DESIGN AND DEVELOPMENT OF TEST RIGS FOR MAIN ROTOR AND MAIN ROTOR TRANSMISSION OF A HELICOPTER IN THE 6-TON-CLASS

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Abstract

The development of dynamic helicopter components such as main rotor head, main rotor blade and main transmission requires meticulous, high-fidelity simulation of

- operating loads
- power outputs to be transmitted and
- aerodynamic conditions.

Henschel Flugzeug-Werke GmbH has designed, developed, manufactured, assembled and commissioned

- a main rotor test rig and
- a main transmission test rig

for a helicopter in the 6-ton-class.

The paper describes the state-of-the-art of test rig technology and its variants with respect to differing test functions and chosen solutions. The characteristic test rig construction types executed to date and the respective values and tolerances achieved are summarized. Helicopter types tested as well as location and duration of service of test rigs are also mentioned. Development tendencies in full-load test rig technology are explained in the light of the further increases in component tbo-times which are proving necessary in particular for main rotor transmissions.

1. Design and Development of a Main Rotor Test Rig

Rotor test rigs are an essential tool in the field of main rotor blade development. The gas-turbine drive systems occasionally used in test rigs in the past have nowadays been entirely replaced by thyristor-controlled direct-current drive systems. Rotor test rigs are generally operated as universal test rigs, i.e. they can be utilized for development purposes as well as for series production. The rotor height above ground seldom approaches the diameter of the rotor, i.e. rotors operate under ground effect.

Dynamic and aerodynamic characteristics and the response of individual rotor blades and of the rotor to dynamic excitation are the parameters of interest to be measured.

Successful development of main rotor blades makes high demands on the design of a main rotor blade test rig. As opposed to the engines utilized in helicopters, the thyristor-controlled direct-current drive units nowadays utilized in test rigs can yield angular acceleration or deceleration levels which are much higher than the permissible levels specified during rotor blade design. Thus the highest priorities during the design phase are firstly optimum functional safety and secondly reserves or redundancies in motor control speed and torque limits. In addition, a high degree of uniformity and speed constancy has to be achieved for all power consumption activities of the rotor. This presupposes high dynamic ratios and simultaneous preclusion of dangerous torsional oscillation including overswing during acceleration and deceleration.

Use of dual or redundant actual value detection systems and torque and speed regulation systems in conjunction with the rigged rotor, which take into consideration the nature of its present motion, and power limitation on the basis of actual rotor power consumption are imperative preconditions for safe operation of the whirl tower.

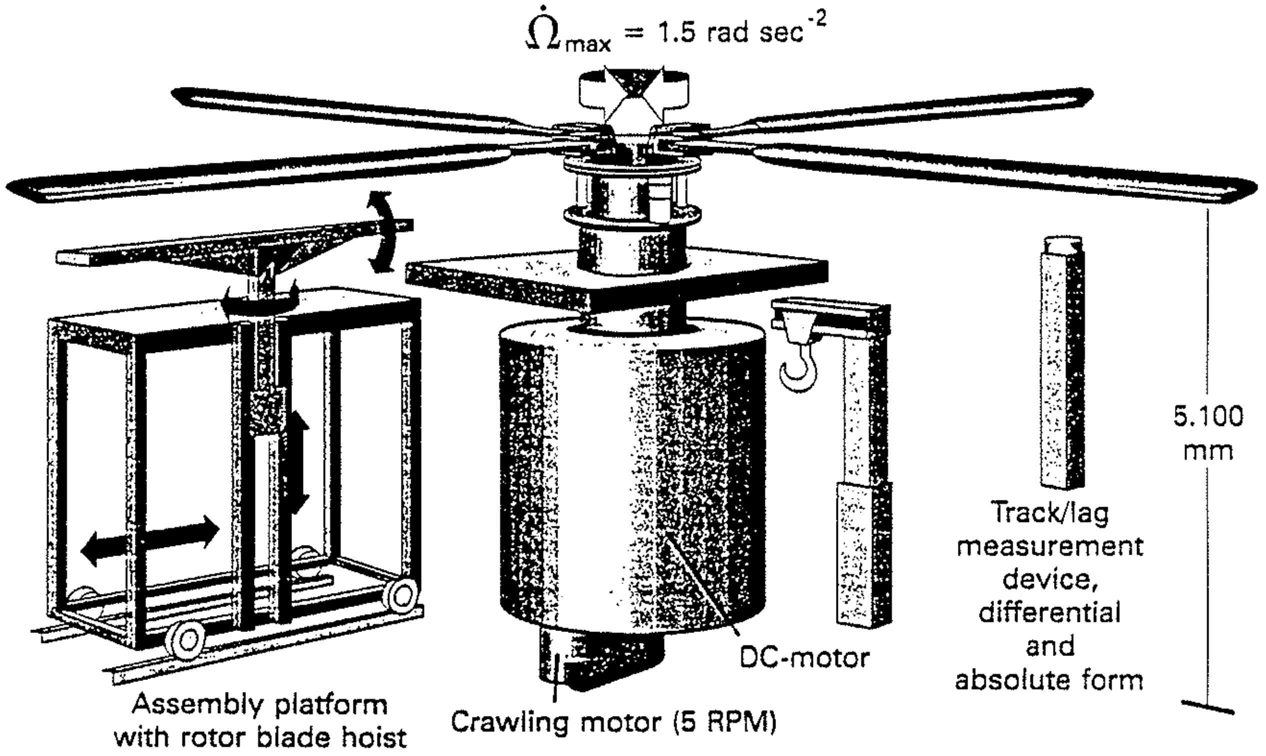


Fig. 1 System configuration

The following design criteria were realized:

- Vertical motor with four-quadrant drive, 1.230 kW power
- 15% power reserve at 560 m / INA
- Infinitely adjustable speed 0 to 450 1/min
- Two directions of rotation, clockwise, anti-clockwise
- Digital speed regulation
- Speed accuracy $\pm$ 0.1 1/min
- Speed variance during power increase as a percentage of adjusted index value $\leq$ 1 %
- Residual speed variance (under load) after 2 seconds $\pm$ 1/min
- Maximum torsional acceleration/deceleration $\dot{\Omega}$ max. = 1.5 rad/sec^2
- Detection of torsional oscillation and suppression thereof between drive motor and main rotor head
- Speed modification under full load by $\pm$ 10 % of nominal speed (100 % = 316 1/min)
- Measurement of drive power by means of motor data (error $\leq$ 1 %)
- Power feed-back during braking
- Mains compensation for Cos phi $\geq$ 0.9
- Measures to preclude retroactive mains interference resulting from power thyristor

- Track measurement in differential and absolute form, tolerance ± 1 mm
- Lag measurement in differential and absolute form, tolerance ± 1 mm
- Speed measurement by means of dual mutually-controlled speedometers
- Rapid exchange of rotor head facilitated by adapter plate
- Integrated auxiliary crane for effecting rotor head exchange
- Crawling speed for mounting or changing blades independent of drive motor 5 1/min via separate drive
- Rotor blade hoist, removable from rotor circuit
- Assembly platform, removable from rotor circuit

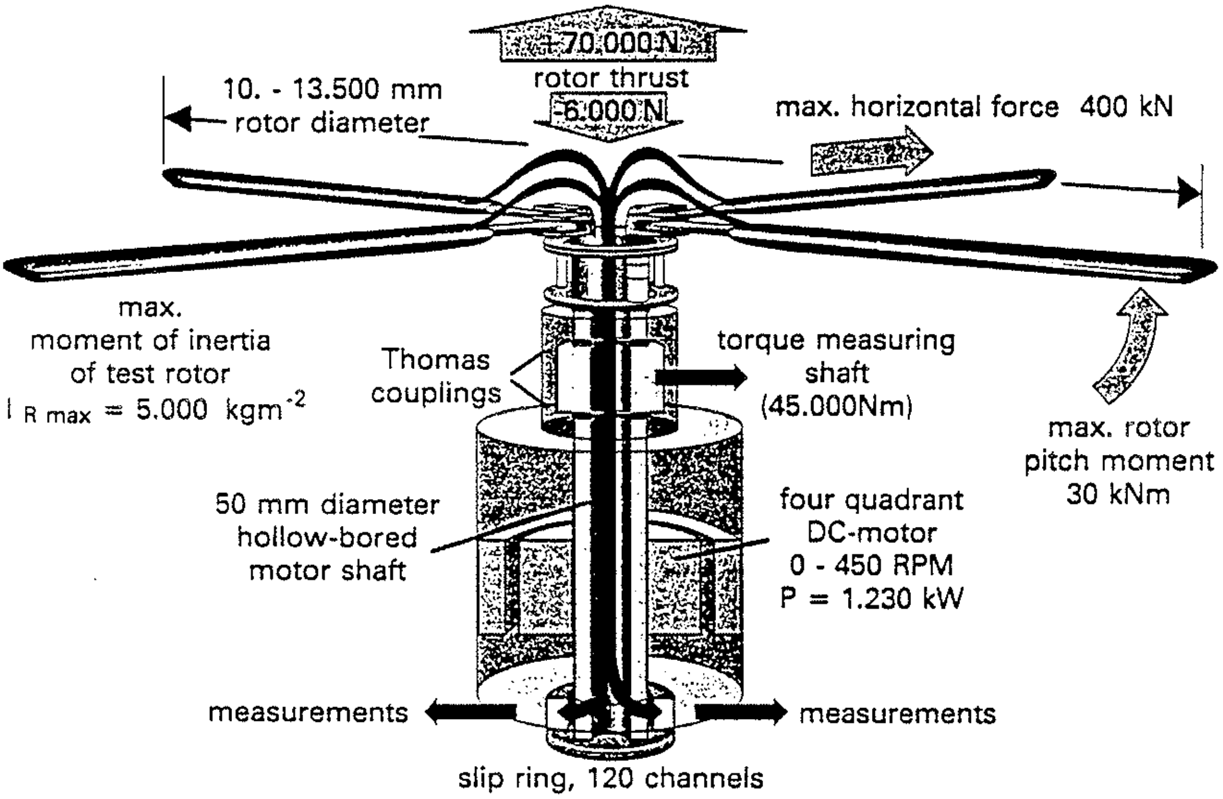


Fig. 2 Design Criterias

- 50 mm diameter hollow-bored motor shaft
- 10 to 13.5 m rotor diameter
- Maximum moment of inertia of test rotors $I_{Rmax.} = 5.000\ kg/m^2$
- Torque measurement via torque measuring shaft (45.000 Nm)
- Rotor thrust measurement minus 6.000 to 70.000 N
- Rotor height above ground 5.1 m
- Slipring for measurements in rotating components (120 channels)

- Maximum horizontal force applied to rotor head (blade fracture) 400 kN
- Maximum rotor pitch moment, rotating 30 kNm

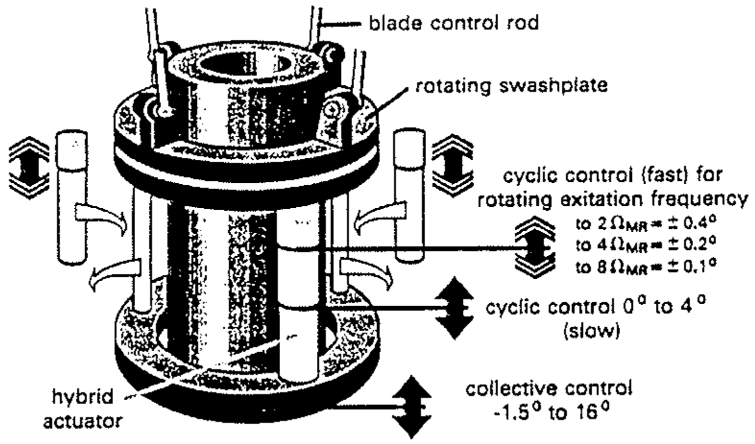
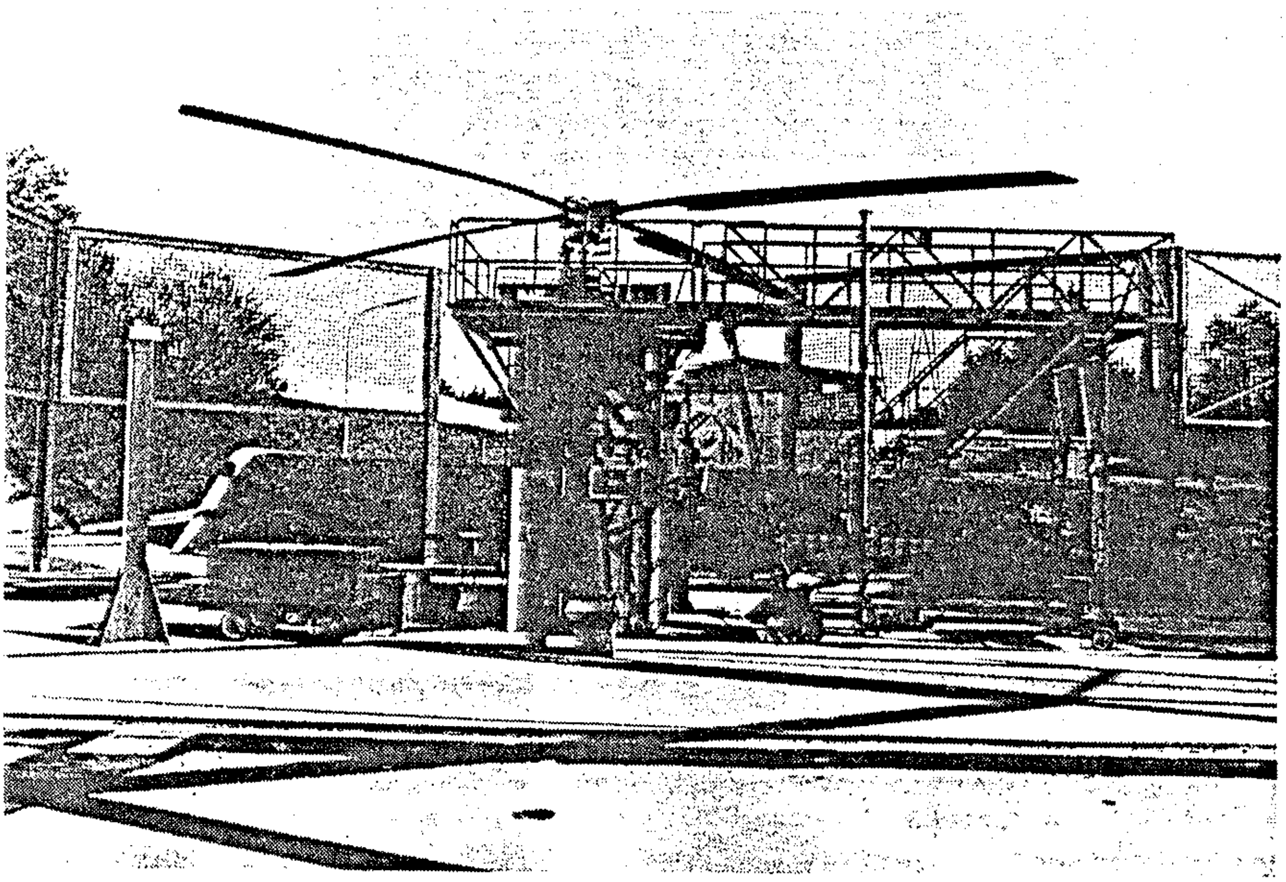


Fig. 3 Controls

- Collective control angle range minus 1.5° to 16°
- Cyclic control angle range 0° to 4°
- Hybrid actuators for slow and fast adjustment of cyclic angle, rotating excitation frequency to $2\,\Omega_{MR} = \pm\,0.4°$, to $4\,\Omega_{MR} = \pm\,0.2°$, to $8\,\Omega_{MR} = \pm\,0.1°$.

This main rotor test rig has been in operation at MBB's plant in Ottobrunn, Munich, since January 1988.



2. Design and Development of a Main Transmission Test Rig

Full-load main transmission test rigs vary according to the type of power routing and according to power consumption. The following types are differentiated:

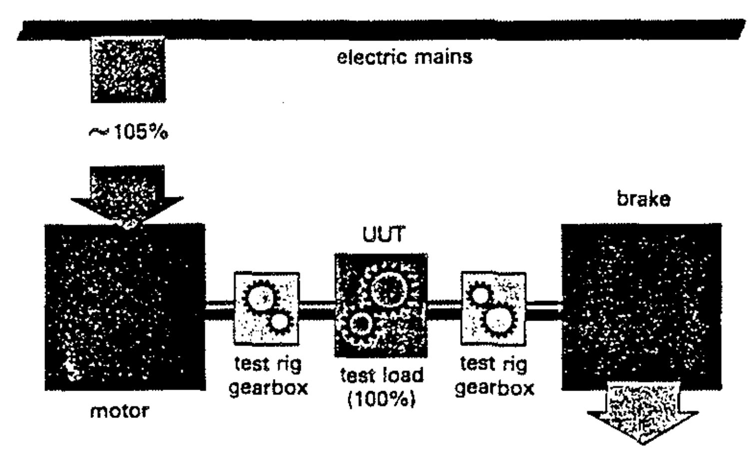


Fig. 5 Principle: Full load via brake

- Full-load via brake (100% power loss)

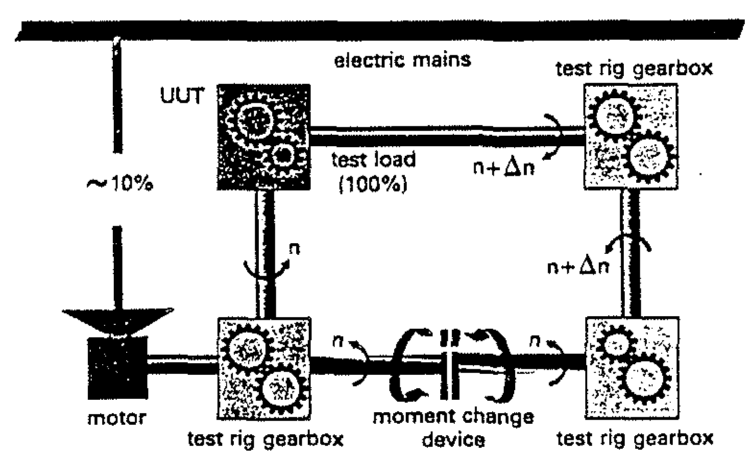


Fig. 6 Principle: Full load via back to back

- Full-load via back-to-back (approx. 10% power loss)

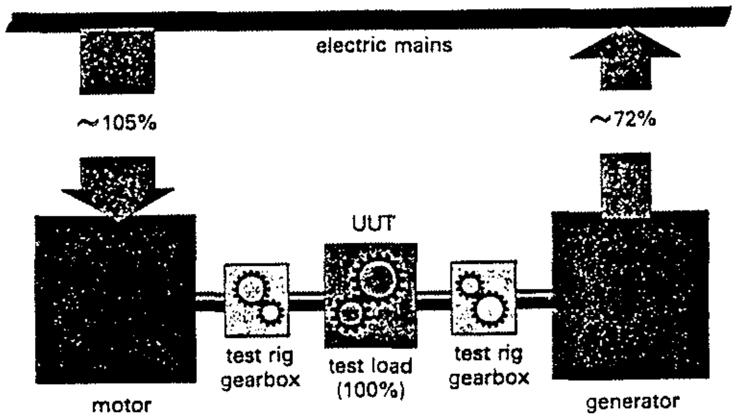


Fig. 7 Principle: Full load via brake generator

- Full-load via brake generator (approx 28% power loss)

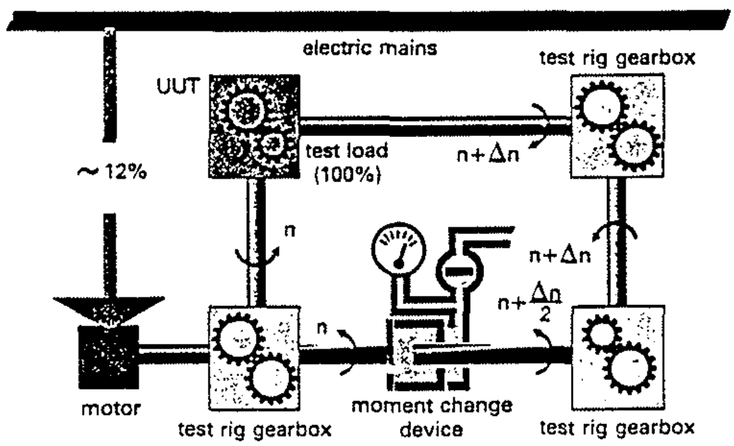


Fig. 8 Principle: Full load via semi back to back

- Full-load via semi-back-to-back (partial load eduction, approx. 12% power loss)

Pure back-to-back systems can only be utilized in conjunction with complex adaptations for a second test unit. Systems with pure braking operation are as a rule only chosen for single-circuit operation with low power ratings.

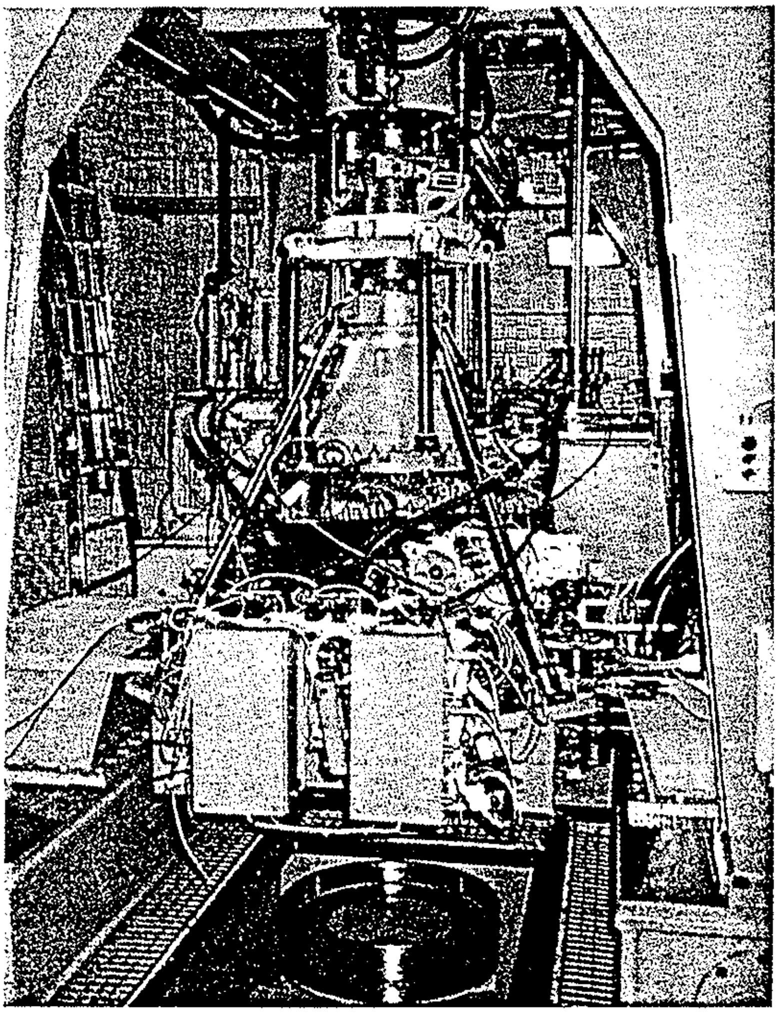
The development of modern main transmissions requires exacting test methods which simulate loads actually occurring during flight during both development and operation phases.

Gear tooth patterns optimized under full load provide the basis for high TBO periods.

This and the lack of reserves or redundancies in the power distribution train necessitate further development of full load test rigs towards multi-purpose testing. HFW is of the opinion that generator braking systems and semi-back-to-back systems will be the most widely used systems in the future.

The prerequisites for the design and development of a modern main transmission test rig can be summarized as follows:

- Long years of diversified experience in this sector
- Ability to integrate customer specification, technical possibilities, existing know-how, schedule requirements and price limits
- Freedom of the test unit developer to modify individual transmission ratios within certain limits
- Safeguarding of the greatest possible multi-purpose function with regard to other existing test units or future test units
- Determination of correct nature of load in the light of the above
- Awareness of possible levels of torsional oscillation resulting from closed-loop operation of the individual load circuits and minimization and/or preclusion of these in theory and practice
- Achievement of shortest possible test unit changing times (series operation).
- Finding the optimum synthesis between development test rig and series test rig
- Utilization of construction materials and components available in the customer's country (availability)
- Control and verification of the entire test sequence with the aid of SPC
- Ability to use foreign programming languages
- Ability to develop necessary software
- Deployment of trained mechanical, hydraulic and electronic engineers on location at customer's facility to ensure short commissioning periods without interruptions
- Ability to compile documentation in the foreign language and to train customer's staff in the foreign language



On the basis of the tender specification, Henschel Flugzeug-Werke GmbH completed design, manufacture, transportation to Marignane and assembly on site within twelve months of placement of order by Aérospatiale.

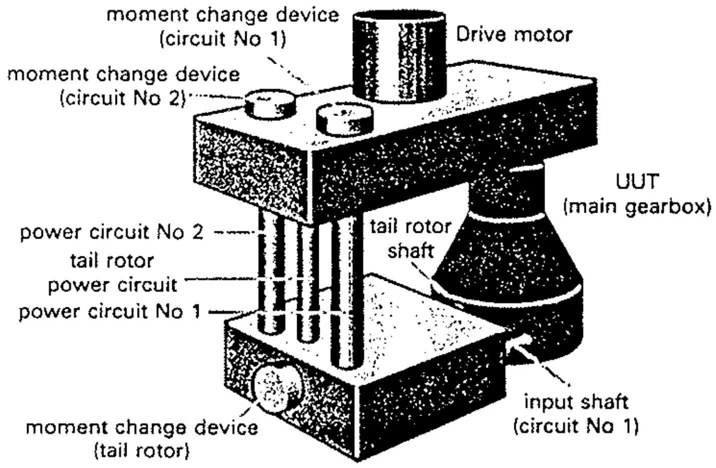


Fig. 10 Principle: Full load via semi back to back

On this semi-back-to-back-type test rig the following design criteria were realized:

- Thyristor-controlled direct-current drive 260 kW
- Portal-type construction increasing multi-purpose function with regard to other test units
- Oil supply reservoir integrated into base plate
- No necessity for special foundations below ground level

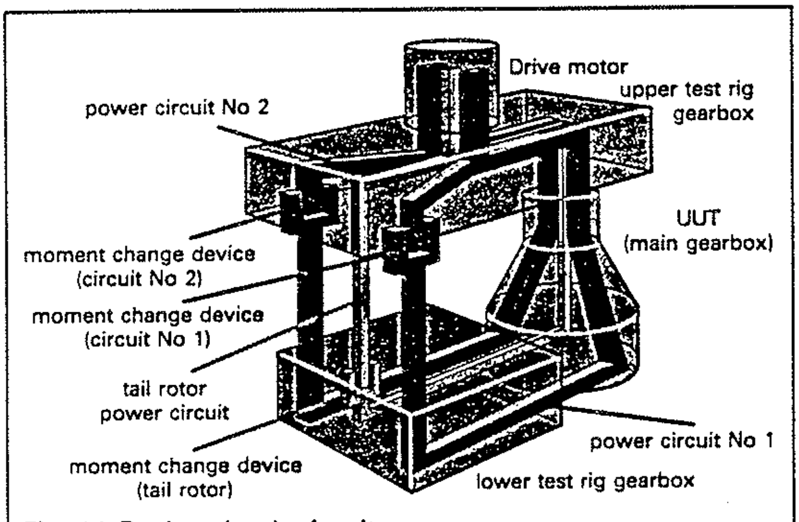


Fig. 11 Back to back circuits

- Grade 5 toothed gearing on main spur wheel and back-to-back gear
- Automatic coupling of all hoselines and measuring lines for the test unit and its auxiliary units
- Triggering of torques via hydromotors, infinitely adjustable for both input circuits and for the tail power take-off circuit

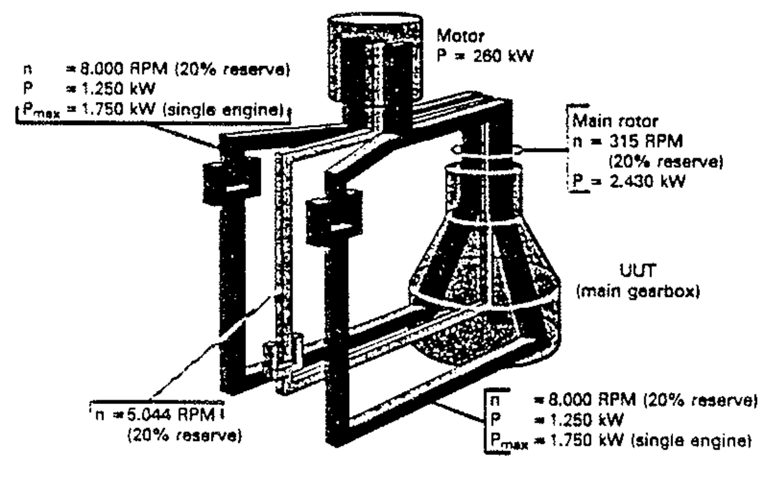


Fig. 12 Power distribution

- Input speed 8.000 1/min (20% reserve)
- Main rotor speed 315 1/min (20% reserve)
- Tail rotor take-off speed 5.044 1/min (20% reserve)
- Maximum input power 2 x 1.250 kW
- Maximum input power, single engine 1 x 1.750 kW
- Maximum power on main rotor mast 2.430 kW

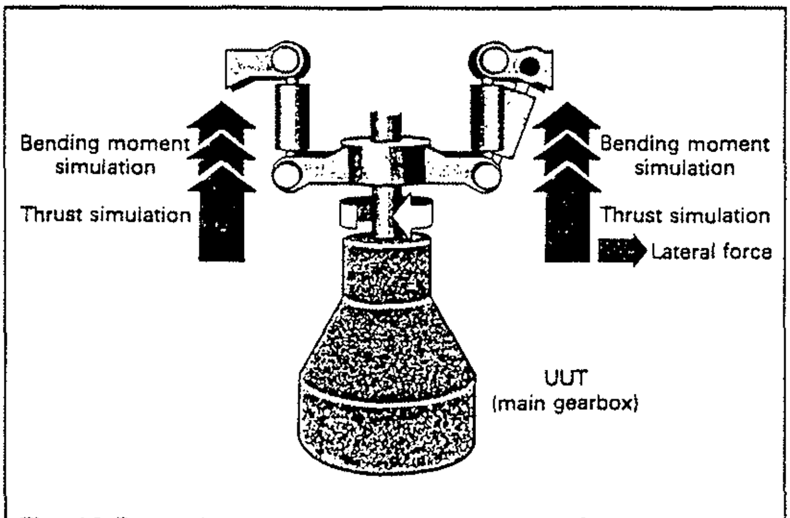


Fig. 13 Rotor force and bending moment simulation

- Thrust simulation on main rotor
- Lateral force simulator on main rotor
- Bending moment simulation on main rotor

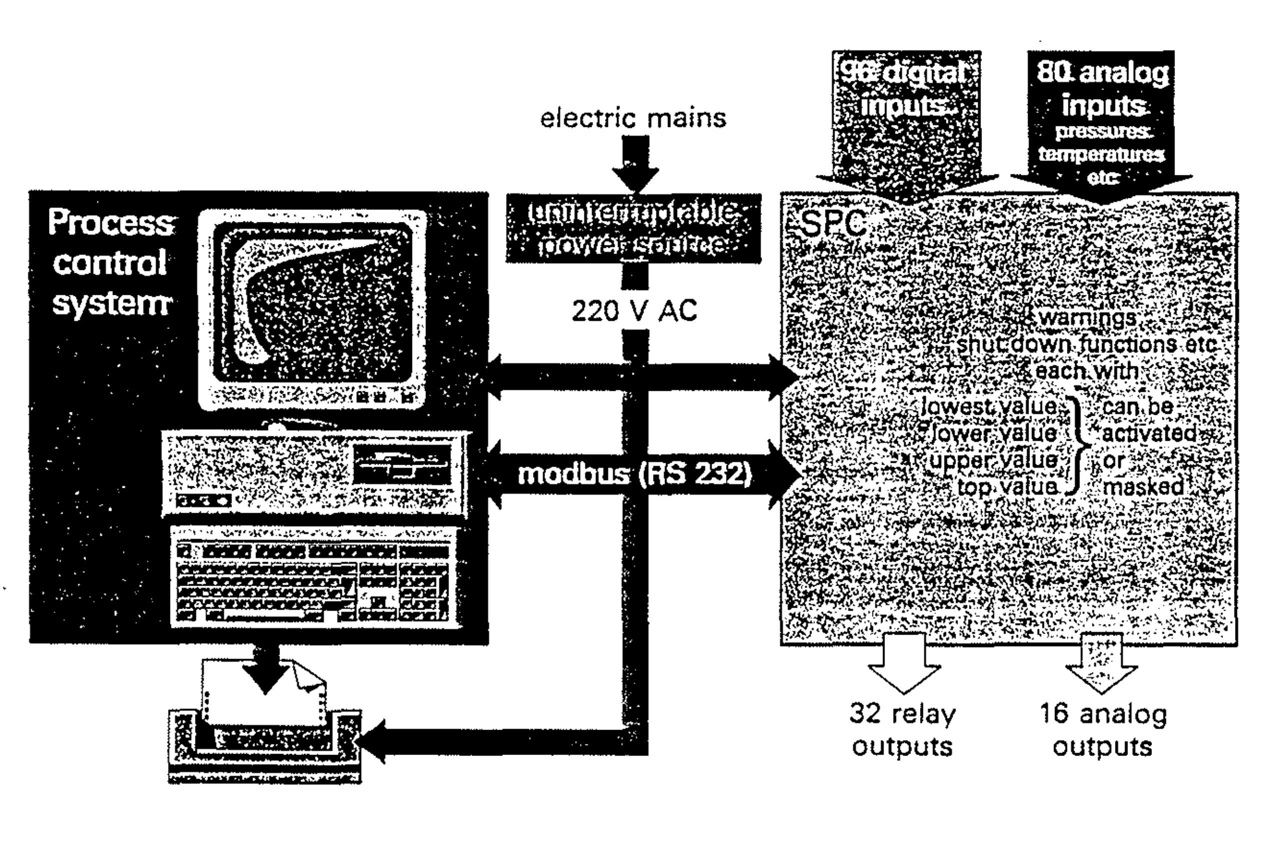


Fig. 14 Control and monitoring system

3. *Conclusion*

It has been demonstrated that rotor and transmission test stands, as important components during development and prototype trials on the helicopter system, have to meet high requirements in order to ensure that development aims are attained.

Due to narrow time schedules it was necessary to develop the test stand systems parallel to the helicopter systems. Thus design modifications to the helicopter systems had immediate impact on test stand systems. Despite these difficulties, these test stands were constructed, commissioned and customer-accepted within very short periods of time. They have since been fulfilling their service in component trials.

4. Reference

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