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ENGINE REGULATION

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Evolution of the helicopter engine control systems over the past 25 years

INTRODUCTION

For 25 years, the control systems of the TURBOMECA engines powering the AEROSPATIALE helicopters have always optimized the engine/airframe marriage by continuously adapting to the new requirements of aeronautical technology.

Thus, the evolution of the control systems took place in a smooth, regular way in order to :

- facilitate starting
- improve performance in transient rating
- ensure load sharing in the case of multi-engines
- increase accuracy
- increase reliability
- facilitate engine handling.

This paper surveys the historical background of this evolution and briefly describes the different systems applied since the 1950's in the chronological order of their embodiment.

Two main parts are to be considered in this survey :

a) The control system of single spool turbo-shaft engines,
b) The control system of free turbine turbo-shaft engines.

I. CONTROL SYSTEM OF SINGLE SPOOL ENGINES

A. ARTOUSTE engine family (Plate I)

On this type of engine, the main objectives of the control system are - besides starting -

1. to keep the engine rotational speed RPM constant in permanent rating independently of the installed power level.

2. to minimize the RPM fluctuations in transient rating (load variation) to avoid compressor surge and engine overheat.

Physically, this control system includes a gear type fuel pump and a hydromechanical governor PI with low remanent error (I 0.25 %) often called an isochronous governor.

A small gear pump embodied in the governor provides the required servo-pressure and servo-flows. The fluid used is the engine lubrication oil

The (Automatic) starting is carried out on the volumetric characteristic of the fuel pump which has been intentionally altered. A relay logic system programmes the starting sequence : start and stop of starter, igniters,etc...

When this control system was first set into service, (beginning of the ALOUETTE helicopters) it constituted a very large technical step forward.

The pilot, until then compelled to manoeuvre separately and simultaneously pitch and fuel now only attends to selecting the general pitch. The engine servo control by the governing system completes all the other functions.

B. ASTAZOU engine family

On these engines, the control principle is fundamentally identical to the one used on the ARTOUSTE engines. However linked to the particular operating condition of this engine on the helicopter, three additional functions are introduced.

These are, quoted in the chronological order of their development :

- flow limitation,
- controlled idling,
- automatic starting.

Flow limitation :

From the first flights, the operation of the ASTAZOU III engine on GAZELLE helicopter reveals an engine operating problem in excess power with surge during severe transient ratings : general pitch increase + turning.

The use of a flow limitation in function of the compressor pressure P_2 enabled to solve rapidly and neatly this difficult problem.

In fact, this limitation sets an engine operating line at a constant predetermined t_3, in excess power, the governor PI of N being saturated. Thus it avoids the engine overheat and surge.

Of a robust and simple technology, the device used has given full satisfaction : it permits a high performance control of the GAZELLE aircraft powered by ASTAZOU III N engines.

This statement can also be extended to the ASTAZOU XVIII and XX engines.

Controlled idling :

The idling speed of the ASTAZOU engines must meet two very precise requirements :

1. Remain in all cases higher than a compressor critical speed.
2. Remain lower than the clutching speed.

This bracket is very small and it excludes the definition of an unsettled idle rating only programmed by fuel flow.

By extension, the governor PI has been developed to regulate the value of this idle rating.

Automatic starting :

The automatic starting with looped programme is installed for the first time on the ASTAZOU XVIII engine. A flow programme function of RPM flat rated by the t_4 exhaust pipe temperature supersedes the operation on the pump characteristic.

Consequently the engine start becomes quicker and more reliable specially near the limits of the temperature operating range.

For this engine the controlled idle function is ensured in double, by an electronic control permitting a take-over without exceeding the RPM.

Technology :

The governors of the ASTAZOU family engines have been greatly improved in the technological field : generalization of castings, pump, governor solid assembly with modular technique, increased use of stainless steels, use of matched subassemblies (sleeves, slides). The tightness between the systems is ensured by 0 rings with decreasing diameters.

II. CONTROL SYSTEM OF THE FREE TURBINE TURBOSHAFT ENGINES

Two types of control systems are to be distinguished :

- First type : Pitch-throttle control

The pilot, when selecting the general pitch, sets simultaneously a controlled Ng rotational speed, owing to the pitch-throttle junction. The gain of this junction is then modified by the rotor control which precisely governs the required rotational speed.
An overspeed device can, if required, jugulate an untimely overspeed of the free turbine.

- Second type : Free turbine RPM control

The pilot selects the general pitch, then the free turbine rotational speed governor modulates Ng (the gas generator RPM) to equalize the engine torque and resisting torque at the predetermined free turbine RPM value.

II. 1. Pitch-throttle control.

This control system is installed on TURMO III C 3 type engines. The Ng governor is a hydro mechanical governor PI with low residual error, using engine lubrication oil as a servo fluid. This fluid is conveyed pressurized by a small gear pump embodied in the governor. The pitch-throttle junction is achieved by S.F.E.N.A.

Overspeed limiters :

There has been a succession of three versions of overspeed limiters :

- the hydromechanical limiter,
- the hydromechanical, pneumatic limiter,
- the electronic limiter.

Hydromechanical version :

It uses a governor P driven by the free turbine and it directly acts upon the injected fuel flow. In this version, the fuel runs twice through the engine hot parts.

This solution considered as dangerous was given up following a serious crash in operation.

Hydromechanical pneumatic version :

It uses the compressor air as servo-fluid and consequently it presents no fire hazard when going through the hot parts.

A governor modulates the air pressure and directly acts upon the fuel flow. From a technological point of view, the device is very simple and its performance is good.

Despite very satisfactory results at the beginning this system had to be abandoned after operation in sandy atmosphere.

A few operating hours in these conditions caused damage by erosion of the servo system master parts (nozzle, control plate), despite the presence of a large filter that gets very rapidly clogged.

Electronic version :

In service to date, this system gives excellent results.

Designed by ELECMN, this system operates on the hit or miss principle initiating the engine shut down if the free turbine overspeed exceeds 120 %.

II. 2. <u>Free turbine RPM control</u>

This is the type of control installed on the TURMO III C 4 engine. The governor is in one piece and it gathers two data :

- gas generator rotational RPM,
- free turbine rotational RPM.

All the correcting elements are directly actuated.the governor is "all fuel".

This governor is very robust, and very simple. It required very little development and its reliability is excellent.

II. 3. <u>Acceleration devices</u>

The free turbine engine controls are fundamentally different not only as regards the principle of the servos but also as regards the acceleration devices.

TURMO III C 3 type

The acceleration device of the TURMO III C 3 engine is a closed-loop self-generating system.

It is fully hydromechanical and mainly includes : a spring-flyweight tachometer continuously measuring the actual gas generator RPM. This tachometer sets with the help of a power stage the selected max-gas generator RPM stop.

In acceleration speed, this stop continuously moves from an impulse signal keeping the gas generator acceleration according to a preditermined programme up to saturation and taking over by the governor.

TURMO III C 4 type

The system used with this type of engine is also applied to the MARBORE engine.

Its technology is simple, but its principle is very complex.This system may be described in a few words as follows :

a volume of air imprisoned in bellows submitted to the injection pressure plus a constant value, is the support of a fuel injection programme which is perfectly adapted to the engine characteristics with centrifugal fuel injection which accelerates to the limits of their possibilities with no surge or overheat.

II. 4. Technological improvements

TURMO III C 3 governor

The improvements in the technological field are similar to the ones embodied in the governors of the ASTAZOU family.

TURMO III C 4 governor

It is our first achievement in "all fuel" one piece. It is a considerable technological improvement. It is really simple and reliable.

III. CONTROL SYSTEM OF THE TURBOSHAFT ENGINES UNDER DEVELOPMENT

III. 1. ARRIEL engine

The control system of the ARRIEL engine is fundamentally different from the control systems of the TURMO III C 3 and C 4. It is designed to operate in a single-engined configuration and twin-engined configuration.

It includes two control systems installed in series

- a proportional control governing the free turbine
- a PI control system governing the gas generator

The control system P sets a controlled speed (gas generator RPM). In these conditions, the case of operation with a twin-engined version the equal load sharing with respect to the rotational speeds is perfectly respected. The only errors -which are very rare- are due to improper setting.

This control system P is given a static droop of 9 to 10 %. Moreover it includes a pitch-throttle junction device fulfilling two essential functions :

a) improve the control system performance in transient rating
b) cancel for the greatest part the static droop of the governor P.

On the governor P I, the gas generator acceleration is programmed by a mechanical stop function of the absolute P_2.

The shape of the fuel metering device is chosen so that a compromise can be reached between acceleration and operation at full power in altitude (6,000 meters).

Starting is carried out according to this same law with the possibility of saturation by manual control in the event of t_4 overtemperature.

This device is called : Manual Starting Device.

An emergency cock short-circuits the governor metering device. In the event of failure of the control system, the pilot may increase or reduce manually the fuel flow injected.

An electronic overspeed limiter limits in all cases the free turbine RPM.

From a technological point of view, this governor is constituted by a one-piece casting receiving mechanically the two data a gas generator RPM and free turbine RPM.

Stainless steel is the material used for most of the component parts. We also find a polyhimid : VESPEL or IMIDUR used to reduce the jamming risks when impurities are present.

The smooth bearings of the fuel pump are made of CARO BRONZE.

The hydraulic potentiometers are generalised as servo devices. This governor has given excellent results during the preliminary tests. Only a few oscillation problems remain when the engines are coupled.

III. 2. MAKILA

In its principle, the MAKILA control system is the same as ARRIEL.

However it is possible to note a few important differences in the field of technology. The hydromechanical control is replaced by an electronic control on the free turbine.

Due to the engine mechanical design requirements we had to choose this solution. As a matter of fact, the absence of free turbine RPM information without any mechanical transmission form, means that this information has to be dealt with by electronics.

The free turbine RPM measurement is carried out, using three phonic wheels. Before entering the governor P, the three data are continuously compared. If one of them is conflicting, a logical discrimination is carried out preventing the erroneous signal from going through.

An Alarm device warns the pilot. The free turbine RPM signals enter the governor P . Via a proportional solenoid valve ; this governor P determines the controlled gas generator RPM setting by actuation of a controlled pressure.

One electronic positioning servo strictly controls the programm Free turbine RPM = indicated gas generator RPM.

The pitch-throttle junction is achieved by a potentiometer and by electronics.

The electronic systems are all dealt with in analogical technique.

IV. FUTURE FORESEEABLE EVOLUTIONS

It is most certain that electronics will play a more and more important role in the control systems of turbine engines.

Further to the first analogical systems, we see control systems with numerical technique control, giving a very appreciable accuracy improvement.

We also find deterministic systems using micro-processors (operated with more or less satisfaction) but they still represent an unprecedented technical and commercial improvement.

And we are already talking about programmable logics.

Consequently it is not easy to make up one's mind on the choice of techniques to be adopted.

Everybody is well aware that the analogical system is drifting that the failure of a most important bit is a catastrophe, that the lock of pitch can have very serious consequences in a deterministic system.

Our duty is to consider and use all these techniques.

At the moment, we are developing on a test basis, a control system in stochastic calculation.

This technique shows many advantages : it is not affected by noise or microcuts. Besides it is very accurate.

This technique, based upon the generation of an aleatory noise used as a support of calculation, has the advantage of using simple electronic components, manufactured on a large scale and the price of which is optimized : gates, triggers, shift register. Its integration should not create any problems. It could constitute a very interesting solution for the future conciliating the advantages of the numerical and analogical techniques, without having the drawbacks.

V. CONCLUSION

We could conclude by saying that the electronics is not always the best replacement to what is usually called the hydromechanical system.

We think that the use of electronics is only substantiated from a certain degree of complexity in the data processing or when the overall dimension requirements are very harsh.

Let us take the example of a proportional governor. In a hydromechanical system, for small engines, this governor is constituted by a simple compact system : flyweight, spring. Δp fuel metering device. The equivalent electronic solution will include at least (without redundancy), 1phonic wheel, 1 frequency voltage converter, 1 power amplifier, 1 electric motor with positioning servo, 1 fuel metering device with ΔP.

It is undoubtedly more expensive and less reliable than the hydro mechanical solution.

Thus, as regards the TURBOMECA engines, we think that the hydromechanical solutions are always up-to-date when they concern single spool engines, the electronic systems are required when dealing with free turbine engines, specially in multi-engined configurations.

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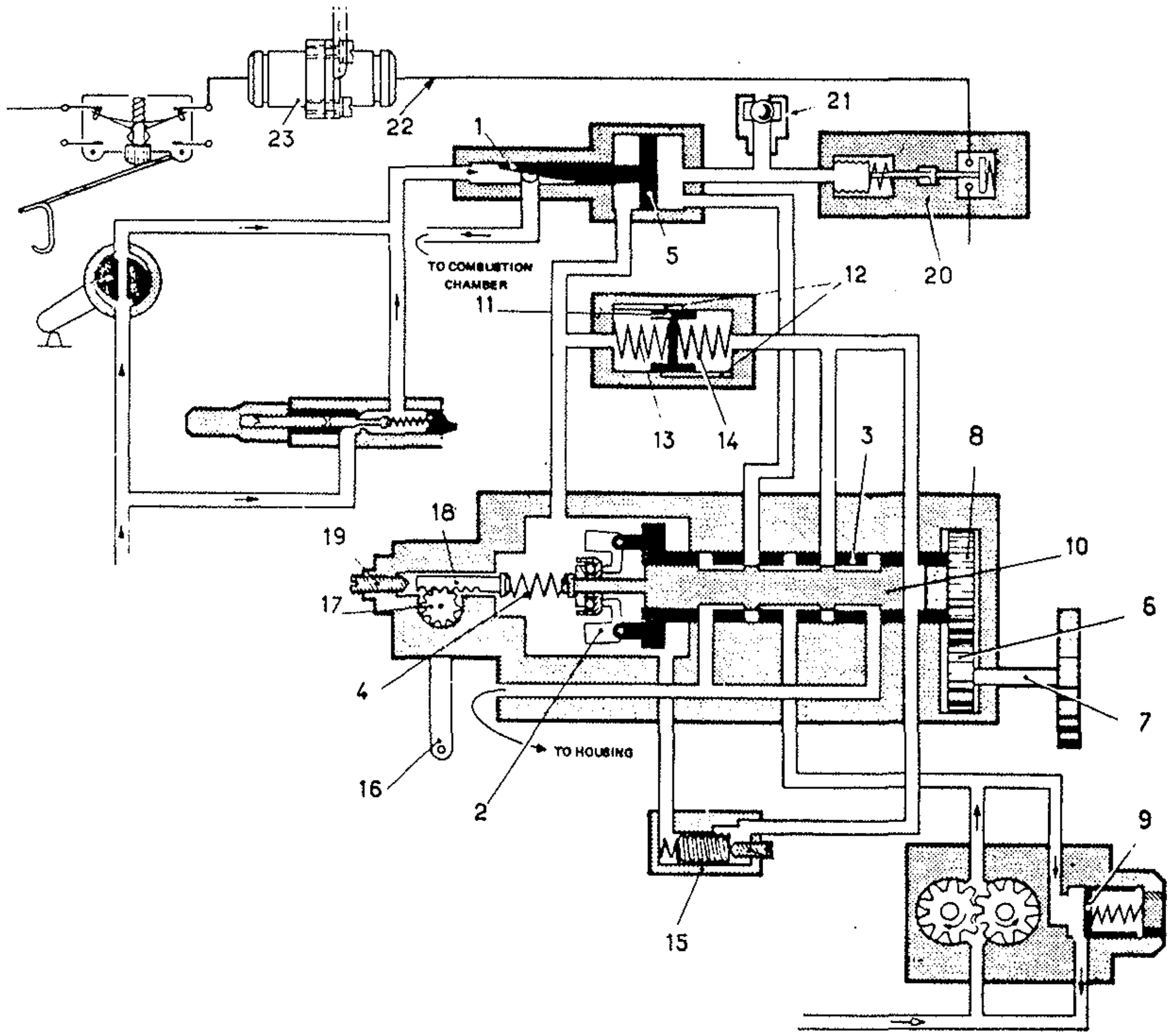
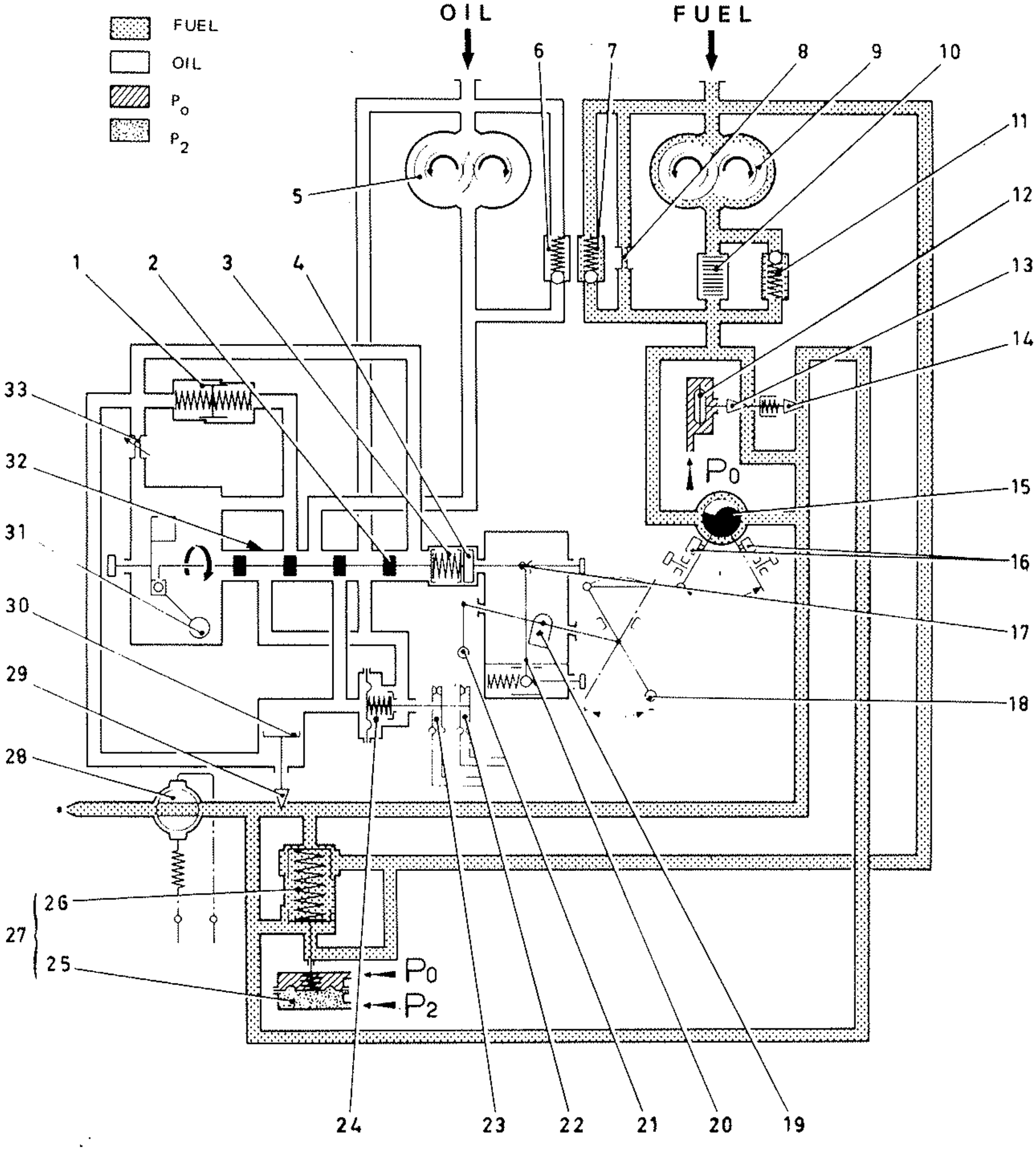


1 - METERING DEVICE
2 - FLYWEIGHT
3 - HOLLOW SHAFT
4 - SPRING
5 - METERING DEVICE WORKING PISTON
6 - DRIVING GEAR
7 - CONTROL SHAFT
8 - DRIVEN GEAR
9 - OIL OVERPRESSURE VALVE
10 - OIL DISTRIBUTION SLIDE
11 - ISOCHRONOUS PISTON
12 - SLOTS
13 - 14 - BALANCING SPRINGS
15 - ISOCHRONOUS VALVE
16 - CONTROL LEVEL
17 - DRIVING GEAR
18 - RACK
19 - STOP BOLT
20 - PRESSURE SWITCH (FLOW LIMIT)
21 - PRESSURE PICK UP
22 - ELECTRIC HARNESS
23 - ELECTRIC PLUG

CONTROL SYSTEM DIAGRAM

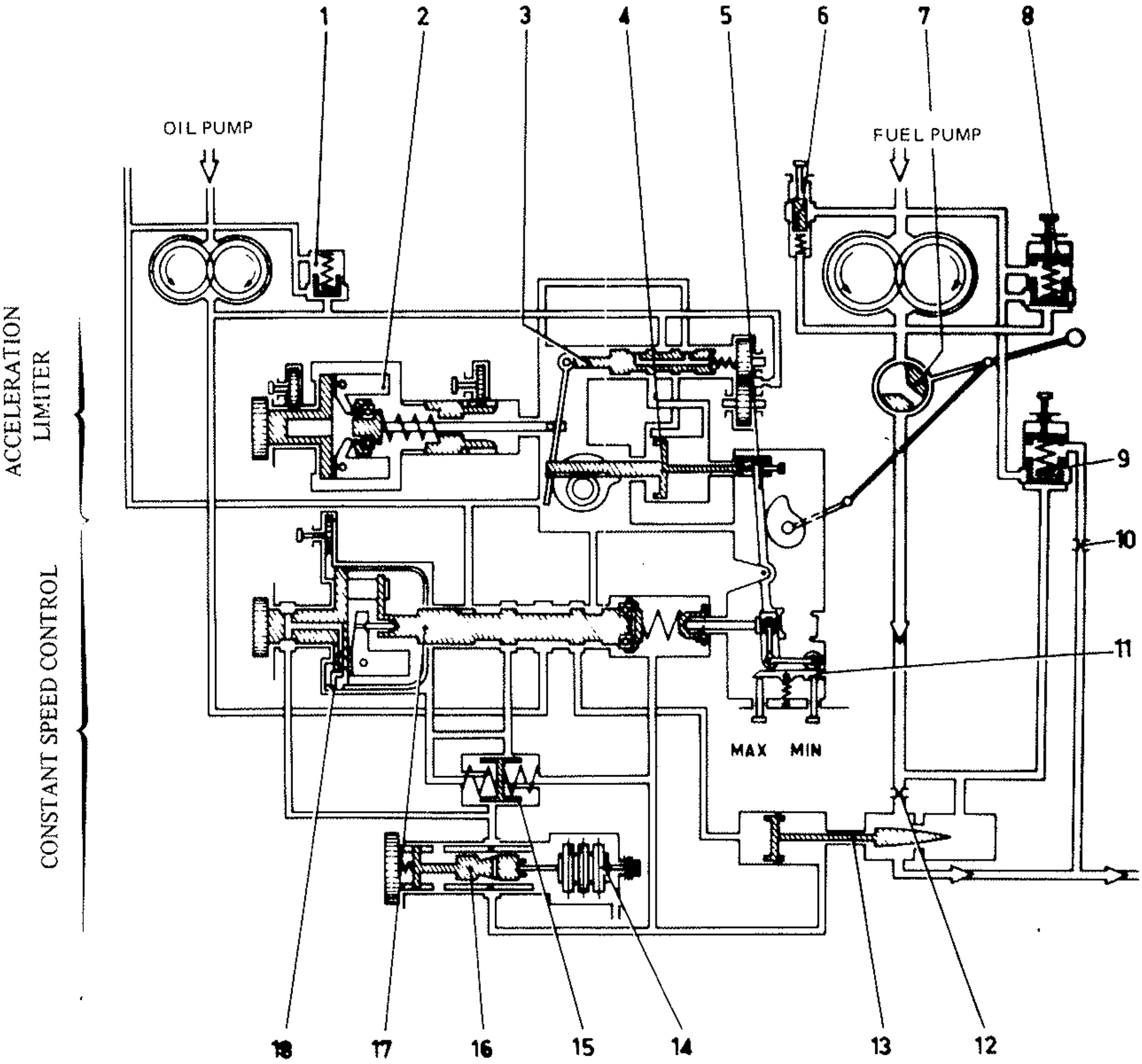
TURBOMECA
ASTAZOU III



1. Damper piston
2. Oil distributing spool valve
3. Spring
4. Compensating capsule
5. Oil pump
6. Pressure relief valve
7. Pressure relief valve
8. By-pass
9. Fuel pump
10. Filter
11. By-pass
12. Barostatic device
13. Spool valve
14. Spool valve
15. Fuel throttle valve
16. Microswitches
17. Stop
18. RPM control lever
19. Cam
20. Lever
21. Lever
22. Starter cut-out microswitch
23. Fuel flow limit microswitch
24. Fuel flow limit pressure switch
25. Fuel flow limit device
26. Constant Δp device
27. Δp device driven by P2
28. Electric fuel cock
29. Fuel metering valve
30. Working piston
31. Flyweight
32. Sleeve
33. Isochronous scroll

CONTROL SYSTEM DIAGRAM

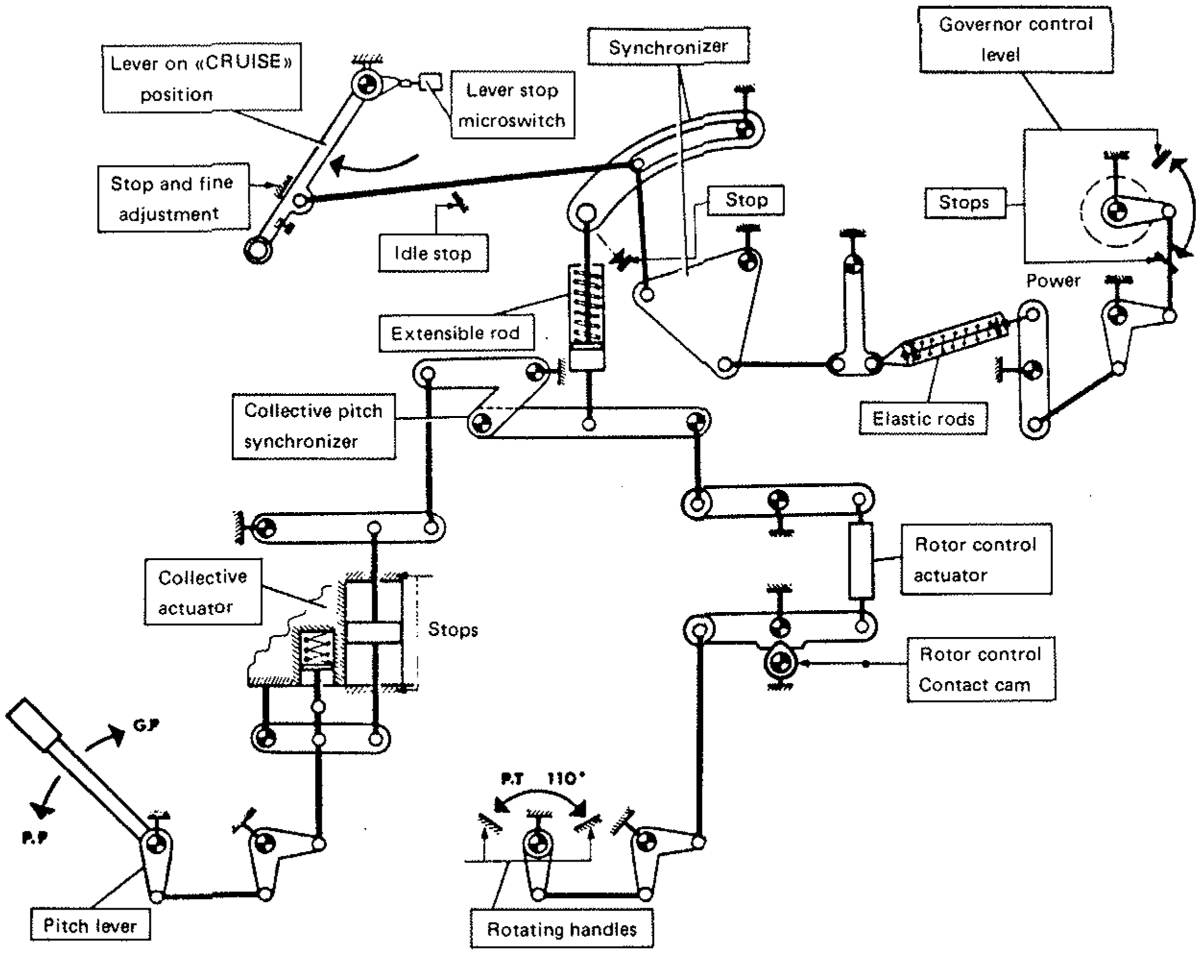
TURBOMECA
TURMO III C3



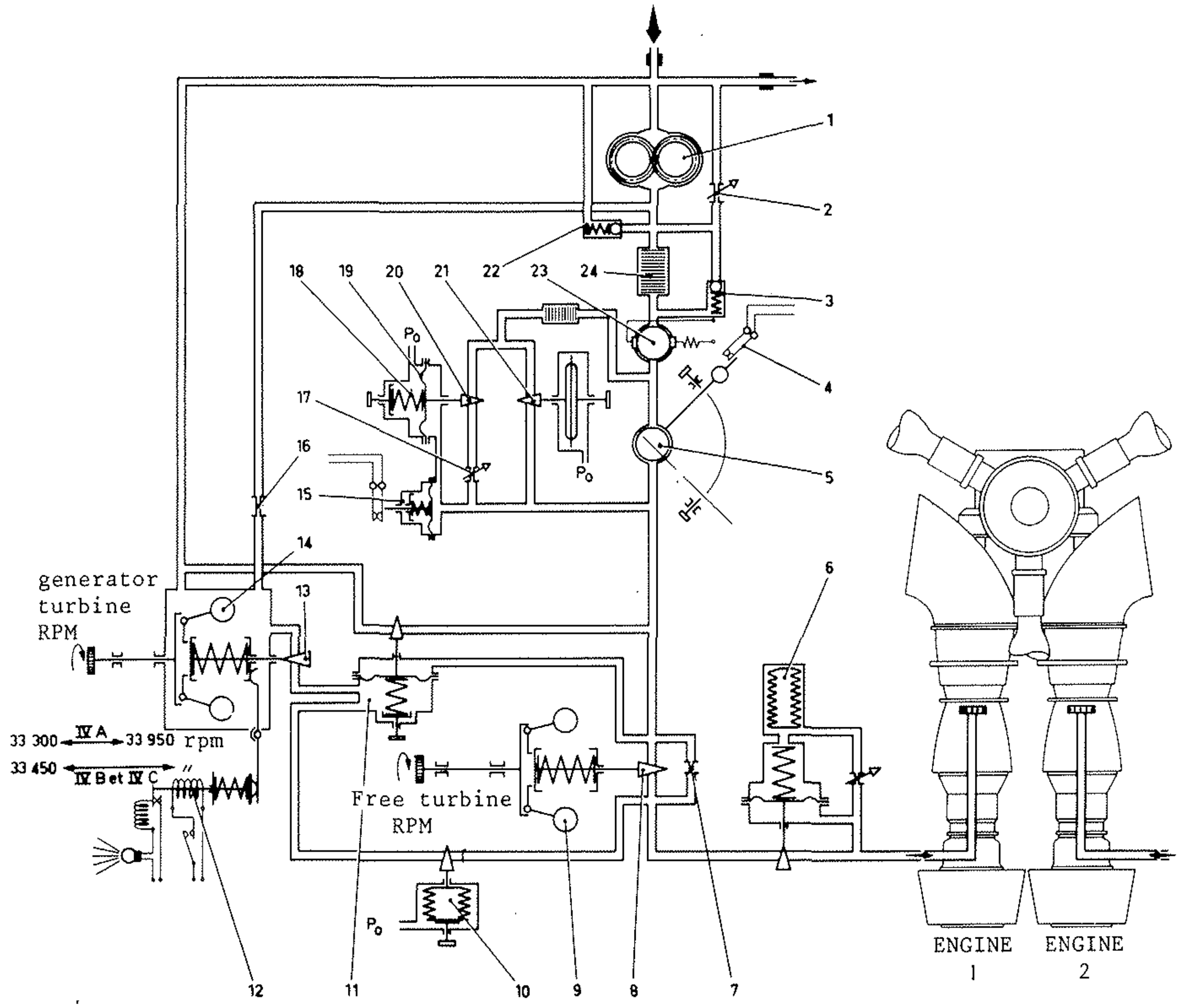
1 - OIL PRESSURE RELIEF VALVE
2 - ACCELERATION LIMITER R.P.M. DETECTOR
3 - ACCELERATION LIMITER DISTRIBUTION SPOOL VALVE
4 - ACCELERATION LIMITER AMPLYFYING PISTON
5 - PIVOTING LEVER
6 - FUEL PUMP BY-PASS
7 - FUEL FLOW COCK
8 - FUEL PRESSURE ADJUSTING VALVE
9 - Δ p CONSTANT DEVICE
10 - DAMPING JET
11 - CONTROLLED MIN ; AND MAX. ADJUSTMENT ROCKING ARM
12 - GAIN DETECTOR
13 - METERING NEEDLE
14 - BARO STATIC DEVICE CAPSULE
15 - CONSTANT SPEED DEVICE PISTON
16 - ROTATING DIAPHRAGM
17 - GOVERNOR DISTRIBUTION SLIDE VALVE
18 - CONSTANT SPEED VALVE

CONTROL SYSTEM DIAGRAM

TURBOMECA
TURMO III C3



PITCH-THROTTLE LINK

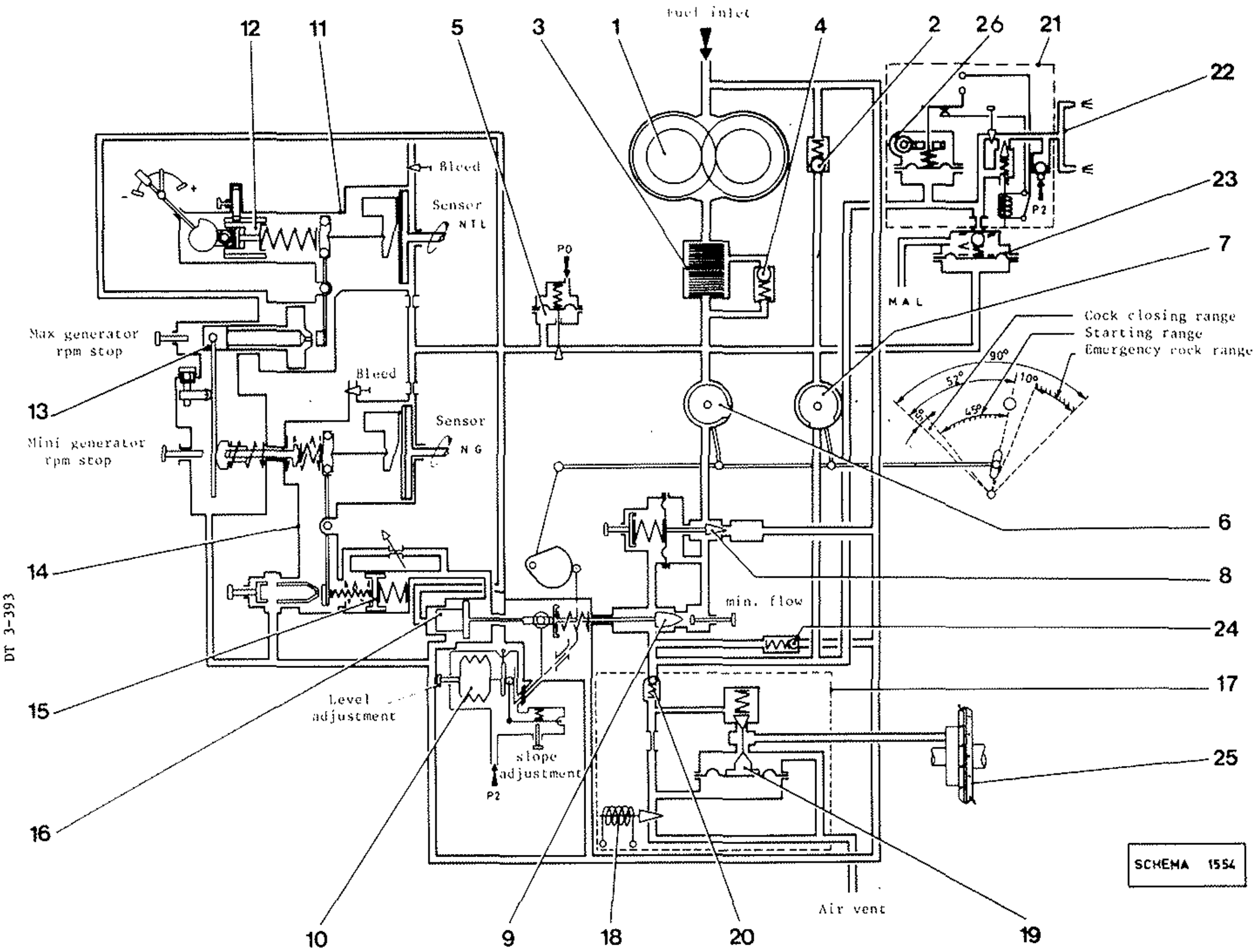


1 - FUEL PUMP
2 - ADJUSTABLE BY-PASS
3 - FILTER CLOGGING BY-PASS
4 - STARTING SAFETY MICROSWITCH
5 - FLOW PROGRESSIVE COCK
6 - ACCELERATION LIMITER
7 - MIN FLOW JET
8 - FUEL METERING DEVICE
9 - FLYWEIGHT
10 - BAROSTATIC CORRECTOR
11 - CONSTANT Δp
12 - SPEED SELECTOR
13 - LIMITER METERING DEVICE (14)
14 - GENERATOR OVERSPEED LIMITER
15 - STARTER CUT-OUT PRESSURE SWITCH
16 - JET
17 - JET
18 - STARTING DEVICE SPRING
19 - STARTING DEVICE DIAPHRAGM
20 - 21 - STARTING DEVICE METERING DEVICES
22 - OVER PRESSURE VALVE
23 - FUEL ELECTRIC COCK
24 - FUEL FILTER

CONTROL SYSTEM DIAGRAM

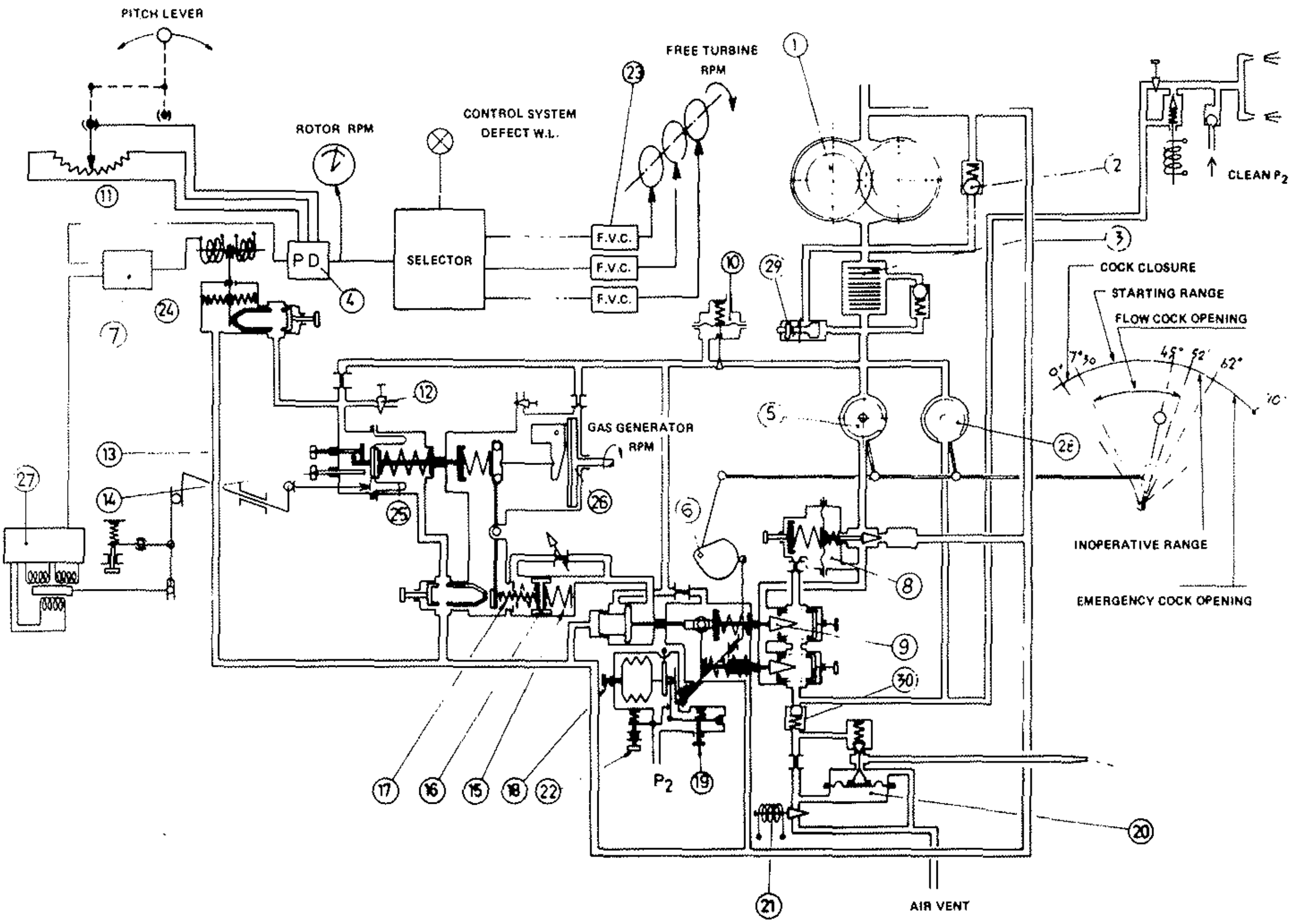
TURBOMECA

ARRIEL I



1. Fuel pump
2. Overpressure valve
3. Filter
4. Clogging valve
5. Pressure reducing valve
6. Main cock
7. Emergency cock
8. Constant Δ p valve
9. Metering device
10. Acceleration controller
11. Free turbine governor
12. Anticipator
13. Amplifier piston
14. Gas generator governor
15. Isochronous piston
16. Metering device piston
17. Overspeed and bleed valve
18. Solenoid valve
19. Bleed valve
20. Level valve
21. Injectors solenoid valve
22. Injectors
23. Bleed valve
24. By-pass valve
25. Injection wheel.
26. Reinjection prohibitio pressure switch

CONTROL SYSTEM DIAGRAM



1 - FUEL PUMP
2 - OVERPRESSURE VALVE
3 - FILTER
4 - DIFFERENTIAL PROPORTIONAL FREE TURBINE RPM GOVERNOR
5 - MAIN COCK
6 - MANUAL STARTING COCK
7 - POSITIONING SERVO
8 - CONSTANT Δp
9 - FUEL METERING DEVICE
10 - PRESSURE REDUCING VALVE
11 - FREE TURBINE RPM ANTICIPATOR AND STATIC DROOP COMPENSATION
12 - BLEED
13 - MAX. RPM STOP
14 - MIN. RPM STOP
15 - RETURN SPRING
16 - ISOCHRONOUS PISTON
17 - ISOCHRONOUS SPRING
18 - LEVEL SETTING
19 - SLOPE SETTING
20 - OVERSPEED AND BLEED VALVE
21 - FREE TURBINE RPM OVERSPEED SOLENOIDE VALVE
22 - MAX. FLOW LIMITATION
23 - VOLTAGE FREQUENCY CONVERTOR
24 - SERVO VALVE
25 - DIAPHRAGM
26 - GAS GENERATOR RPM DETECTOR
27 - TROUBLE TRANSMITTER
28 - EMERGENCY COCK
29 - CLOGGING INDICATOR
30 - LEVEL VALVE

CONTROL SYSTEM DIAGRAM