked to the load.

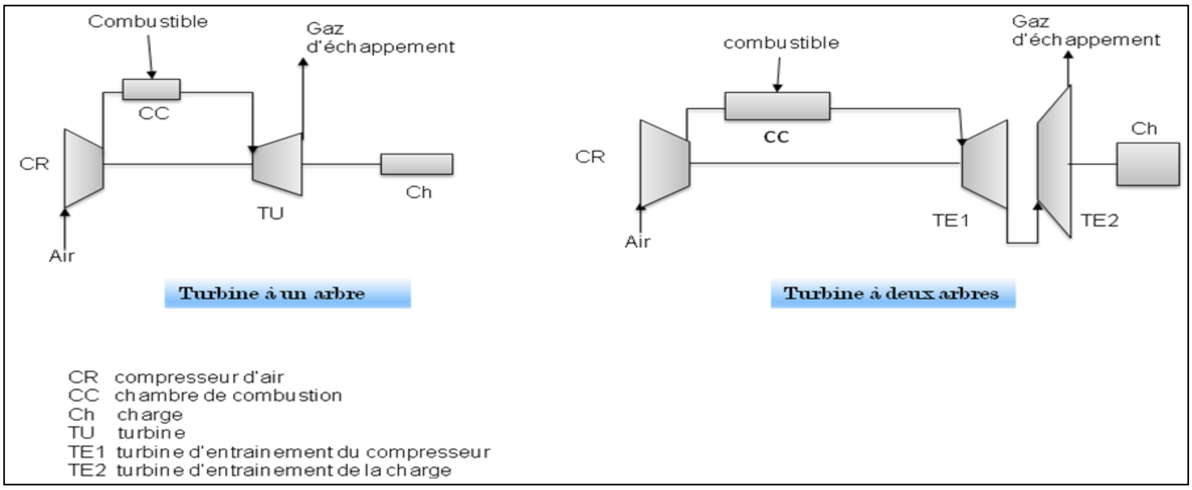

Fig. 1.13: Single shaft and double shaft gas turbine

- Multiple shafts: This is a turbine in which the rotors of the mechanical elements are mounted on more than one rotating shaft. These shafts may or may not rotate with each other at a given speed ratio. They are called floating shafts, except for the coupling shaft.
- Gas turbine classification flow chart

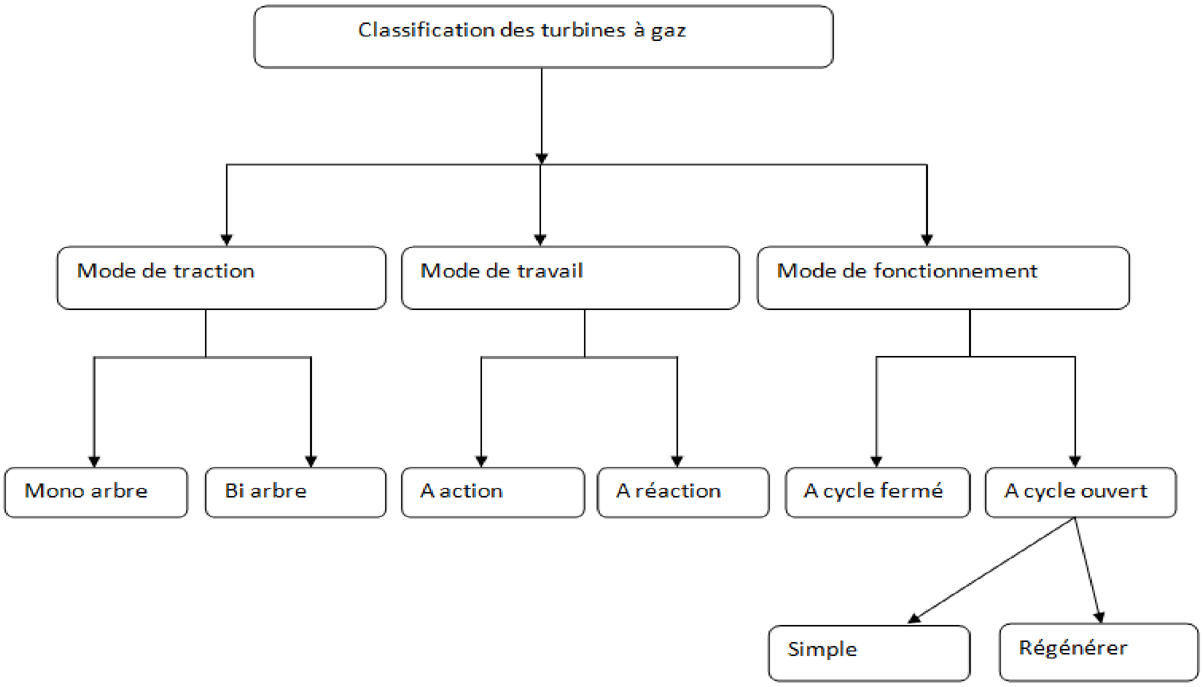

Fig. 1.14: Classification of gas turbines.

1.2.5 The theoretical cycle of gas turbine plants :

The cycles of the gas turbine plant are different. Depending on the use of the working medium in the cycle, a distinction is made between closed and open cycles.

In the open-cycle gas turbine plant, the motive medium after providing work escapes into the environment (as in internal combustion engines) and on the contrary, in the closed-cycle gas turbine plant, the motive medium (air or other gas) circulates constantly in the contour and completes the closed cycle.

According to the thermodynamic cycle, we can mention the simple GTI (gas turbine plant), the GTI with intermediate cooling and heating.

As far as heat input is concerned, there are two types of G.T.I:

I.T.G with heat input at constant pressure and I.T.G with heat input at constant volume.

In modern gas turbine installations, the heat supply is mainly used at constant pressure.

Therefore, let's start to study the G.T.I. with constant pressure heat input and which works according to the open cycle.

Let us consider the thermodynamic cycle of I.T.G. without taking into account the losses in the turbine and in the compressor. Such a cycle is called a theoretical cycle.

The compressor sucks in and compresses the air (adiabatic transformation1-2), and then there is heat input into the combustion chamber at constant pressure.

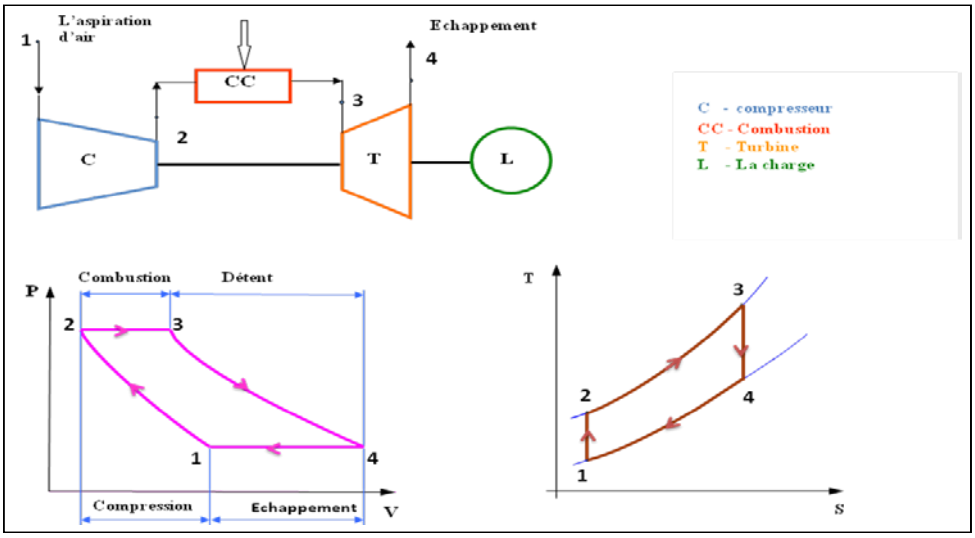

Fig. 1.14: Baritone cycle

- 1-2: Isentropic compression.
- 3-4: Isentropic expansion.
- 2-3: Isobaric combustion.
- 4-1: Exhaust.

The gas temperature in the combustion chamber rises from T2 to T3, after which the gas expands adiabatically in the turbine from pressure P3 to atmospheric pressure P4.

During the expansion of the gases in the turbine the potential energy is transformed into kinetic energy and then in the moving blades the kinetic energy is transformed into mechanical energy, i.e. into rotational energy of the turbine rotor.

1.2.6 Area of use

The applications of gas turbines are directly related to their specific advantages. For example, the high power density is well suited to aeronautical propulsion, particularly in helicopters. Gas turbines are also increasingly used in naval propulsion, especially for high- speed ships.

Finally, there are examples of applications in railway propulsion and military vehicles such as tanks (XM-1) Abrams or Leclerc)[4]. On the other hand, the gas turbine is poorly adapted to road vehicles. Indeed, the load and speed variations are too important and too fast to be achieved with a correct efficiency. Moreover, the efficiency hardly reaches 30% for compact and low power engines.

The other major area of use for gas turbines is in power generation. These are constant speed and relatively constant load applications where the efficiency of these machines is the best. The power ranges from a few hundred kW to nearly 300 MW.

The most powerful machines are generally associated with steam turbines in combined cycles whose overall efficiency currently tends towards 60%. In a simple cycle, the efficiency is around 30 to 35%. At low power levels, the efficiency is even lower than 30%, but the ability of combustion turbines to recover heat in cogeneration applications (simultaneous production of electricity and heat) is then used.

Use of gas turbines in oil and gas field reinjection stations:

One of the processes used to improve oil field production is to maintain reservoir pressure by injecting natural gas into the reservoir.

Due to the high feedback pressure (up to several hundred bar), the compression ratio is very high.

It is therefore necessary to provide several compression stages with intermediate cooling.

There are essentially three types of machines used to compress gas at reinjection stations.

- Gas turbine driven centrifugal compressors.
- Gas engine driven piston compressors.
- Centrifugal compressors or piston compressors driven by electric motors.

Gas turbines are particularly well suited to drive centrifugal compressors. Both machines use similar technologies and many manufacturers are able to supply a complete package. Furthermore, both machines are of the rotary type, and it is possible to transmit the motive power directly to the driven compressor, usually by a direct coupling between the power turbine and the compressor.

Also, in the majority of cases for gas transport, centrifugal compressors are driven by two-shaft gas turbines. The re-injection process is shown in (Fig I.2.5).

The residual gas is fed to the suction tank on the first floor of the BP re-injection compressor at a pressure of 70 to 80 bar effective and a temperature of 60°C. The HP compressor increases the gas pressure from 80 to 163 bar. The hot gas discharged from the HP is cooled to 60°C in the air cooler and then fed into a second stage of the HP via the storage tank at a pressure of

160 bar and a temperature of 60°C. The gas is compressed to 321 bars. The discharged hot gas is cooled to 85°C in the aero cooler before being routed to the re-injection circuit to the well for pressure maintenance to increase the life of the oil field.

1.2.7 Name of the gas turbine

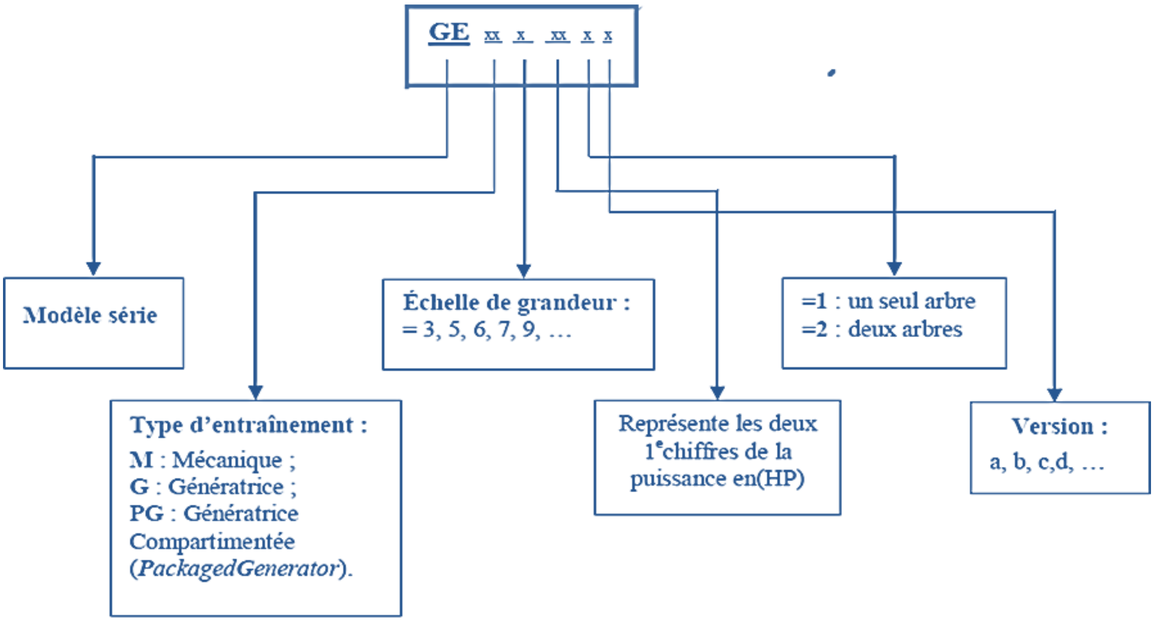

Fig. 1.15: Naming method for gas turbines

1.3 A little history

The discovery of magnetism is traditionally attributed to Thales of Millet who, according to legend, noticed that his walk was slowed by the attraction of the nails of his sandals on a volcanic rock. The phenomenon may have been known before, but it was from this time (around 585 BC) that magnetite became known as a magnet stone. Until the 19th century, knowledge of magnetism only progressed very occasionally.

In the 6th century, the anti-Aristotelian John Philopon of Alexandria noticed the phenomenon of attraction and repulsion of magnets. Around the 9th century, the Chinese Shen Kua became interested in the magnet stone and mentioned the magnetization of a steel needle by the influence of a natural magnet. The alignment of the magnet towards the south is known in the tenth century but it is not excluded that the Arabs were the first to have exploited the phenomenon for navigation from the middle of the eleventh century: this would explain why Chu Yu mentions the introduction of the compass by foreigners in 10861. Finally, the compass was known in its present form in Europe in the early 12th century. The first real experimentation was carried out by Pierre de Maricourt in 1269 who defined the notion that William Gilbert would call in his work De Magnete in 1600, magnetic poles (by analogy with terrestrial magnetism). Gilbert's drawing (Fig I.3.1) shows the positions of the compass around a bar magnet. The quality of the experimental description is exceptional for the time.

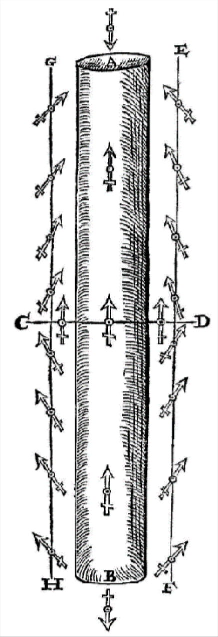

Fig 1.16: Positions of the compass around a bar magnet, source De Magnete by W. Gilbert [1]

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[1] Some Chinese historical texts date the discovery of the compass to an earlier date, but the texts are more recent and certainly disingenuous.

Until the 19th century, the magnetism of materials remained an occult virtue supposedly at the origin of the most far-fetched phenomena, ranging from curative virtues to the revelation of adulterous women! Throughout this period, Descartes was the only one in 1644 to reject occultism and to propose a mechanistic interpretation, admittedly erroneous, but at least reasoned in light of the knowledge of the time.

The explosion of the science of magnetism took place in 1819 with the fortuitous discovery of the action of electric current on the deviation of the compass by Christian Oersted. Learning of the experiment, André Marie Ampère in 1820, suddenly became fascinated by this phenomenon. Although he had not been concerned with physics until then, he founded the theory of electrodynamics in four months. In 1827, he put forward the hypothesis that magnets were the seat of molecular currents (the atom was not yet known) which produced the magnetic field. Scientists from all over the world took up this theory and electrodynamics made great strides forward, thanks in particular to Jean Baptiste Biot, Félix Savart, Joseph Henry, François Arago, William Sturgeon, Perter Barlow...

It was at this time that Michael Faraday, a simple bookbinder's worker, became Humprey Davy's assistant. In 1821 he discovered the principle of the electric motor and induction in 1831. In 1845 he became interested in the magnetism of matter and distinguished ferromagnetism, paramagnetism and diamagnetism. He showed in 1852 that iron heated to red loses its magnetism. While Maxwell formalized the laws of electromagnetism in 1872, knowledge of materials progressed little until the beginning of industrial electricity.

In 1882, J.A. Ewing gave new impetus to magnetism by discovering hysteresis and then publishing in 1891 a complete work on the knowledge of the magnetism of matter (containing numerous measurements of magnetization as a function of field and temperature), after which he left to study earthquakes in Japan, where he founded the Japanese school of magnetism. In 1885, Hopkinson invented the chromium steel magnet, which was more coercive than magnetite and hardened steel, and in 1887, Lord Rayleigh established the first behavioral model of permeability as a function of field.

In 1895, Pierre Curie brought back the leadership of magnetism on our side of the Channelthanks to his work on the magnetism of pure bodies. He showed that diamagnetism is independent of

The temperature and established that the susceptibility of paramagnetics follows an inverse law of temperature, $\chi = C/T$ (Curie's Law). He measured very precisely the temperature at which ferromagnetism disappears (Curie's point) for various known magnetic materials (iron, nickel, magnetite...) but completely missed the law $\chi = C/(T-T_C)$ for ferromagnetics, which Pierre Weiss would only state in 1904. The same year, Paul Langevin exposed the theory of diamagnetism and paramagnetism, then in 1906, Weiss invented the molecular field and postulated the existence of magnetic domains. These two ideas were verified by the theoretical developments of Brillouin in 1927, Heisenberg in 1928 and Bitter's experiments in 1931, which made it possible to visualize the domains. During this time, materials were developed by Hadfield who invented iron-silicon (1900), Weiss (Fe2Co at 2.45 T, 1912), Elmen (permalloy, 1913), Honda (hard steel Co-W-Cr, 1917).

Finally, the 1930s saw the beginning of a constant progression in the performance of known materials and in the number of inventions, including: Alnico (Mishima, 1931), Cobalt-Platinum (Jellinghaus, 1936), soft ferrites (Snoek, 1933-45), hard ferrites (1952), amorphous (Duwez, 1960), SmCo magnets (1966), NdFeB (1980), and finally nano-crystalline (1988).

1.4 Phenomenology of magnetism

1.4.1 Hysteresis cycle, definitions

The first magnetization curve (Fig 1.17), corresponds to the evolution of B (induction) or J (polarization) as a function of H increasing from the demagnetized state (J=0, H=0). This curve is not reversible. For very small field strengths (typically less than 1 A/m for soft materials), the polarization depends linearly on the field. [3]

$$J = \chi\mu_0 H \text{ as } B = J + \mu_0 H$$

We find

$$B = (1+\chi_i)\mu_0 H = \mu_0\mu_i H$$

Where χ_i (μ_i) is the initial susceptibility (relative permeability).

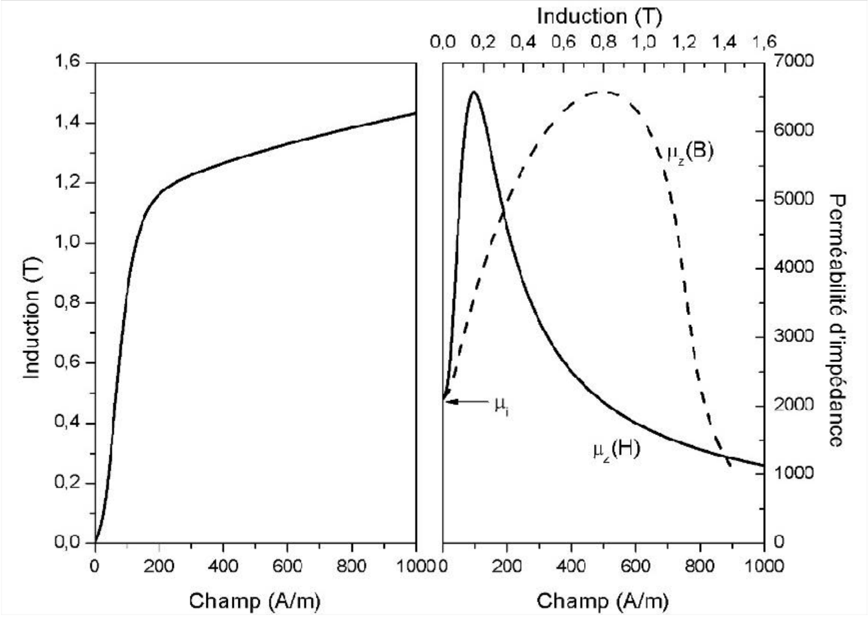

Fig 1.17: Typical first magnetization curve of a soft material (right) and variation of the impedance permeability with field (solid line) and induction (dashed line).

For larger values of H, this linear relationship no longer exists and the permeability is therefore no longer defined. To simplify the calculations, we linearize:

$$\mu_z = \frac{B_{max}}{\mu_0 H_{max}}$$

where µz is called the (relative) impedance or amplitude permeability. It corresponds to the value used to model magnetic circuits supplied with sinusoidal alternating current and depends on the amplitude of B (or H, see Fig 1.17).

When the material is saturated, we can write the induction

$$B = J + \mu_0 H = \mu_0 \mu_z H \qquad \Longrightarrow \qquad \mu_z = 1 + \frac{J_s}{\mu_0 H}$$

The energy that must be supplied to the material to reach a polarization point from the demagnetized state is called the magnetization energy (or sometimes work) density, WA. Since dWA=HdB, H>0 and dB>0, then WA>0. If we decrease the magnetic field until it is cancelled, the return branch does not follow the same path. Since dB<0, part of the energy is returned to the source and the rest is dissipated by Joule effect via various phenomena depending on the nature of the material.

If an alternating field is applied to the material, a cycle in the (H,B) or (H,J) plane, called the hysteresis cycle, is completed after one period. This cycle is traversed in the trigonometric direction. The area of this cycle corresponds to the volume energy dissipated in the form of heat during a cycle. The shape of the cycle depends on the chemical and structural nature of the material.

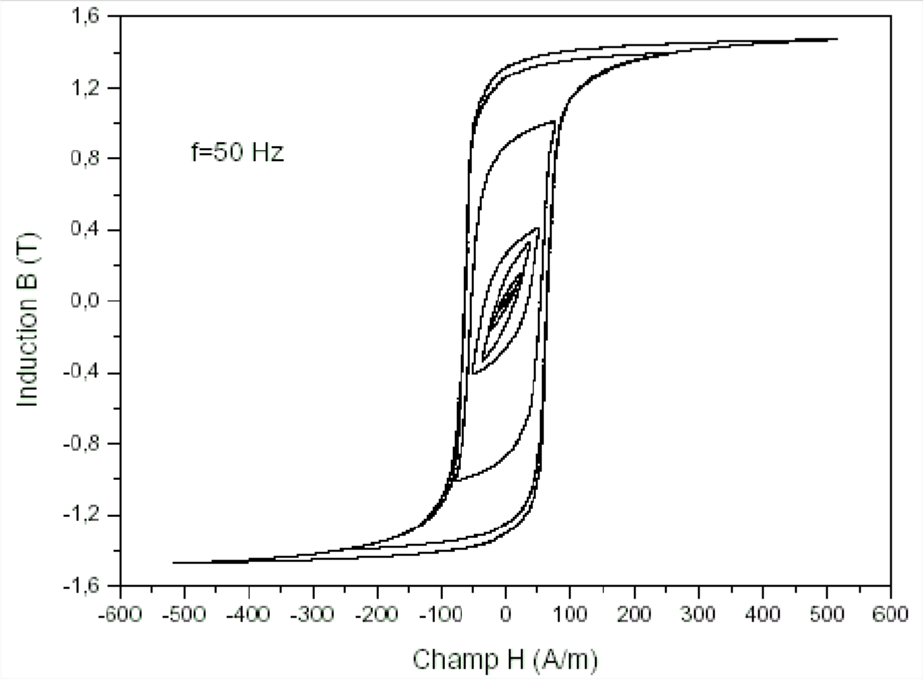

Fig 1.18: Major hysteresis cycle and minor cycles of a 3% FeSi sheet with non-oriented grains.

1.4.2 Soft-hard distinction

The characteristic quantities of a hysteresis cycle are as follows:

J_S: saturation polarization
J_R: remanent polarization (H=0 starting from the saturated state)

H_{CJ} : coercive field (J=0 starting from the saturated state)

H_K : anisotropy field (when $J=J_S$)
In the plane (H, B) we can define

$B_R = J_R$ the remanent induction (because at this point H=0)

H_{CB} : coercive field (B=0 starting from the saturated state)

It should be noted that the term "saturation induction" has no physical meaning insofar as

$B=J_S+\mu_0H$ if $H \rightarrow \infty$

The distinction between soft and hard is made by the coercive field.

- $H_{CJ}<100$ A/m, the material is soft: it is magnetizable and spontaneously demagnetizes
- $10^4<H_{CJ}<2.10^6$ A/m, the material is hard: if it is magnetized it remains so permanently
- $100<H_{CJ}<10^4$ A/m, the material is said to be semi-hard

For a soft material, JS is of the order of a tesla and saturation is reached for a field of the order of H=8000 A/m, hence:

$$B=J_S+\mu_0H \sim 1+4.10^{-7} \sim 1.01 \text{ T}$$

i.e. a difference of about 1% between polarization and induction, which explains the misuse of the term saturation induction for soft materials.

For a magnet under a field at
$H=H_{CJ}\sim 800$kA/m
$B=J_S+\mu_0\mu_iH_{CJ} \sim 1+4.10^{-7}10^5\sim 2$ T
In this case it is essential to differentiate between the notions of polarization and induction, as can be seen in Fig I.3.4, where we also see that $H_{CB}<H_{CJ}$. For a very good magnet, $H_{CJ}>\mu_0B_R$ which implies that $H_{CB}=\mu_0B_R$.

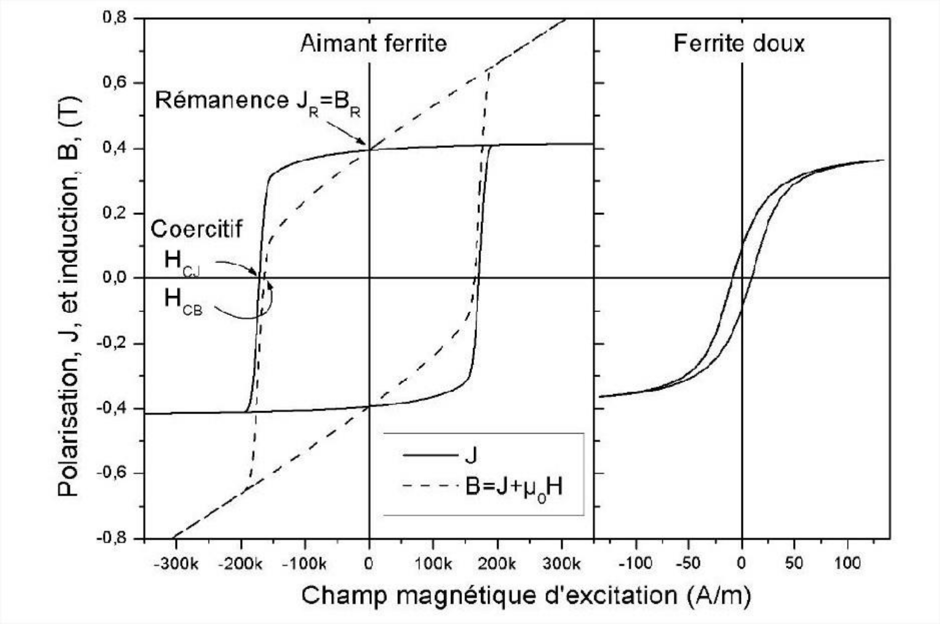

Fig 1.19: Example of hysteresis cycle for hard and soft ferrite

1.4.3 Domain structure

Paramagnetic and ferromagnetic elements all carry a magnetic moment, but in the first case they are thermally excited, so that the polarization is zero in the absence of a field and very weak at usual temperatures and fields. In the second case, the exchange energy, which is linked to the exchange of electrons between the atoms, tends to orient all the moments

These moments orient themselves towards the direction of easy magnetization (a particular direction of the crystal). These moments orient themselves towards the direction of easy magnetization (a particular direction of the crystal). This situation gives rise to significant magnetostatic energy. The system tends to minimize the magnetostatic energy by creating zones of opposite magnetization. When passing from one area to the other, the Bloch wall, the magnetization turns 180° in a helix. The energy associated with the wall depends on the magneto-crystalline anisotropy constant (which tends to align the magnetic moments in a particular crystallographic direction) and the exchange constant. Depending on the magnitude of these terms, a finite number of walls are created in each grain. The Bloch walls have a width of the order of 5 nm (~15 atoms) for hard and 100 nm for soft (~300 atoms). If the anisotropy energy is small, the material is demagnetized in the absence of a field and magnetization occurs by wall displacement and moment rotation (see Fig I.3.5).

If the anisotropy energy is strong, the walls are thin and easily trapped by the defects of the crystal and the influence of the magnetostatic energy is weak. After magnetization, the moments remain locked along the axis of easy magnetization and we have a magnet.

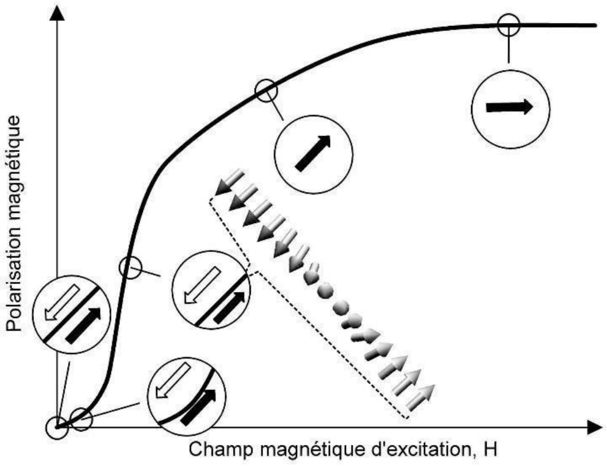

Fig 1.20: Evolution of the domain structure as a function of the field for a soft magnetic material. The zoom shows the structure of the wall.

1.5 Crystalline metallic materials

1.5.1 Pure magnetic metals

There are only three elements that carry a strong magnetic moment at room temperature: iron, cobalt and nickel. Of these three elements, iron has the highest magnetic moment, Js=2.16 T at 300 K, and is by far the most abundant and therefore the least expensive. Pure iron is rarely used because its hardness and elasticity are poor, it cannot be finely rolled, it is susceptible to corrosion and its resistivity is low. Pure iron is therefore only used in massive form and under continuous magnetic field (large electromagnets).

Pure cobalt is not used because it is not really soft or hard enough and nickel has too low a polarization to be interesting (Js=0.6 T at 300 K).

1.5.2 Iron-silicon alloys

In the early history of electricity, metallurgists sought to obtain the purest iron possible to improve these magnetic qualities. In fact, it was mainly a question of eliminating the carbon responsible for the precipitation of hard phases in steels (notably marten site). In 1896, Hadfield discovered that the fortuitous presence of a few percent of silicon in iron improved its mechanical qualities, but he did not study its electromagnetic properties until 1900.

The presence of silicon at a rate of 2 to 4% of the mass confers to the alloy a strong increase in hardness and yield strength, a clear improvement in limitability, a better resistance to corrosion, a multiplication of resistivity by 4 and an anisotropy divided by 2 for a loss of polarization to saturation of less than 10%.

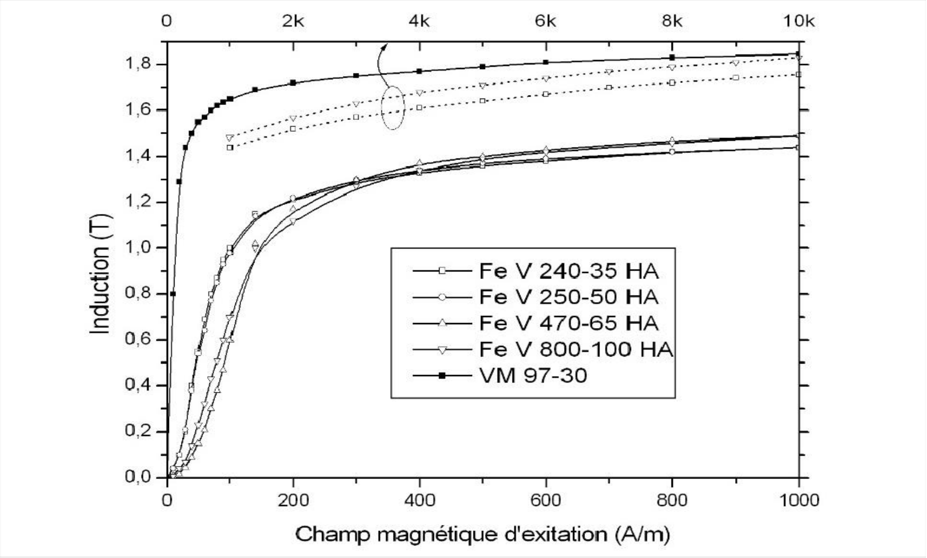

Fig 1.21: Magnetization curves for 4 types of NO laminations compared with a conventional GO. It can be seen that all curves converge towards 1.8 T but for fields that differ by an order of magnitude between NO and GO. For NO laminations, the permeability at low field increases with the thickness.

There are two families of Fe-Si sheets.

Non-grain oriented sheets, NO, are essentially isotropic in the plane and grain oriented sheets, GO, are anisotropic in the rolling axis.

NO plates are produced by hot rolling (1000-13000°C) and cold rolling (300-40°C) to 40-60/100 mm followed by annealing (800°C). The so-called "semi-process" sheets are then insulated and cut. The so-called "full process" plates are usually cold worked to 35/100 mm, cut, annealed and insulated.

GO plates are hot rolled once and cold rolled twice and then annealed. They are treated with magnesia before undergoing a recrystallization annealing process which will promote the growth of crystals along the rolling axis and will allow to obtain the Goss crystallographic texture, named after its inventor (GOSS also means grain oriented steel sheet, it can't be invented!) GO plates, known as HiB (pronounced "aïe bi"), undergo a more advanced process that increases the size of the grains and improves the orientation. At the same time the thickness is increased to 20, 10 or even 5/100. In addition, a special coating is used to apply a permanent tensile stress which increases permeability and reduces losses.

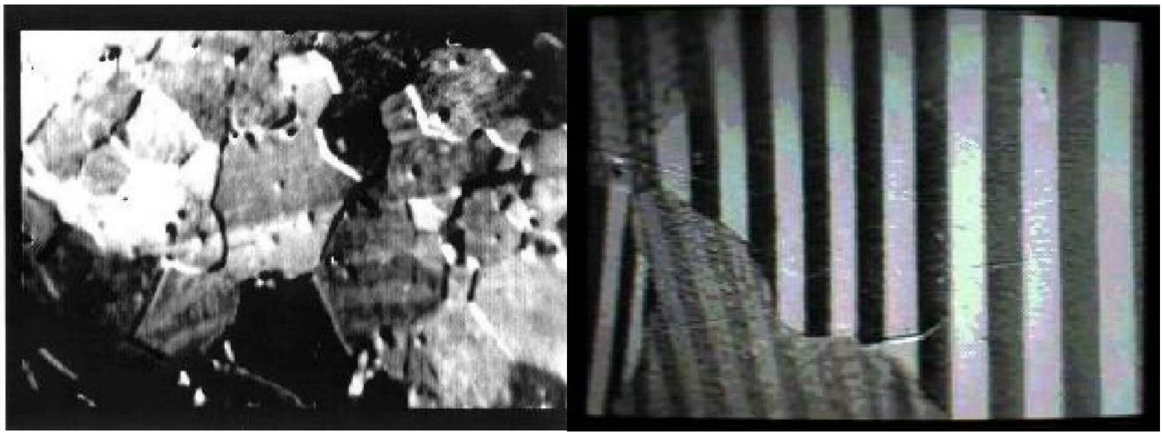

Fig 1.22: Domain structures visualized by magneto-optical Kerr effect (width of the images 3mm). In the NO laminations the orientation and size of the domains is very variable (left). GO laminations have much larger grains and wide domains (right).

In (Fig 1.21), we can see that the induction in the GOs rises very quickly to a value close to saturation. This can be explained very well when we look at the domain structure in (Fig 1.22) the domains are large and well aligned along the rolling direction (LD). When the field is applied along this axis, the domains move easily and the rotation process is almost absent. For the NWs, we see that the wall displacement process is completed around

200 A/m (as for GOs). On the other hand, since the domains are misaligned, it takes a lot of energy to rotate all the magnetic moments in the direction of the field.

GO laminations are used in transformers or chokes. For transformers above 1 kVA, they can be cut into E-I, knowing that the field in the E columns and the I must be //DL. In the E yoke, the field is transverse to the DL, so the losses are higher in this area (about 4 times). Transformers over 10 kVA are made from assembled I's (the connections are cut at 45°). It is also possible to make toroidal or rectangular wound magnetic circuits from 100 to 50 µm GO laminations (in this case they are cut in two to pass the windings). NO laminations are reserved for small transformers (because of the price) and rotating machines.

The steel standard classifies FeSi plates with respect to losses and thickness as :

M - 000 - 00 X

The M stands for magnetic, the first digit indicates the losses expressed in W/kg 100 measured at 50 Hz 1.5 T (1.7 T for S or P), the second digit indicates the thickness expressed in 100th of mm and the final letter the quality (A, D or E for NO, N, S or P for GO).

1.5.3 Iron-cobalt alloys

After Weiss' work on FeCo, G.W. Elmen showed in 1926 that the alloy containing 50% of each metal was much more permeable with approximately equal polarization (2.4 T). However, as this material is difficult to roll, additions are necessary. The most common industrial alloy is Fe48Co48V2 because the vanadium, in addition to improving the laminability, increases the resistivity of the alloy from 6.3 to 26 µcm. This material is reserved for military and aeronautical applications because cobalt is an expensive and strategic metal (39% of the world resource in Zaire, 30 in Cuba, 10 in Zambia, 7 in New Caledonia). The current trend is to reduce the percentage of cobalt to 25 or 18% by improving the orientation of the grains to preserve the magnetic softness.

1.5.4 Iron-nickel alloy

The first Fe-Ni alloys were studied by Hopkinson in 1889, but it was not until 1921 that an alloy containing 78% nickel (Permalloy 78) found application as a magnetic material in telephony.

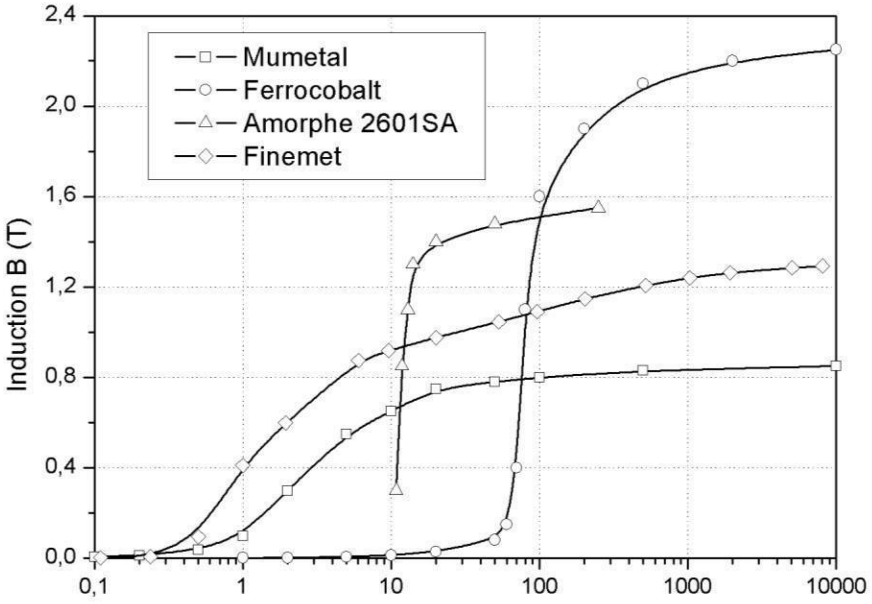

Fig 1.23: First magnetization curves of different crystalline and amorphous special alloys.

Fe-Ni alloys are high permeability alloys. They are mainly divided into two families:

- Permalloy 50, Ni50Fe50, high bias (1.6 T)
- Permalloy 80, Ni80Fe20, with high permeability (~90,000) and low polarization (0.8 T).

Many grades of Permalloy 80 are available containing additive elements whose role is to slightly modify certain physical parameters in order to obtain, for example, zero magnetostriction2 and zero anisotropy at the same time and to increase the resistivity. The main commercial alloys are

- Mollypermalloy, Fe15Ni80Mo5 with optimum resistivity and permeability, which is also used in the form of bonded powders for circuits with a distributed air gap (permeability 20 to 300) which can be used at high frequencies thanks to their fine grain size (20 to 100 µm).
- Mumetal, Fe13Ni78Mo4Cu5 or Fe16Ni77Cr2Cu5, with lower performances but much easier to manufacture (therefore cheaper).

Magnetic FeNiCr stainless steel is also used for induction tableware. The composition allows the Curie point to be adjusted to the desired temperature, thus allowing natural regulation of the cooking temperature.

These alloys are intended for specific applications where very high permeability is essential. Nickel is less strategic than cobalt because resources are more abundant and better distributed.

Magnetostriction is a phenomenon of deformation of material under the action of a magnetic field. The opposite phenomenon can be used to make force transducers, but it is often considered harmful because a stress applied to the magnetic circuit can lead to a degradation of the magnetic properties

Chapter II : Description of the MS5002C turbine

2.1 Introduction

In this chapter we will present a detailed description of the MS 5002C gas turbine. This type of turbine is widely used in the petroleum industry for, among other things, driving the high-powered compressors used in natural gas compression stations. We are going to describe technologically and functionally this turbine by spreading on each constituent part.

2.2 Features of MS 5002C Gas Turbine

The technical characteristics defining a gas turbine type MS 5002C are summarized as follows: [55]

- Brand	GENERALE ELECTRIQUE
- Manufacturer	NUOVO PIGNONE
- Model	MS 5002C series
- Simple	Cycle
- Shaft rotation	Counter clockwise
- Type of operation	Continuous
- Shaft speed	HP5100 rpm
- Shaft speed	BP 4903 rpm
- Command	MARK V
- Exhaust temperature	515°C
- Fuel flow rate	2.314 m^3/s
- Starting system	Expansion turbine
- Thermal efficiency	≈ 28.8%.
- Noise attenuation	Intake andexhaust silencers according to local requirements

- Gas turbine normal speed identification plate (ISO conditions) :

Basic output	35000 MW
Suction temperature	15°C
Output pressure	1 bar

- Compressor section:

Number of axial compressor stages	16
Compressor type	axial flow, heavy duty series
Joint plane	horizontal flange
Type of inlet guide vanes	variable
Inlet pressure	1 bar
Discharge pressure	8.8 bar

- Turbine cross-section:

Number of turbine stages	02 (two shafts)
Joint plane	horizontal flange
Director of the first floor	fixed
Director of the second floor	variable

- Combustion section:

Type	12 multiple hearths, flow type inverses
Concentric chamber	configuration around the compressor
Fuel	Natural gas
Type spark plugs	two, self-retracting spring injection electrode types
Flame detector	Ultraviolet type

- Bearing package:

Quantity	04
Lubrication	Pressure

2.3 Operating principle of a gas turbine type MS 5002

Before the gas turbine is fed and started, the rotor of the high-pressure compressor/turbine is rotated by means of a starting device (launching turbine) until it reaches the ignition speed (20% of its nominal speed) and at the same time helps it to reach a self-supporting speed.

Atmospheric air at ambient temperature and pressure conditions is drawn in and compressed by the 16-stage axial compressor and fed to the combustion. Constant pressure combustion takes place continuously until the fuel is interrupted, thus producing hot gases at high pressure and temperature which expands through the turbine wheels until it reaches the pressure atmospheric pressure. The first impeller, known as the high pressure (HP) impeller, is designed solely to drive the axial compressor and the accessories attached to the shaft, while the second impeller, known as the low pressure (LP) impeller, is connected to the shaft known as the low pressure (LP) impeller, which is designed to drive the centrifugal compressor (Fig II.1).

The starting device consists of :

- An expansion turbine.
- A jaw clutch.
- A shut-off valve and pressure regulation.

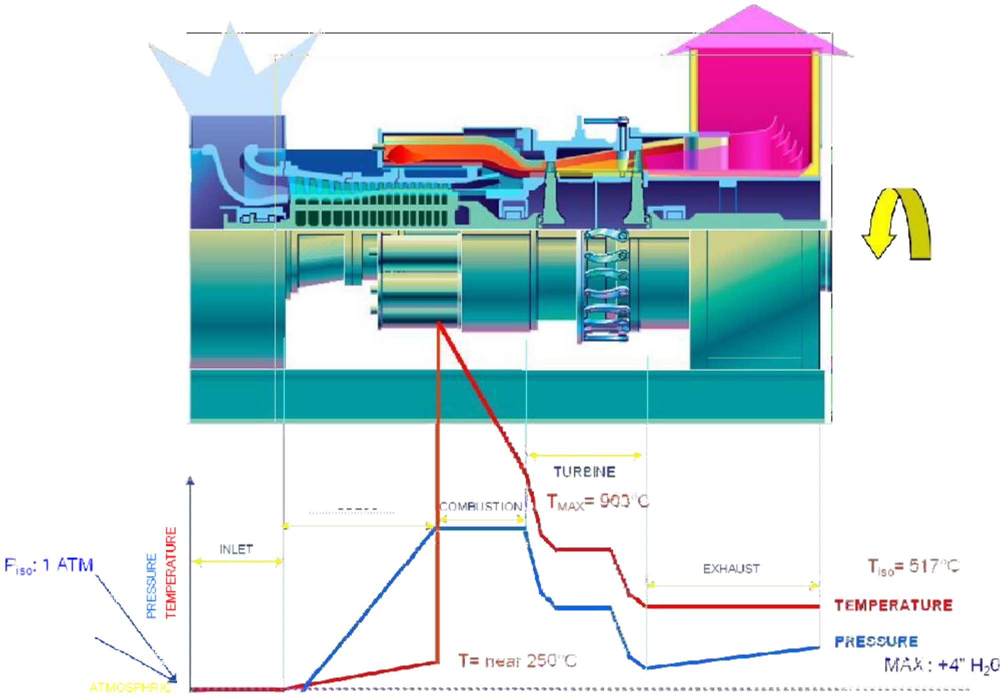

Fig 2.1: Pressure and temperature variations in the different sections of the machine (ISO conditions).

2.4. Technological Description of MS 5002C Gas Turbine

2.4.1. Turbine base

The baseplate that supports the gas turbine is a structural steel frame made of L-beams and plates. The base frame, composed of two wide-flanged longitudinal beams with three transverse elements, forms the bed on which the vertical supports for the turbine are mounted. For disassembly, there are trunnions and lifting supports, two on each side of the base, in line with the first two transverse elements of the base frame structure.

2.4.2. Axial compressor

The axial flow compressor section consists of a rotor and a compressor body which includes the sixteen compression stages, variable inlet guide vanes and two outlet guide vanes. In the compressor, the rotor blades provide the force for compressing the air in each stage and the stator blades guide the air into the next stage of the rotor at the corresponding angle. The compressed air exits through the compressor discharge casing to the casing and combustion chambers.

- Compressor rotor

The compressor rotor consists of a set of sixteen impellers, a stub shaft, anchor bolts, and the compressor rotor blades. Each of the impellers and the impeller portion of the front stub shaft has slots pinned around its periphery. The rotor blades are inserted into these slots and held in axial position by spacers stapled to each end of the slot. These blades are wing-shaped and designed to compress air efficiently at high speeds. The impellers and stub shafts are joined together with mating rabbets for concentricity control and are held together with anchor bolts. Selective positioning of the impeller is done to reduce the balancing correction. After assembly, the rotor is dynamically balanced to the fine limit. (Fig 2.2).

- Compressor stator

The stator (body) area of the compressor section consists of three major sections:

- Inlet body
- Compression body
- Compressor discharge body

These sections, together with the turbine casing, form the primary external structure of the gas turbine. They support the rotor at the support points and form the outer wall of the gas path annulus. The bore of the casing is maintained to closed tolerances relative to the rotor blade tips for maximum efficiency (Fig 2.3).

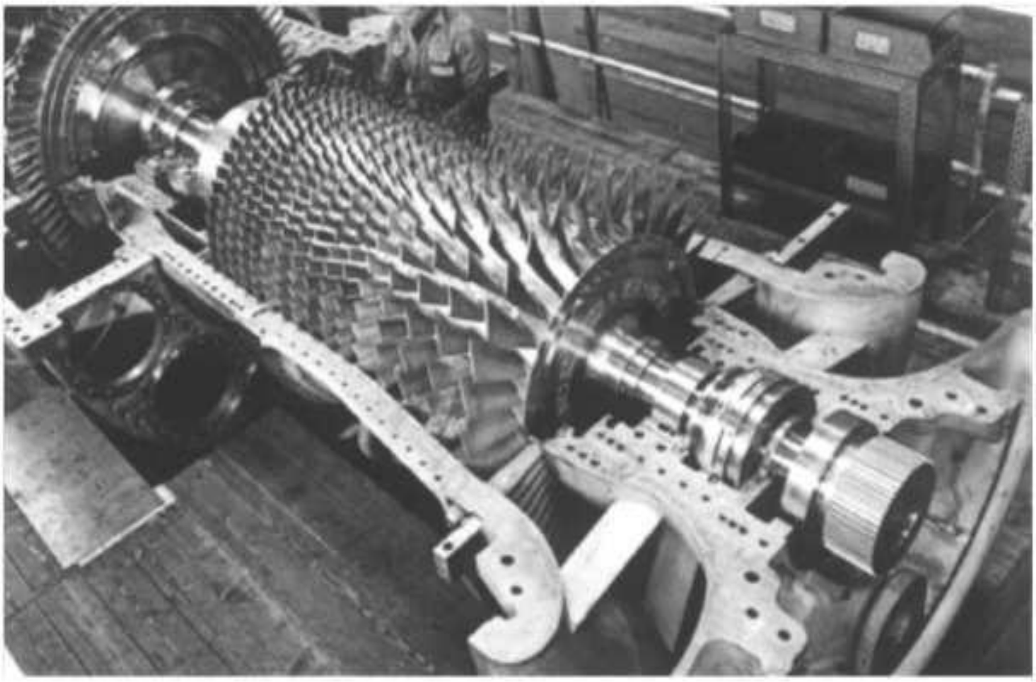

Fig 2.2: Axial compressor rotor

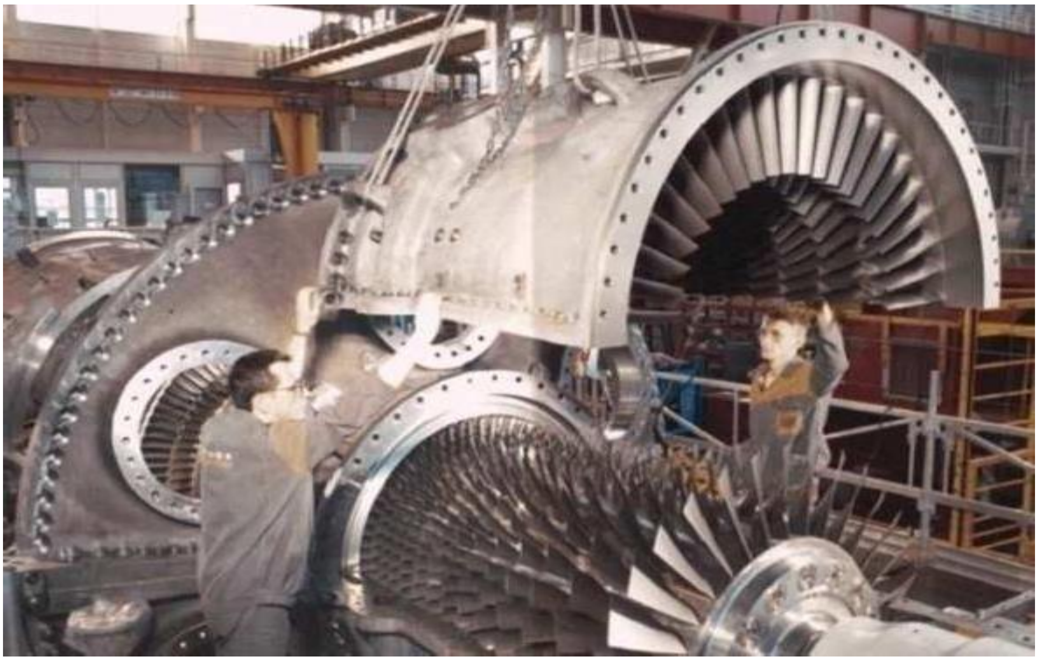

Fig 2.3: Stator of the axial compressor

- Inlet body

The inlet casing is positioned at the front end of the gas turbine. Its main function is to direct air evenly into the compressor. The casing also supports the No. 1 bearing assembly, the lower half of which is a separate casing, flanged and bolted to the lower half of the casing. The elements and bars are encased in the flare walls. The variable inlet guide vanes allow rapid, uniform acceleration (IGV) of the turbine without compressor shock (impulse).

- Compressor body

The compressor housing contains the first 10 stages of the compressor stator. The compressor casing is equipped with two large integrally cast trunnions which are used to lift the gas turbine when it is separated from its baseplate. The first four stages of the stator blades in the compressor casing are assembled in slotted semi-circular rings. The stator blade and ring assemblies are then installed in dovetail grooves machined into the wall of the compressor housing. Locking pins, installed in a groove machined into the left and right side of the upper half horizontal seal flange, prevent these assemblies from rotating in the stator grooves and falling out when the upper half of the body is lifted. The fifth and tenth stage stator vanes are installed on the dovetail grooves machined into the wall of the compressor body. Long locking pins installed in machined grooves on the left and right side of the horizontal flange of the half body, prevent the stator blades from turning in the stator grooves and falling off when lifting the half body.

- Compressor discharge body

The compressor discharge housing is the aft portion of the compressor section. It is the longest single body, located at the center point between the front and rear turbine supports. The functions of the compressor discharge casing are to enclose the compressor shock balance, form the inner and outer walls of the compressor diffuser and join the compressor and turbine stators, and provide support for the first stage turbine nozzle. The compressor discharge casing consists of two cylinders, one being a continuation of the compressor casing and the other being an inner cylinder surrounding the compressor rotor. The two cylinders are concentrically positioned by eight compressed elements which are rounded to respect the large diameter of the turbine casing. The support structure for the No. 2 bearing is located in the inner cylinder. A diffuser is closed by the conical annular space between the outer cylinder and the inner cylinder of the discharge casing. The diffuser converts part of the compressor's output speed into added pressure.

The compressor discharge casing contains the remainder of the six (eleventh through sixteenth) stator blade stages and the two rows of exit guide vanes which consist of single vanes installed in dovetail grooves machined into the wall of the EGV compressor discharge casing. Locking keys installed in grooves machined into the horizontal flanges of the upper half of the casing joints prevent the blades from rotating and serve to prevent the stator blades from falling out of the grooves when the upper half of the casing is lifted.

2.4.3. Combustion section

The combustion section of a gas turbine engine consists of the combustor casing, twelve combustor outer shells, twelve cover and liner assemblies, twelve reduction gear assemblies, twelve fuel injectors, two spark plugs, two ignition transformers, four flame sensors, twelve cross tubes, and miscellaneous hardware and fittings. The combustion chamber shell surrounds the aft section of the compressor discharge housing and receives the discharge air from the axial flow compressor.

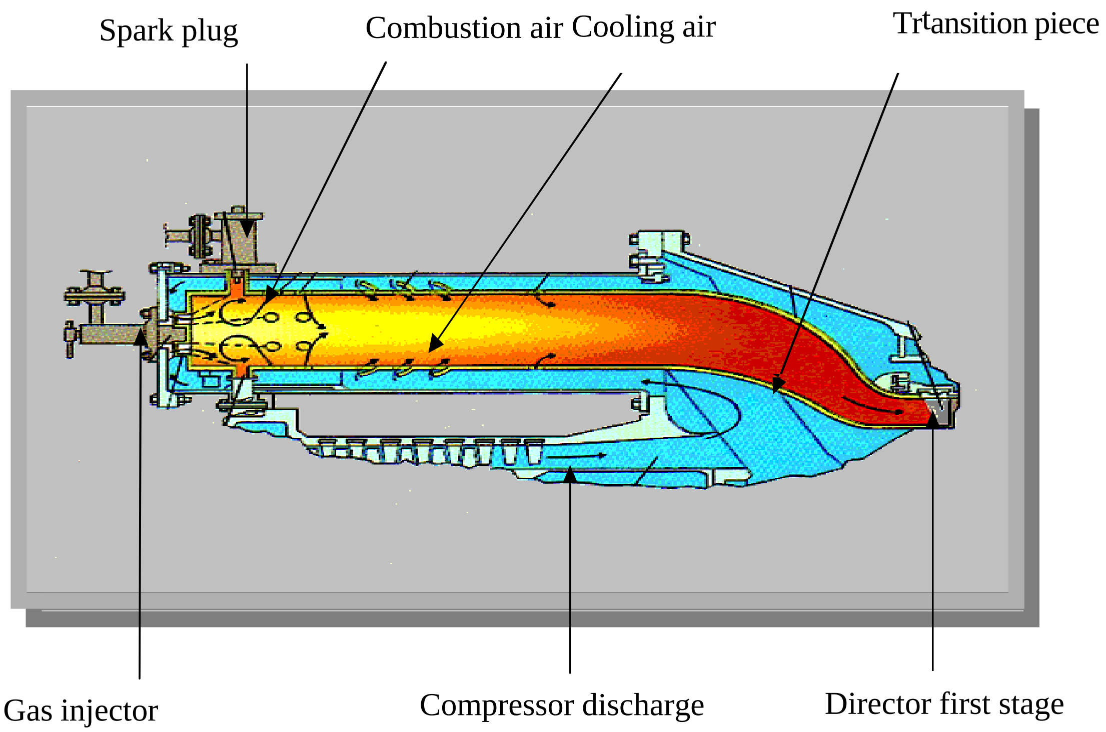

Fig 2.4: Combustion chamber [2]

Various designs of combustion chamber casings are used for MS 5002C gas turbines, including short and long casings. The combustor casings are positioned on the outside of the short casing and on the inside of the long casing. Fuel is fed into each combustion chamber liner by a fuel injector mounted on the combustion chamber cover that extends into the liner. The combustion of the fuel-air mixture is initiated by two spark plugs, when ignition is activated in one of the two chambers, the hot combustion gases flow through the cross tubes to ignite the fuel-air mixture in the other chambers through interconnections.

- Combustion chamber casing

The combustion chamber shell supports the twelve combustion chamber housings and contains the twelve reduction parts. It is a welded enclosure that receives the discharge air from the axial flow compressor and transfers it to the combustion chambers. The top and bottom halves of the casing are joined to the rear section and the entire casing is bolted to the vertical front flange of the turbine casing, the front flange is bolted to the rear flange of the compressor discharge casing (Fig III.5).

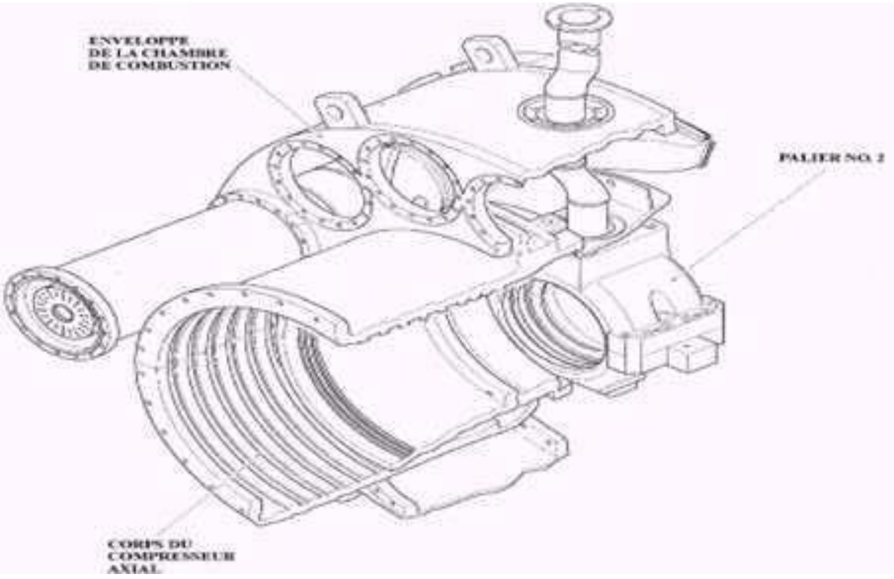

Fig 2.5: Combustion chamber shell, compressor discharge housing and bearing assembly N°2 [2]

- Combustion chamber

All twelve combustion chambers are assembled in the combustion jacket with each of the covers and liners interconnected by cross tubes. Fuel injectors mounted on the combustion chamber covers extend into the chambers and supply the fuel required for the combustion process.

During operation, compressor air flows into the combustion chamber shell and into the annular space between the chamber liner and the flow sleeves. This high-pressure air flows into the liner, mixes with fuel and ignites. The resulting hot gases flow from the liner into the tightly packed reduction piece at the first stage injector assembly. Flame detectors, installed in two chambers, send a signal to the control system indicating that ignition is initiated.

The combustion of the air-fuel mixture is initiated by spark plugs with retractable electrodes. Two candles are installed in each of the two combustion chambers (N°9 and N°10). The combustion in the rest of the chambers, without spark plugs, is initiated with the flame of the chambers in question through its transversal interconnection tubes. During the start-up sequence, it is essential that an indication of the presence or absence of flame be transmitted to the control system. To this end, a flame monitoring system consisting of four sensors is used.

Each of the combustion chambers is equipped with a fuel injector that injects a measured amount of fuel into the combustion chamber. The gaseous fuel is admitted directly into each chamber through metering holes positioned at the outer edge of the fuel injector tips. The swirling action of the casing cover imparts a swirl to the air entering the combustion chamber in order to have a more complete and homogeneous combustion (Fig II.6).

The twelve combustion chambers are interconnected by means of transverse tubes. These tubes allow the flame from the initially primed chambers containing candles to propagate to the unprimed chambers (Fig II.7).

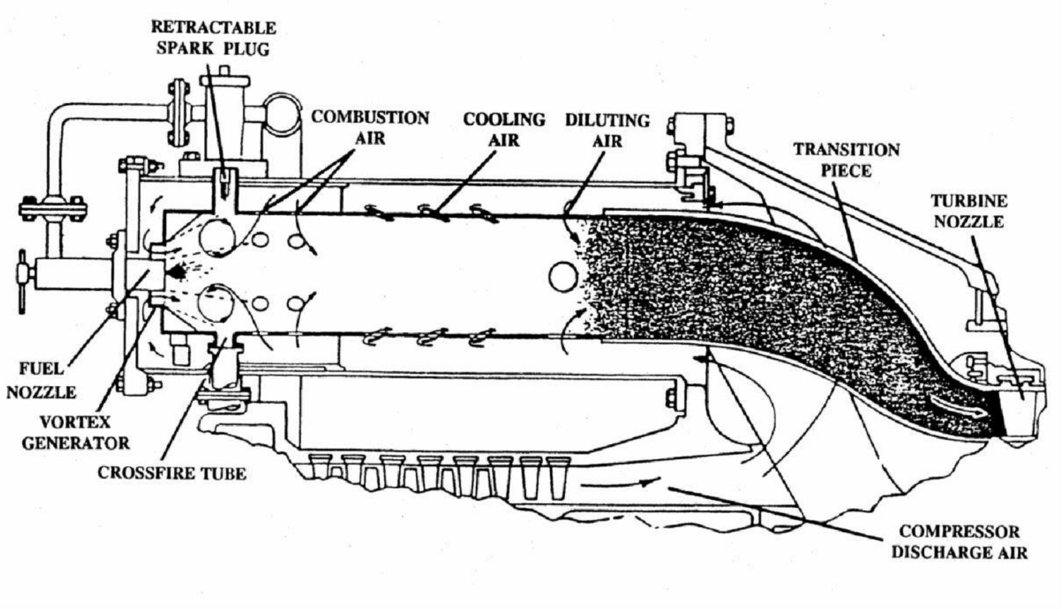

Fig 2.6: Schematic showing the components of a combustion chamber [2]

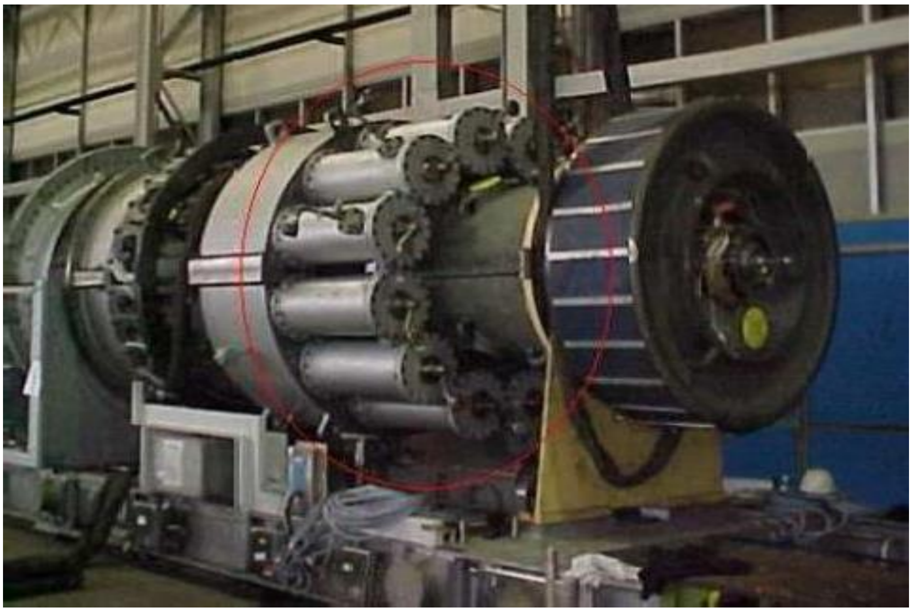

Fig 2.7: The twelve combustion chambers [5]

2.4.4. Turbine section

The turbine section is where the high-temperature gases from the combustion chamber section are transformed into power measured on the shaft. This section contains the following components:

- The turbine housing
- The first stage injector

- The first stage turbine wheel referred to as a high pressure turbine
- The variable director
- The turbine wheel of the second stage is powered as a low pressure turbine

2.4.4.1 Turbine stator

The turbine casing is the main component of the gas turbine assembly. It is attached to the end of the compressor discharge casing. The burnt gases leaving the combustion chamber pass through the turbine where a work exchange takes place by means of a partial expansion of the gases, and finally go to the exhaust frame; it consists of the following parts:

- The partitions and protection rings of the first stage injector
- The segments of the inner and outer walls of the gas path between the floors
- The diaphragm and the air seal of the second stage as well as the partitions and the protection rings of the second stage injector

2.4.4.2 First stage injector

The first stage injector assembly consists of injector segments assembled in a locking ring. The ring is supported in the gas path by a turbine housing mounting arrangement. The design of the injector assembly and arrangement for being supported in the casing will accommodate the effects of thermal growth due to hot gases and keep the assembly neatly aligned in the gas path. Another unique feature of this design is that it allows removal of the lower half of the injector assembly without removing the rotor.

2.4.4.3 Second stage injector

The second stage injector consists of partitions (rotating vanes) that form a variable angle nozzle in the annular space of the gas path, more precisely before the second stage turbine wheel. These partitions can be turned in unison with shafts that penetrate the turbine casing sleeves. The levers, attached to the ends of the shafts, are connected by joints to the uprights in a control ring that is turned by a hydraulic cylinder. The partition shafts are installed in the turbine body to maintain minimum clearances between the partitions and the protection rings when the turbine is at operating temperature (Fig 2.8).

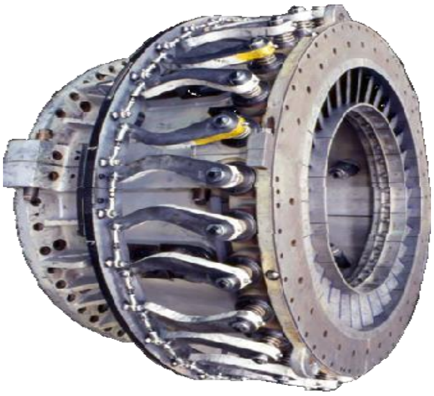

Fig 2.8: Variable director

2.4.4.5 Rotors and turbine wheels

The gas turbine, the subject of this study, consists of two separate rotors:

- The first stage rotor or high pressure turbine that drives the axial flow compressor and other accessories driven by this shaft (Fig 2.9)
- The rotor of the second stage or low pressure turbine which controls the load (Fig 2.10)

Fig 2.9: HP rotor of the MS5002C gas turbine

Fig 2.10: LP rotor of the MS5002C gas turbine [2]

The two turbine rotors are positioned in line in the turbine section but are mechanically independent of each other, allowing the two turbines to operate at different speeds. The first stage turbine wheel is bolted to a gear shaft to form the low pressure (load) turbine rotor, which is supported by two bearings.

The turbine blades are assembled in axial, pine tree dovetail bearings with covers installed over the blade shafts. Each second cover is a locking cover. The blades are locked in position by means of a twist lock, the head of which is staked in place.

2.4.5. Bearing and coupling

2.4.5.1 Bearings

The gas turbine has four main bearings supporting the compressor and turbine rotors. These bearings are numbered 1, 2, 3 and 4. Bearing No. 1 is located in the compressor inlet casing, bearing No. 2 is located in the compressor discharge casing, and bearings No. 3 and No. 4 are located in separate extensions bolted to the rear of the inner baffle of the exhaust frame. Bearings 1 and 2 support the high pressure turbine compressor rotor and bearings 3 and 4 support the turbine rotor.

Of power (low pressure). The bearing types used in the gas turbine are listed in the table below.

Bearing		
N°	Type	**Type**
1	Carrier	**Elliptical**
	Stop (active)	**Oscillating skid (six skids) Self-balancing**
	Stop (inactive)	**Conical shape**
2	Carrier	**Elliptical**
3	Carrier	**Oscillating skid (five skids)**
4	Carrier	**Oscillating skid (five skids)**
	Stop (active)	**Oscillating skid (eight skids) Self-balancing**
	Stop (inactive)	**Oscillating skid (four skids) Non-balancing**

Table 2.1: Bearing assemblies [2]

2.4.5.2 Coupling

The basic functions of the gear type couplings used on this turbine are:

- To connect two shafts in rotation, so as to transmit the dome from one to the other.
- Compensate for all three types of misalignment (parallel, angular and a combination of the two).
- To compensate for all axial movements of the shafts, so that neither exerts excessive thrust on the other.

Parallel misalignment occurs when the two coupled shafts are parallel, but not in the same alignment. Angular misalignment occurs when the axes of the two shafts are aligned but their centerlines are not parallel. A

Combined misalignment occurs when the shafts are neither parallel nor in alignment. Axial movement occurs when one of the two shafts is displaced along its axis (centerline).

2.4.5.3 Continuously lubricated auxiliary gear coupling

This coupling is a continuously lubricated, elastic type device. It consists of a hub fitted at each end with a gear-type assembly. At both ends, the coupling meshes with the teeth of the shafts to be connected to transmit torque. The teeth of the male shafts of the coupling are crowned and can slide forwards and backwards within the female splines. This allows all three types of misalignment. The sleeve on the shaft on the auxiliary gearbox side is bolted (hub) which has been hot pressed onto the auxiliary gearbox shaft. The sleeve on the turbine end is bolted directly to the turbine shaft.

2.4.5.4 Non-lubricated load coupling

The non-lubricated coupling consists of a flexible diaphragm, an adapter shaft and a centering shaft. The adapter shafts, mounted at the ends of the centering shaft, include flanges that connect to the load gearbox and the load turbine rotor shaft, also providing supports for the flexible diaphragms. The sections of the diaphragms provide the flexibility to compensate for any misalignment of the load gearboxes and load turbine rotor, allowing axial movement of the turbine relative to the load gearbox.

2.4.6. Turbine auxiliaries

The gas turbine includes a number of control, protection and auxiliary systems associated with the proper operation of the turbine.

These systems include:

- Fuel gas system.
- Lubricating oil system.
- Hydraulic oil system.
- Control oil system.
- Air sealing and cooling system.

2.4.6.1 Fuel gas system

The Fuel Gas System is designed to deliver gaseous fuel to the turbine combustion chambers at the appropriate pressure and flow rate to meet all turbine start-up, acceleration and power-up requirements. The main element of this system is the control and stop/expansion valve located in the accessory area. This valve is associated with the vent valve, servo control valves, pressure gauges and distribution piping to the injectors.

2.4.6.2 Lubricating oil system

The lubrication of the gas turbine is carried out by a pressurized lubrication circuit and includes various accessories such as: pump, airfoil, filters, valves and other control and protection devices. The lubricating oil from the tank is pumped into a manifold, cooled and filtered before being injected into the four axial compressor bearings. Some of this oil feeds the hydraulic circuit, the control circuit and the seal oil circuit. The oil drained from the equipment returns via a manifold to the oil tank, which is slightly pressurized by the sealing air flowing through the bearing seals and therefore reaches the tank. The lubricating oil system is vented to atmosphere.

2.4.6.3 Hydraulic oil system

The functions of the hydraulic system are numerous and include the supply of high pressure oil for the position control of the shut-off valve. Speed ratio, fuel control valve, second stage director and operation of the hydraulic turbine protection release system. Filtered and regulated lubricating oil from the turbine bearing manifold is used as the high pressure fluid required to meet the needs of the hydraulic system. This oil is first pressurized using a piston-type pump driven by the accessory gear.

2.4.6.4 Air sealing system

The vast majority of the compressed air is used for combustion. Some of this air is removed from the 10th stage compressor and used as cooling air, some comes from the compressor discharge and is used as pressurization air, some is used for combustion, and some is used for combustion.

Part comes from the ambient air. The different parts of the turbine that have to be cooled are :

- Front and rear of the HP and BP turbine wheels.
- The ^{1st} stage nozzle and its retaining ring.

- Spacer for supporting the inner cylindrical body.

2.4.6.5 Extracted air from the 10th floor

The air extracted from the 10th stage of the compressor is used to :

- Sealing of bearings No. 1, 3 and 4 against oil leakage. This air is first passed through a centrifugal dirt separator which removes any dust particles or foreign matter that could damage the bearings. The accumulated dirt is discharged from the separator by a continuous extraction. The sealing air is drained from the bearings into the main oil tank.

- The cooling of the front and rear faces of the HP and BP turbine wheels, of the 1^{st} stage nozzle, of the turbine rotor casing and of the exhaust frame. Indeed, at these places the temperatures are very high and can reduce the life of these parts.

2.4.6.6 Air leakage from HP seals

The N2 bearing which supports the HP turbine shaft is sealed by the leaking HP seal air from the axial compressor. This air is also drained to the oil tank.

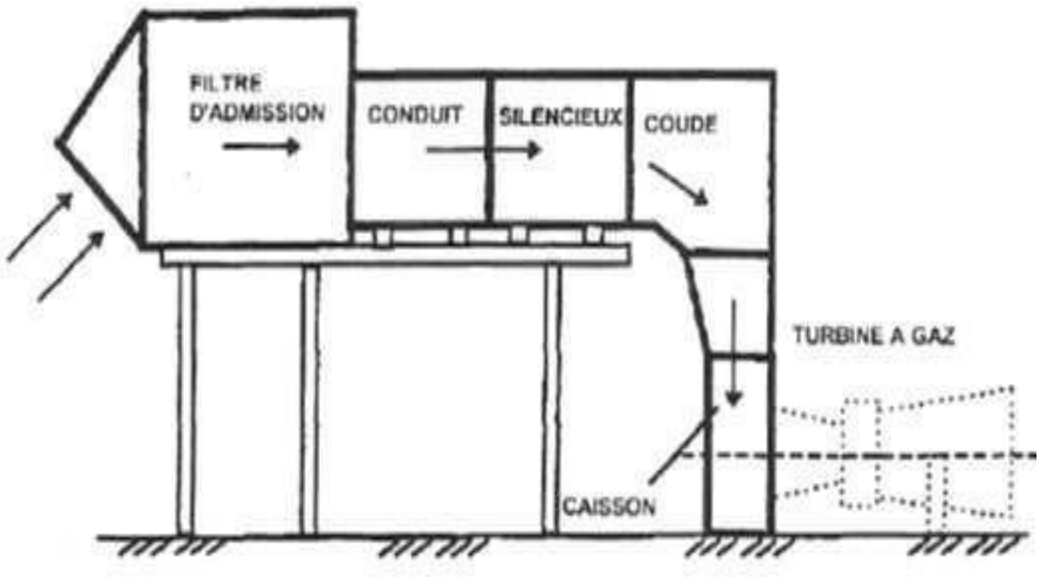

Fig 2.11: Typical intake system [2]

2.5. Command and control systems

The role of control is to ensure a specific operating point characterized by a fixed holding variable to which limitations of other operating parameters are added. An automatic control system maintains a stable system, so that when it receives the measurement of a variable such as temperature or pressure, it activates a consumption device so that the variable is maintained at or near the desired value. There are several turbine control systems:

- Microprocessor control
- Electropneumatic
- Electronic (speed tronic)

The choice of the type of regulation is based on two fundamental factors:

- The precision of the regulation (desired result)
- The difficulty of regulating the process

The operation of the gas turbine is managed by a set of controls that take care of the machine from the launch and acceleration phase to the load. In the following, we will develop a very common control system specific to the manufacturer General Electric.

2.5.1 Launch command

The start control performs the fuel supply program for the gas turbine from the momentthe rotor starts turning until the turbine is under the control of the speed governor.

Fixed fuel levels control and protect the turbine during this period which includes the following steps:

- VCE Zero
- VCE ignition
- VCE Reheating
- VCE Acceleration
- VCE Maximum
- VCE Minimum

The following diagram shows graphically the fuel sequence during the start-up cycle. During the initial start-up period, the ECV (fuel) is maintained at zero until ignition speed is reached (about 22% of nominal speed) and the ventilation (purging) of the turbine is completed. It should be noted that the ventilation phase is very important because it allows all the fuel residues to be evacuated, thus eliminating any risk of explosion.

The ignition ECV level is then requested and ignition is produced by spark generation from the spark plugs. After flame detection, the ECV is reduced to the reheat value; the fuel supply to the combustion chambers is gradually increased at a predetermined rate until the ECV reaches a fixed acceleration limit.

As the turbine accelerates to its rated speed, the airflow increases so that more fuel must be supplied to the combustion chambers. When the turbine ECV is under the control of the speed governor, the fixed fuel limit is transferred from the acceleration level to the maximum level. However, the ECV that is actually applied remains at the level requested by the speed control system.

2.5.2 Speed control

The speed control system compares the turbine speed with a digital set point (D.S.P.), i.e. the requested speed (customer signal), and adjusts the fuel VCE to the value necessary to maintain the operating speed equal to the requested speed. The speed control system basically consists of two sub-systems:

- The speed signal
- The speed set point.

Various functions of the turbine speed control system are programmed according to the speed of the turbine shaft. Therefore, a speed sensor system is required for the speed control system.

2.5.3 Temperature control

The temperature control system compares the turbine exhaust temperature to a temperature limit set point and reduces the fuel ECV to prevent this temperature limit from being exceeded. In this system, the turbine exhaust temperature Tx is measured as an indication of the operating point and is compared to the setpoint limit by a control system. Although the exhaust temperature is measured, the actual temperature limit is the inlet temperature of the first turbine wheel, called the firing temperature Tf. If the nominal temperature at the turbine inlet is exceeded, the life of the parts in the hot gas stream would be reduced. The temperature at the turbine inlet is difficult to measure accurately because the thermocouples installed there would have a very short life due to the temperatures prevailing there. The temperature control system consists of three main subsystems:

- Temperature measurement ;
- Thermocouple signal processing module ;
- Temperature comparison.

2.5.4 Control of a two-shaft turbine

All two-shaft gas turbines have two mechanically independent turbine wheels: the first stage wheel or HP turbine wheel drives the axial flow compressor. The second stage wheel, the so-called low pressure wheel, drives the compressor which represents the load. The use of two separate turbine wheels allows the two shafts to rotate at different speeds to meet the varying load requirements of the centrifugal compressor, while allowing the high pressure gas generator to operate at the rated speed of the axial flow compressor.

The second stage variable angle director separates the high and low pressure turbines. The total energy level corresponding to the fuel flow is established by the load requirements on the low-pressure shaft, while the energy distribution between the high- and low-pressure turbines is determined by the pressure drop across each turbine. When the variable angle second stage nozzle is opened, the back pressure on the high pressure turbine decreases, increasing the pressure drop and torque produced by the high pressure turbine. This allows the speed of the low pressure shaft to be controlled.

2.5.5 Axial compressor inlet variable vanes

The action of the variable blades at the inlet is twofold. Firstly, by restricting the flow of air to the compressor, they modify the conditions determining the pulsations of the compressor and by limiting the mass flow of the turbine, they reduce its cooling, which results in a higher exhaust temperature for a given fuel flow.

The axial compressor is subject to pulsation in the low speed range, the compressor pulsation is due to instability or flow reversal which can damage the turbine. The variable inlet vanes are held in the low flow position and the tenth stage bleeders open to protect the compressor from launch pulsation. As soon as the compressor speed is no longer in the pulsation zone, the inlet vanes are opened and the tenth stage bleeders are closed.

2.5.6 Variable second floor directors

The second stage director assembly is composed of rotatable blades that allow avariable angle with the direction of gas flow in the annular section just before the second stage of the turbine. These vanes can be rotated as a whole by means of shafts that protrude through the sleeves provided in the turbine housing. Levers are keyed to the end of these shafts and are connected by rods to points on the control ring which is itself operated by a hydraulic piston.

The second stage variable angle guideways separate the HP and LP turbines, the fuel flow is determined by the load demands of the LP shaft while the energy split between the HP and LP turbines is determined by the speed required by the HP. The variable directors divide the available energy between the two impellers by changing the drop of the respective turbines.

The minimum opening position of the guide vanes allows for easy start-up because the axial compressor requires little power at low flow rates. In addition, combustion is easier because the temperature in the combustion chamber increases. This position prevents the compressor from pulsating. Their role is also to keep the rotation speed of the HP turbine constant at 100% of the nominal speed whatever the load required by the working machine.

2.6. Protection systems

Turbine protection is provided by primary and secondary protection systems. The components of some of these systems operate through the switchboard of the turbine control panel. Other protection systems act directly on the turbine components and are therefore independent of the control panel. The hydraulic trip system is the primary protective interface between the turbine control panel and the turbine-mounted components that shut down the main fuel by closing the shut-off valves. These devices shut down the turbine through the hydraulic trip system by discharging pressurized oil through an electro-hydraulic valve.

- **Protection against overheating (excess temperature)**

This system protects the gas turbine against possible damage due to over- combustion. It is a backup system that comes into play only after the speed and temperature override loops fail. Under normal operating conditions, the exhaust temperature control system responds to adjust the fuel flow when the inlet temperature limit is reached. However, for certain failure modes, the exhaust temperature and fuel flow may exceed the control limits. Under these conditions the system will give an alarm signal before tripping. This allows the operator to react to reduce the load. The alarm setpoint is 11°C above the temperature setpoint and the trip point is 22°C above the control point.

- **Protection against vibrations**

The vibration protection system consists of several independent channels. Each channel detects an excessive level of vibration by means of a vibration transducer mounted on the turbine bearing housing and on the bearings of the driven machine. The system detects two levels of vibration:

- An alarm level
- A trigger level

The system alarms and triggers the turbine in the event of excessive vibration via the Speed tronic panel of the hydraulic release system and the relief valve.

- **Overspeed protection**

The speed of the gas turbine is controlled by two secondary systems which are:

- The speed sensor control system
- The exhaust temperature control system

In order to achieve overspeed protection, each rotating shaft of the gas turbine assembly is equipped with two independent overspeed trip systems, namely:

- An electrical system
- A mechanical system with over speed weights

- **Flame detection and protection system**

The flame detection system is used to detect the flame in the combustion chambers and to trigger it in the event of incorrect combustion during the start-up and operating phases.

- During the launch, the fuel is ignited by the spark plugs when the speed value reaches 20% of the nominal speed. These spark plugs are energised for approximately one minute. When the ignition period is over, the flame sensor shall signal the presence of a flame in the combustion chambers or the ignition test shall be cancelled by closing the fuel shut-off valve and cutting off the power supply to the ignition system.

- During normal operation, the turbine is also protected against flame loss (flame-out). If a flame failure is detected, the turbine is switched off.

2.7 Conclusion

A detailed description of the MS 5002C gas turbine has been presented throughout this chapter. All the constituent parts of this turbine have been discussed from a technological and functional point of view. Finally, a study of the command and control system and the protection system has been presented.

Chapter III :

Experimental study

3.1. Introduction

Various methods have been implemented to optimize combustion performance. A promising way to reduce exhaust emissions and fuel consumption is to use magnetized fuel (Okoronkwo et al., 2010).[1]

Most researchers use permanent magnets or iron as the source of the magnetic field. It is believed that the use of magnetized fuel can improve the combustion performance of the turbine, as shown by the reduction in fuel consumption. [1]

This is based on several previous studies (Faris et al., 2012; Mane and Sawant, 2015; Vivek, Nikhil, and Lutade, 2013), which showed that by using fuel exposed to a strong magnetic field (>2 kG) , The combustion performance of the engine will increase, and the magnetic field strength will decrease over time. Otherwise, the magnetic field generated by the winding at the coil core will be electrically traversable, which is commonly known as an electromagnet reduce.

Magnetic effects cause changes in fuel molecules from aggregated to disaggregated. This effect is expected to result in a 40% reduction in HC emissions and a 35% reduction in particulate matter.

The information provided in this study is less complete due to the number of solenoids in the combustion chamber of the MS5002C turbine. In addition to influencing the operation of other electronic instruments, generating such a strong field takes a lot of work.

3.2 Methodology

Magnetic fuel treatment works by the interaction of a magnetic field with the fuel hydrocarbon and oxygen molecules. Liquid fuel is a mixture of organic chemicals consisting mainly of carbon and hydrogen atoms - hydrocarbons. Due to the different forces of physical attraction, they form densely packed structures called pseudo-compounds that can further organize into clusters or associations. [5]

These structures are relatively stable and during the process of mixing air with fuel, oxygen atoms cannot penetrate inside them. Thus, it is difficult to access the appropriate amounts of oxygen to the interior of these molecular groups (associations).

This results in incomplete combustion of fuel inside such associations and causes the formation of carbon particles and carbon monoxide, and an increase in the amount of hydrocarbons emitted to the environment.[6]

It is now generally accepted that hydrocarbon fuels can be polarized by exposure to external forces (such as magnetism). The function of this magnetism is to generate the torque generated by the movement of the outer electrons of the hydrocarbon chain, and move the electrons to a state of higher principal quantum number.

This state effectively decomposes the fixed valence electrons involved in the bonding process of the fuel compound. These states create conditions for more freely associating fuel details. In doing so, the hydrocarbon fuel becomes oriented or aligned, which does not necessarily produce new hydrocarbon chains, but it is more explainable that the conductive magnetic moment is arranged in a dipole relationship within itself.

This magnetic arrangement then allows rapid bonding with the corresponding oxidizing medium. Of course, the result is more complete and faster combustion of hydrocarbon fuels.[7,8]

Hydrocarbon molecules treated with a high magnetic field tend to declustered, forming smaller associations, with a higher specific surface area, used to react with oxygen, thereby improving combustion. According to the weak agglomeration force discovered by Van der Waals, there is a strong combination of hydrocarbons and oxygen in this magnetized fuel, which ensures optimal combustion of the mixture in the engine room.

The result of treating fuel with a high magnetic field is to improve fuel combustion, thereby increasing engine power and reducing fuel consumption. Another result of improved fuel combustion is the reduction of carbon particles, carbon monoxide and hydrocarbon emissions. In our research, the focus is on understanding the magnetic interaction modes that lead to fuel economy and reduced exhaust emissions in turbine applications.[5,10]

Hydrocarbons basically have a "cage-like" structure. This is why the oxidation of its internal carbon atoms is hindered during the combustion process. In addition, they combine into a larger group of pseudo-compounds. These groups form clusters (associations). The right amount of oxygen is blocked from entering the molecular group, and it is this lack of oxygen that prevents full combustion.[11]

The exhaust gas should theoretically contain carbon dioxide, water vapor and nitrogen in the air, which do not participate in combustion. In fact, exhaust gas contains CO, H2, HC, NOx and O2. In fact, the complete combustion of the fuel will never be achieved, and the incompletely oxidized carbon obviously exists in the form of HC and CO, or is deposited as black carbon residue on the inner combustion chamber wall.

Hydrocarbon fuel particles exposed to magnetic energy tend to decay, creating smaller particles that are more easily penetrated by oxygen, which leads to better combustion.They become normalized and independent, spaced apart, have a larger surface area available to bind (attract) with more oxygen (better oxidation).

According to van der Waals' discovery of the weak focus force, such magnetized fuel binds hydrocarbons with oxygen, which ensures optimal combustion of the mixture in the engine compartment.

In our study, we focused on understanding the magnetic operation modes that have led to fuel economy and reduced engine exhaust emissions.

3.3. Data processing

The test data results were compared between the fuel before and after magnetization and then quantified into several graphs that show fuel consumption by fuel composition and CO and NOx emissions to fuel composition, then reanalyzed referring to several reference journals listed in the bibliography. The efficiency of a diesel engine is shown by the success rate in converting the chemical energy contained in the fuel into mechanical energy. Fuel consumption (fuel consumption) Fuel consumption (fuel consumption) is the amount of fuel used by an engine over a given time period. Meanwhile, sfc (Specific Fuel Consumption) is the amount of fuel used by an engine in a given unit of time to produce effective power. If the test obtained data on fuel consumption m (kg) in s (seconds), and the power produced is bhp (hp), then the fuel consumption per hour $\dot{m}_{\text{bb}}$: [12]

$$m_{bb} = \frac{m_{bb}}{s} \quad \text{(kg/s)}$$

$$\dot{m}_{bb} = \frac{3600 \cdot m_{bb}}{s}$$

While the amount of specific fuel usage is Dengan

$$Sfc = \frac{3600 \cdot \dot{m}_{bb}}{bhp} \quad \text{(kg/kW.hour)}$$

$\dot{m}_{bb}$ = fuel consumption per unit of time (kg/secor kg/hour)

S = fuel consumption time (sec)

Sfc = specific fuel consumption (kg/hp.hour)

3.3.1. Combustion process with Stoichiometric calculation

Hydrocarbon fuels will be oxidized thoroughly to carbon dioxide (CO2) and water vapor (H2O) if there is sufficient oxygen supply. Such combustion conditions are called stoichiometric combustion and the chemical reaction equation for stoichiometric combustion of a Biodiesel fuel (esters from palmitate) (CxHyOγ) with air written as follows [13]

CαHβOγ + a(O2 + 3,76N2) → bCO2 + cH2O + dN2

Equilibrium C : α =b

Equilibrium H : $\beta =2c$à$c =\beta /2$

Equilibrium O: γ + 2a = 2b + c à 2a = 2α + β/2 - γàa = α + β /4 – γ/2

Equilibrium N :2(3,76)a = 2d à d = 3,76a àd = 3,76 (α + β /4 – γ/2)

Substitution of the equilibrium equations above into the combustion reaction equation CxHyOγ produces the following equation:

$C_\alpha H_\beta O_\gamma + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O + dN_2 + \text{energy}$

3.3.2. Incomplete combustion

The combustion mechanism is required to be rapid, so that the combustion systems are designed with excess air. This is to predict air shortages due to imperfect mixing of air with fuel. Such combustion is called non-stoichiometric combustion. Chemical reaction equation for non-stoichiometric combustion of biodiesel fuel (palmitate ester) ($C_\alpha H_\beta O_\gamma$) with air is written as follows

$C_\alpha H_\beta O_\gamma + a(O_2 + 3.76N_2) \rightarrow b\,CO + cH_2O + dNO_x + eN_2 + \text{energy}$

3.3.3. Results and Discussion

The test results were compared between the fuel before and after magnetization and then quantified as several graphs showing the fuel composition of the fuel and the emissions of CO and NOx to the fuel composition, and then reanalyzed referring to several reference journals listed in the bibliography. The efficiency of a diesel engine is shown by the success rate in converting the chemical energy contained in the fuel into mechanical energy.

3.3.4. Fuel Magnetization on Fuel Consumption.

It appears (Figure 3.1) that magnetised fuel reduces the SFC by 4-8%, but in the gas composition above 70%, the SFC increases by 1.8% compared to non-magnetised fuel. This is because the fuel composition is 0-70%, the magnetic field is 713.57 Gauss is able to break down the fuel molecules, which initially become clusters, making the reaction between the fuels and air easier, and combustion becomes more perfect, making the engine more efficient. Biodiesel fuel produces a low viscosity and the fuel particles will be better atomized, resulting in smaller fuel grains. Under these conditions, the fuel-air mixing process will be more homogeneous, allowing the fuel to burn more and the energy released to increase. In other words, for the same load, the amount of magnetized fuel injected into the engine is less or more reduced.

On the contrary, if the composition of the fuel is more than 70% and the magnetic field is 713.57 Gauss, the fuel cannot be broken down into decluttering, which makes it difficult for fuel molecules to react with air, resulting in imperfect combustion and waste of the engine. Fuels with large biodiesel components will cause high viscosity, and fuel molecules will be difficult to atomize to produce larger fuel particles. Under these conditions, the mixing process of fuel and air becomes uniform, so less fuel is burned, or more fuel is used, and the energy released is reduced. The same thing happens on an engine with a given load of 10.37 KW, as shown in Figure 2b. The difference is that for a large load, the fuel consumption is greater than that of an engine with a small load. SFC decreased by 2-9% in 0-70% of biodiesel components, and increased by 1.8% in more than 70% of dual diesel components.

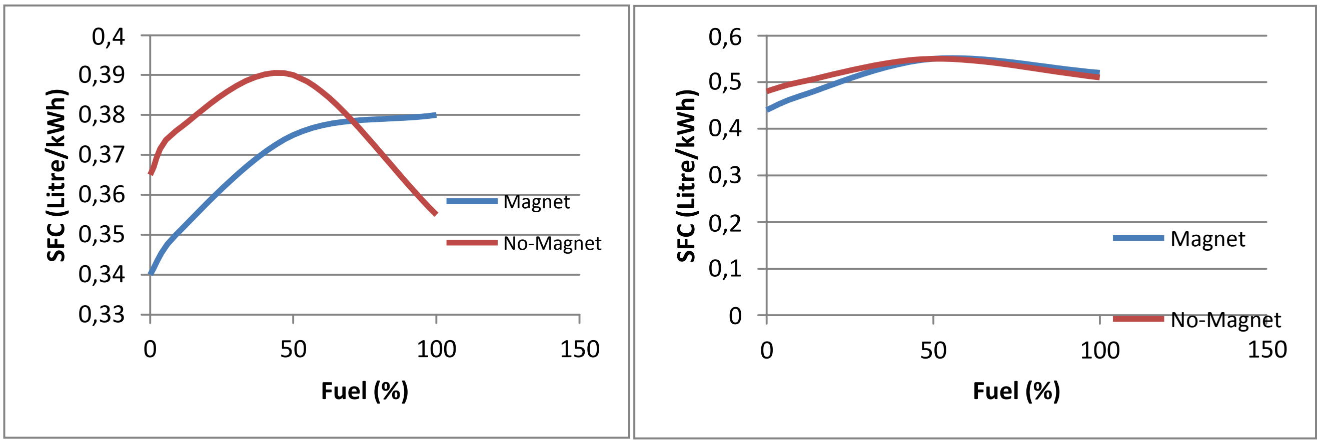

Figure 3.1: Specific fuel consumption (SFC) before and after magnetization for a 3 cylinder diesel engine. (a) 4.45 KW (b) 10.37 KW

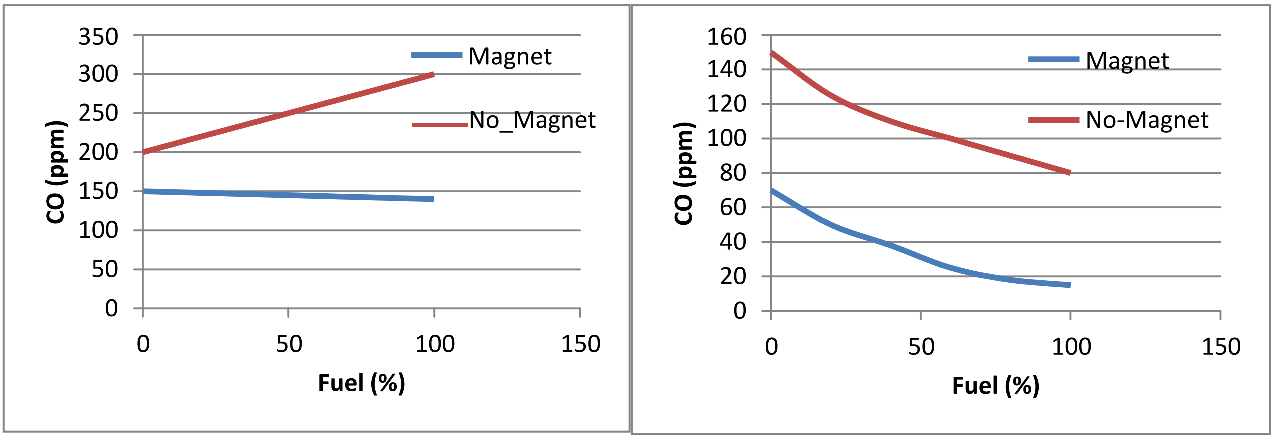

Figure 3.2: CO exhaust gas before and after magnetized engine load (a) 4.45 KW (b) 10.37 KW.

Figure 3.2 shows the relationship between CO emissions and the fuel composition under a load of 4.45 KW. It seems that the magnetized fuel reduces CO (carbon monoxide) exhaust emissions by 45-67%, while for an engine with a 10.37 KW CO 2 exhaust gas, it reduces by 13-53%. Carbon monoxide gas is formed due to the lack of oxygen in the reaction with the fuel during the combustion process. When the diesel engine continues to rotate, it overcomes the ever-increasing load and injects more fuel. As the amount of fuel entering the combustion chamber increases, the amount of combustion increases and the temperature increases. At high temperatures, carbon dioxide (CO_2) and carbon (C) will react to produce carbon monoxide gas. The higher the combustion temperature, the greater the amount of CO2 gas decomposed into CO and O [14]

The addition of the percentage of biodiesel mixture in diesel fuel causes a decrease in CO 2 emissions. This is due to the influence of oxygen which is bound to the methyl ester, this oxygen molecule causes no CO molecule formation but CO2 molecules are formed, causing a more perfect combustion. .

The greater the addition of biodiesel, the greater the oxygen in the mixture and the more complete combustion, resulting in low carbon monoxide [15]. This is evident from the data obtained from the results of the study that in B100 there was an average CO decrease of 56%. Fuel magnetization causes fuel viscosity to decrease so that when injected into the combustion chamber it will form finer granules so that the mixture of air and fuel becomes more homogeneous which results in a more perfect combustion. This perfect combustion causes CO emissions to decrease.

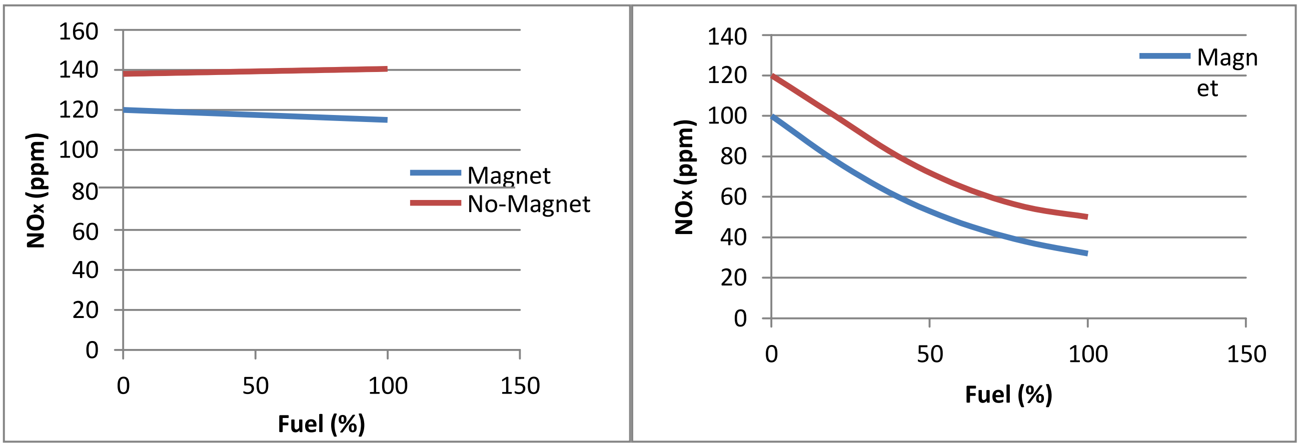

Figure 3.3: NOx exhaust gases before and after magnetized engine load (a) 4.45 KW (b) 10.37 KW

Figure 3.3 shows a graph of the relationship between NOx exhaust emissions and the composition of biodiesel. The vertical axis states the NOx (ppm) and horizontal axis states the composition of biodiesel. It appears that the magnetized fuel causes NOx exhaust emissions to decrease by 5-33% for engines that are given a load of 4.45 KW, while for engines that are given a 10.37 KW load of CO 2 exhaust decreases 7-21%. There are several causes of NOx emissions including high oxygen concentrations coupled with high temperature of the combustion chamber. In addition, the carbon crust in the combustion chamber will also increase engine compression and can cause hot spots that can increase NOx levels. Machines that often detonate will also cause high NOx concentrations [16]

The addition of the percentage of biodiesel mixture in diesel fuel causes a decrease in NOx exhaust emissions. This is due to the influence of oxygen bound to the methyl ester so that for less combustion of the required air, this causes the combustion temperature to decrease, and NOx concentration also decreases [13]. Fuel magnetization causes fuel viscosity to decrease so that when injected into the combustion chamber it will form finer granules so that the mixture of air and fuel becomes more homogeneous which results in a more perfect combustion. This perfect combustion causes NOx exhaust emissions to decrease. NOx gas emissions decreased the most occurred in B100 fuel which was an average of 26.5%. All emission test results state that fuel magnetization causes decreased levels of exhaust emissions

3.4. Conclusion

In this chapter we have exposed our fuel to a magnetic field and found that its properties are changed.

Magnetic treatment does not require energy and is therefore economically feasible and inexpensive

Modifying certain properties of the fuel by the magnetic field, allows us to take advantage of some of the applications that belong to the industry and the environment.

Increasing the efficiency of most equipment and machines that use hydrocarbons and reducing consumption by up to 14%.

We can understand the mechanism of fuel magnetization through the impacts of the external magnetic field on the microscopic structure, which is the displacement and polarization of fuel molecules.

At the end of our study we noticed clear changes in the value of the surface tension of the fuel, which was used in this study and the use of these changes in the applied fields.

This technique helps a lot to reduce the amount of environmental pollutants in the exhaust gases up to 40%.

General conclusion

General Conclusion

Magnetic energy has been used in this research for the treatment of turbine fuel, to reduce consumption, increase efficiency as well as to reduce the emission of certain pollutants.

Our study included the use of magnetic coils with different intensities, which were installed around the combustion chamber and to study their impact on the fuel consumption, as well as on the exhaust gases.

In order to be able to compare the results, it was necessary to carry out experiments without the use of magnets. The impacts of magnetic field enhancement on low-octane fuel in the combustor of an MS5002C turbine were investigated.

The result of this study indicates that magnetic field enhancement can improve the level of completion of the combustion process by increasing the chances of reaction between hydrocarbon molecules and oxygen. The increased reaction between hydrocarbon molecules and oxygen is due to the weakening of bonds, accompanied by an increase in molecular vibrational energy.

Based on the results of the investigation and characterization carried out, it is necessary to optimize the design of the magnetic field sources both in terms of geometry and type of source (use of permanent magnets or coils). Optimization of the location of the magnetic resources in the system must also be carried out to make it technically feasible.

In addition, further studies are needed on the long-term impacts of magnetic field exposure on combustion performance.

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