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ELECTROMECHANICAL BLADE FOLD SYSTEMS:

CURRENT STATUS AND FUTURE DEVELOPMENTS

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ABSTRACT

In the last few years, on some advanced helicopters, electro-mechanical Blade Fold Systems have replaced those of the conventional hydraulic type.

One of the most recent examples is the electro-mechanical Blade Fold Actuator designed and developed by MICROTECNICA for the AGUSTA/WESTLAND EH101. This actuator is particularly interesting, being a single motor, multi-function actuator which provides both the structural linkage between the rotor and the blade and the folding/spreading, locking/unlocking of the blade.

Based on the experience gained with this application, further developments of the concept are being devised in view of future applications.

This paper describes the Blade Fold Actuator developed for the EH101 and proposes a series of possible developments for future applications of Electro-mechanical Blade Fold Systems.

1. INTRODUCTION

Shipborne helicopters require a folding system in order to reduce their overall dimensions and allow high density storage under the flight deck.

Folding/spreading operations must be performed in any environmental condition and in the shortest possible time. Therefore, fully automatic and fast operation is necessary for the folding systems. One effective way to accomplish this task is the use of electro-mechanical systems. They offer some interesting advantages over the hydraulic systems such as:

- simplicity of the control
- ease of installation and maintenance
- high reliability
- cleanliness
- low weight

In addition for the blade folding system there is the advantage that it is not necessary to route hydraulic lines to the root of the blades, thus eliminating the problem of the dynamic seals.

In the first part of this paper one current application of an electro-mechanical folding system is described, the Blade Fold Actuator for the AGUSTA/WESTLAND helicopter EH101. The second part presents some considerations for possible future applications of blade folding systems.

2. EH101 BLADE FOLD ACTUATOR

2.1 Description and operation

The EH101 Blade Fold Actuator is an electromechanical actuator, the function of which is to lock, unlock, fold and spread the blade of the helicopter main rotor.

In addition, the actuator forms the structural pivot around which the blade hinges and is the link between the fixed (root) and folding sections of the blade.

The actuator is essentially modular in construction and comprises of a composite housing assembly, containing the gear train, two rotary actuators, two linear actuators and an electric motor.

The housing assembly forms the base which carries all other assemblies and also provides the mounting points for attachment to the blade.

Fig 1 shows a picture of the actuator.

The operation of the blade fold actuator is entirely automatic and does not require any external controller. The locking/unlocking and folding/spreading functions are performed in the correct sequence by use of the common electric motor and the differential gearing. In this gearing the sun gear is connected through the gear train to the motor, the carrier through a worm-wheel coupling to the linear actuator and the outer ring through another worm-wheel coupling to the geared rotary actuators.

Fig 2 shows a schematic of the Blade Fold Actuator. Reference to this figure is made in the following section.

In the folding sequence the outer ring of the differential is locked, since the rotary actuators cannot rotate, the blade rotation is prevented by the engagement of the pins (L). In this way, when the electric motor is started and the sun gear rotates, the carrier rotates in its turn, retracting the pins (L) until the blade is unlocked. At this stage, the pins cannot be driven any further, the carrier of the differential gearing is locked and the outer ring gear free to rotate. Rotation of the outer ring results, through the rotary actuators (A), in the rotation of the blade which continues moving until the folded position is reached. At this point a stroke limit switch stops the electric motor. The blade is held in the folded position by means of an electromagnetic brake fitted into the motor.

The spreading sequence is similar: as soon as the electric motor is started, the electromagnetic brake of the motor is released and the rotary actuator drives the blade. During this phase any movement of the pins (L) and therefore of the carrier of the differential gearing is prevented by a mechanical interlock device. When the blade reaches the spread position, it comes against a mechanical stop which prevents further rotation. At this stage, as the interlock device has already been released, the carrier of the differential gearing is free to rotate and the pins are actuated. When the locking position is reached, a stroke limit switch stops the electric motor.

A slipping type clutch (I) is fitted into the actuator with the purpose to prevent over stressing of the gears in the event of an overload condition on the blades. An emergency mechanical stop (D) prevents undesired excessive overtravel of the blades in case of failure of the limit switches, thus avoiding possible damage to the blades and helicopter structure.

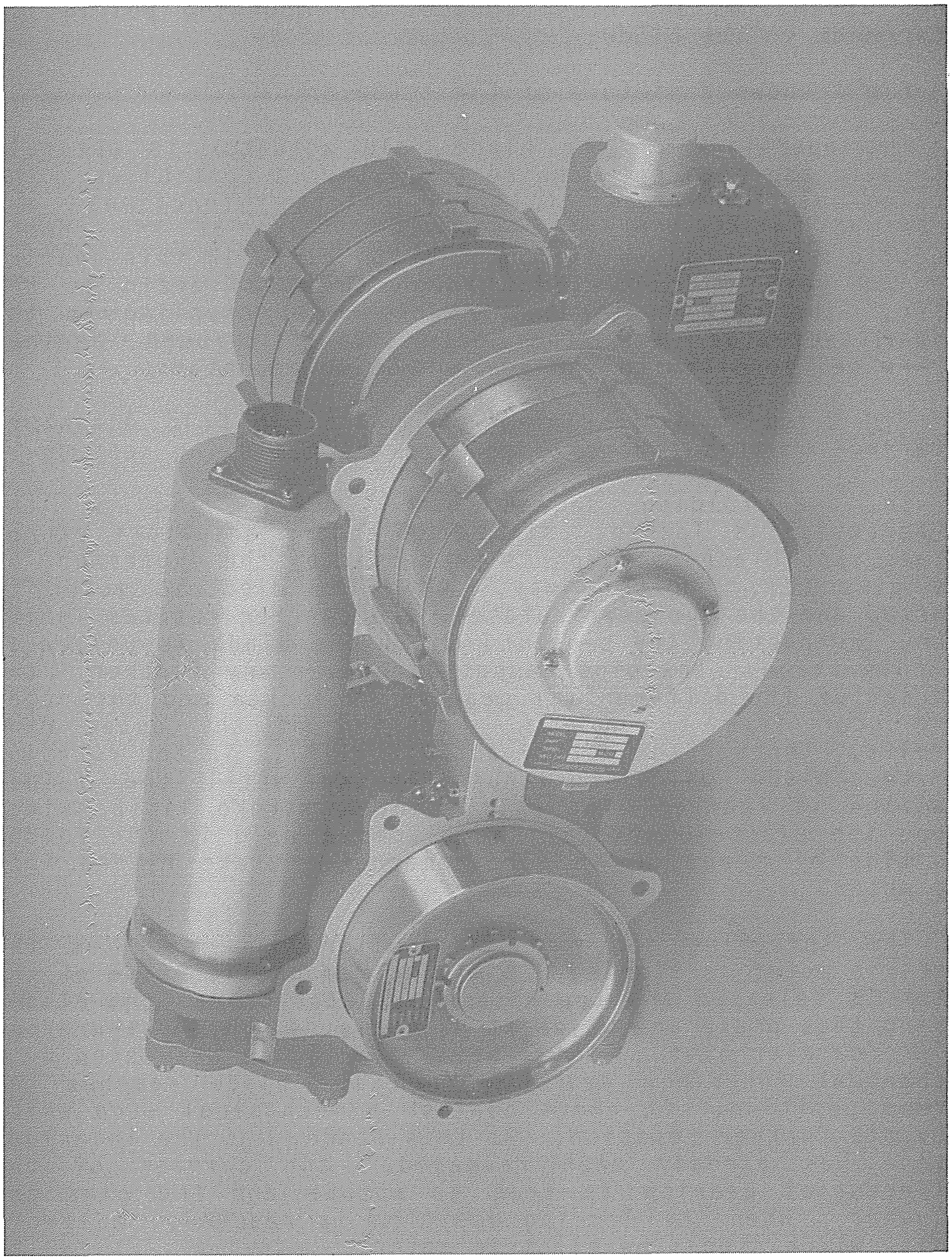

FIG. 1 EH101 BLADE FOLD ACTUATOR

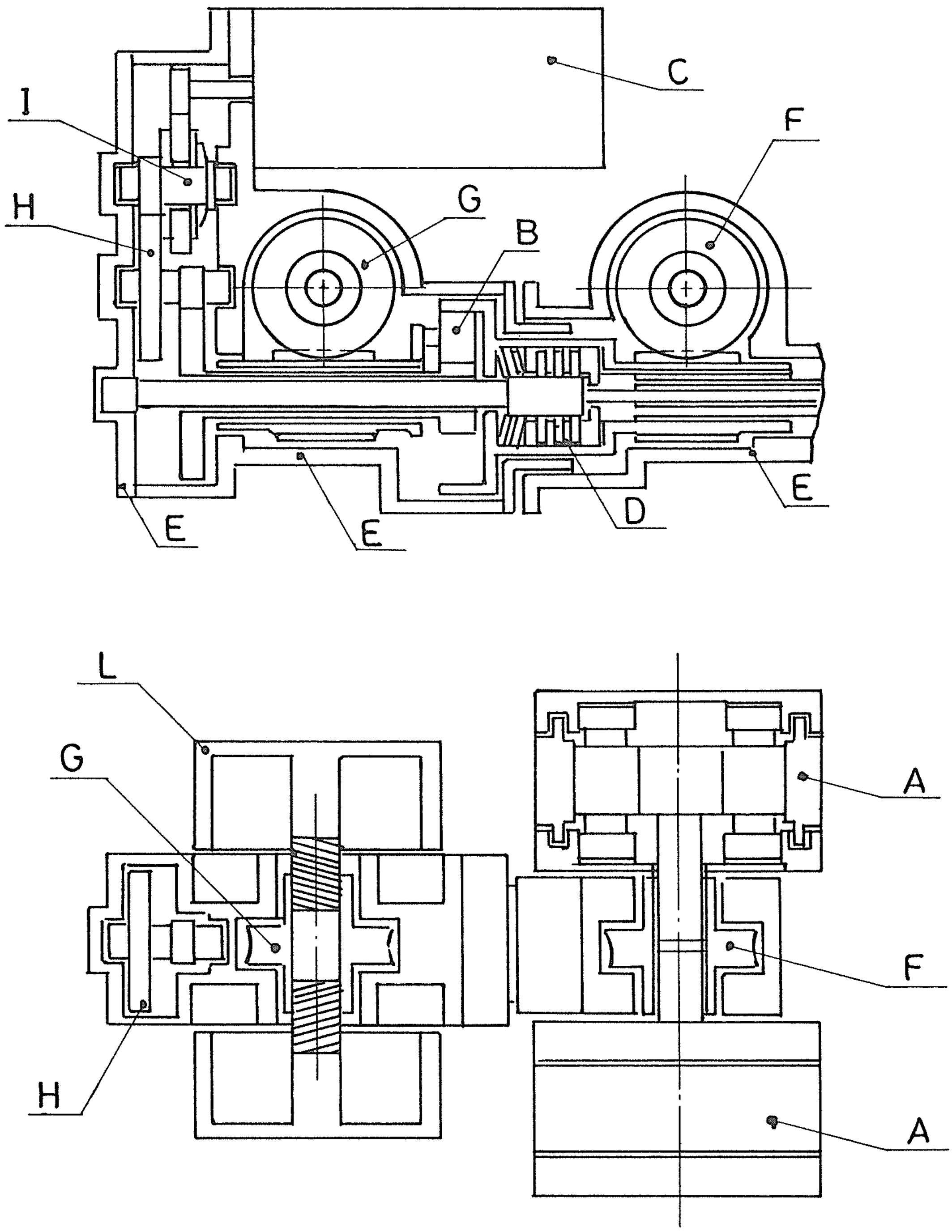

FIG. 2 SCHEMATIC OF EH101 BLADE FOLD ACTUATOR

Fig 3 shows a sectional view of the geared rotary actuator.

The rotary actuators use conventional gear toothed components to perform the two functions of structural hinge and rotary actuation. A compound planetary gear arrangement is used as the reduction stage. The design is simplified from the conventional by eliminating the carrier assembly for the planetary pinions. This is made possible by balancing the tangential tooth forces on the planetary pinions at the ring gear meshes. The outer and pinion gears (2) are identical as are the two fixed outer ring gears (3,5). The planetary pinions mesh with the centre, movable output ring gear (4). The tangential tooth load at the centre mesh is reached by the two identical mesh forces at the fixed meshes.

A full complement of planetary pinions (seven) is used to distribute the load over a large number of gear teeth which in addition to minimizing tooth stress, ensures more even load distribution and increases the stiffness. The multiple planets are held radially into proper mesh by two support rings (1). These offer no circumferential restraint to the planets, which are free to position themselves, to automatically achieve optimum load sharing. The design of the geared rotary actuator is such that it can react all torque and shear loads transmitted through the hinges. The shear reaction is isolated from the actuator gears by spigotting the fixed ring gears into plain bearings recesses in the moveable output ring gear. Because the fixed ring gears are earthed (supported by the nonfolding portion of the blade) all shear loads on the output are transmitted, via the plain bearings and the fixed ring to the structure of the blade.

2.2 Features and leading particulars

The actuator described in the previous paragraph presents unusual features which are worth emphasizing. First of all there is a single electric motor which sequentially operates two separate actuators, one linear for pin locking/unlocking and one rotary for blade folding/spreading.

No electric or electronic controller is required to activate the sequence which selects the operation of the two actuators. As already described, mechanical interlocks allow operation of only one actuator at a time depending on the blade position and on the type of operation required (folding or spreading). This means that once the electric

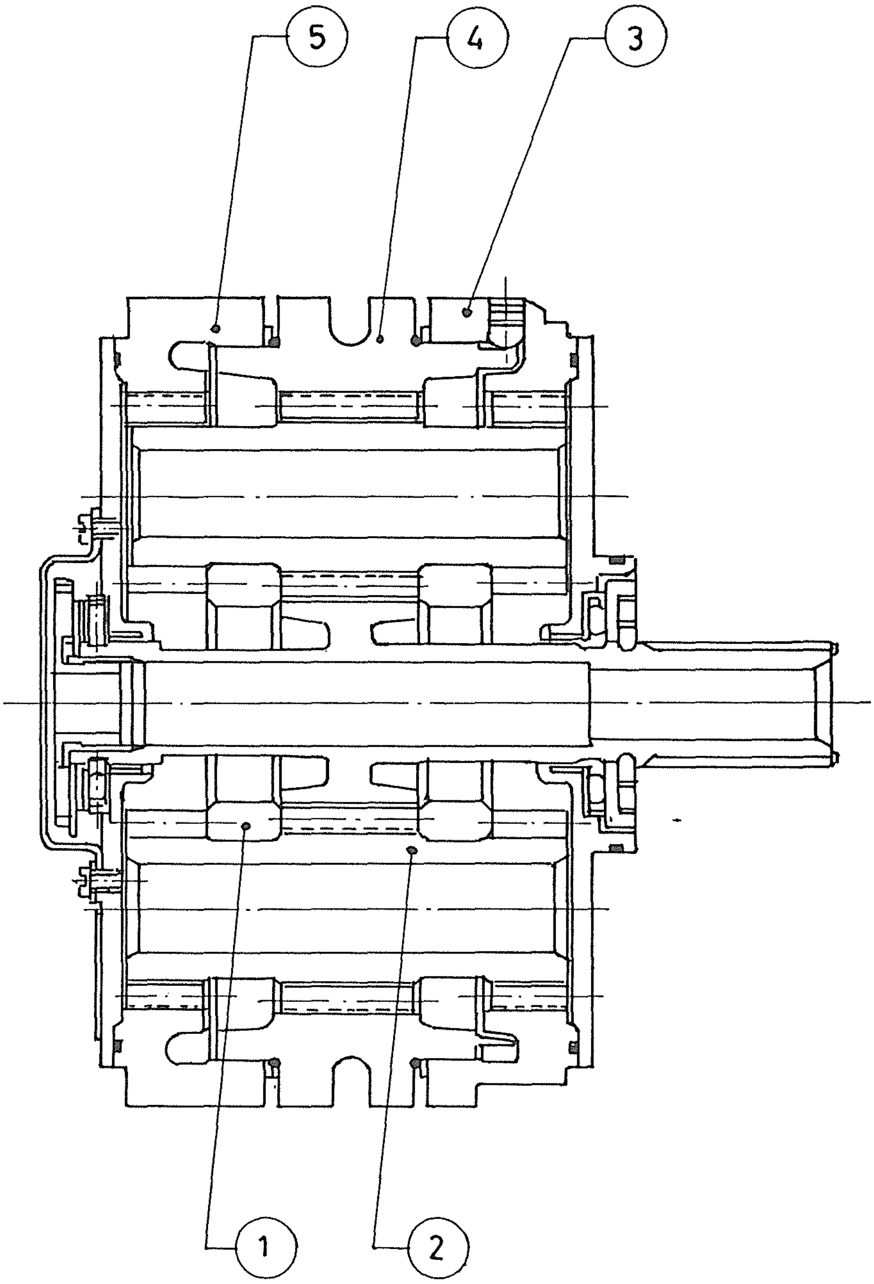

FIG. 3 GEARED ROTARY ACTUATOR

motor is supplied the entire sequence of pins unlocking and blade folding is performed without any further input from the controller.

Another feature of the system is that the blade fold actuator constitutes also the mechanical link between the blade and the rotor hub. The two locking pins and the rotary actuators are the only elements which bear the centrifugal and the pulsating forces generated by the blade rotation.

Finally, the rotary actuators are also the hinge around which the blade rotates.

This configuration i.e. actuator also acting as a structural element, provides the lightest and most compact solution for the blade fold system.

The following table provides a list of the more significant performance and characteristics of the system:

-	electric supply	200 V 115 Hz 3 phase
-	rated current	3 A
-	rated torque	5400 Nm
-	stall torque	7000 Nm
-	limit torque	11000 Nm
-	ultimate torque	16500 Nm
-	operating time	50 s
-	flight loading	340000 N
-	mass	19 Kg

2.3 Development status

The blade fold actuator for the EH101 helicopter has successfully completed the development tests and is presently undergoing the formal qualification process.

The functional tests have been performed on the special test stand shown in fig 4.

The test stand reproduces the installation of the actuator on the aircraft and simulates the inertia of the blade. Two hydraulic pumps apply a controlled load to the actuator, thus reproducing all the wind conditions under which folding/spreading operations may occur.

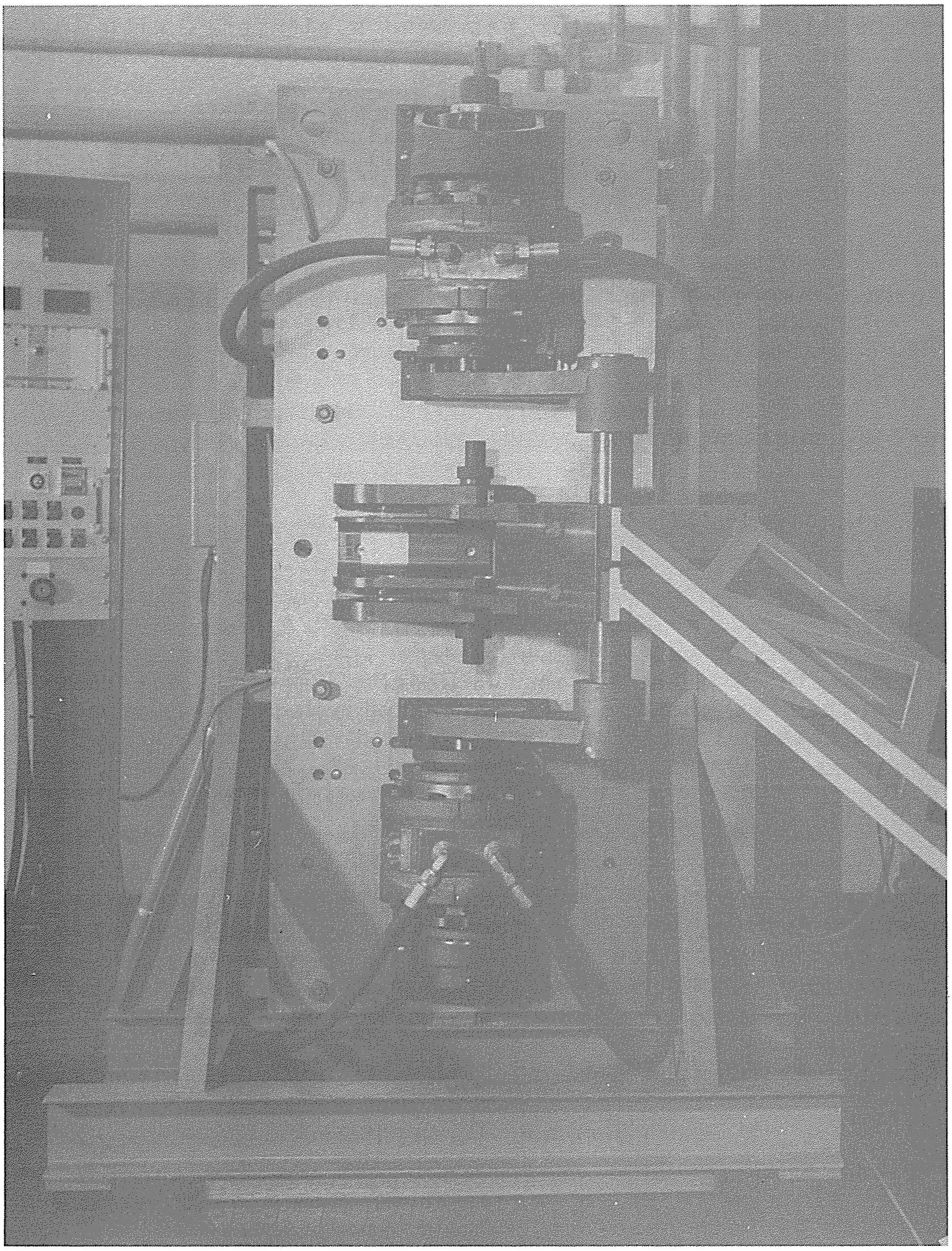

FIG. 4 TEST RIG FOR EH101 BLADE FOLD ACTUATOR

The development tests include functional test under various load conditions and endurance tests. In addition, on a separate rig, the actuator has been subjected, with the relevant parts of the helicopter, to structural tests which simulate the flight loading.

Environmental tests, which include high and low temperature, vibration, humidity, salt mist and EMC tests are in progress.

3. FUTURE APPLICATIONS OF ELECTROMECHANICAL BLADE FOLD SYSTEMS

3.1 General consideration

The experience gained with the development of the blade fold actuator for the AGUSTA/WESTLAND EH101 has allowed to prove the functionality and the effectiveness of a multifunction actuator in the folding system of a shipborne helicopter.

In addition, the extensive tests carried out have greatly helped in showing the potentially critical aspects of the application.

Based on this experience, alternative solutions for future applications are being considered.

In the following paras, the critical performance as well as alternative solutions are discussed. Finally, a proposal for a blade folding actuator for a new European helicopter will be briefly described.

3.2 Critical performances of an electromechanical blade fold actuator

A blade fold actuator must be able to operate under any condition of wind, which means that the loads on the actuator may be both opposing and aiding. In case of aiding loads, it shall be prevented that these loads are transmitted from the actuator to the motor, otherwise the motor will have to operate as a brake. In the EH101 actuator, the external loads cannot backdrive the motor since the gear train is irreversible: however, irreversibility also means low efficiency in the direct mode with a consequent increase in power consumption.

As described in para 2.2 of this paper, one of the features of the EH101 blade fold actuator is the employment of a differential gear to transfer the motion from the motor to the linear or to the rotary actuators. The differential gear, in this application, never allows the contemporary rotation of the carrier and of the outer gear connected respectively to the linear and to the rotary actuators, otherwise a movement of the locking pins and/or a rotation of the blade would occur in a wrong phase.

The contemporary movement of the two actuators is prevented by an interlock device activated and released by a cam on the rotary actuator. Only in case when the blade is in the spread position, the interlock device allows the motion of the locking pins. It is evident that the setting of the interlock must be very accurate to prevent either an early or a late start of the motion of the pins which could lead to some damage to the structure of the helicopter.

The presence of a single motor to drive two actuators greatly restricts the freedom in selecting the gear ratios between the motor and the actuators. As a matter of fact, the gear ratio between motor and locking pins shall be determined in such a way as to prevent overloads on the structure in case of jamming.

3.3 <u>Alternative solutions</u>

Retaining the basic concept of the EH101 actuator, some alternative solutions have already been considered for possible implementation on future application.

One possibility is the use of a no back device instead of an irreversible gear in the chain between the differential and the rotary actuator. This solution would add some complexity to the system but would increase its efficiency thus allowing the use of a smaller motor.

A more radical change would be the system whose schematic is shown in fig 5. The motion is transferred from the motor to the linear and rotary actuators through a differential gear like in the EH101 blade fold system.

Connected to the carrier and to the outer ring of the differential there are two electrically released brakes which in deenergized mode prevent any movement of the actuators. A linear and a rotary position transducer are connected to the linear and to the rotary actuators to sense the actual position of the locking pins and of the blade.

Following is a short description of the operation of the system.

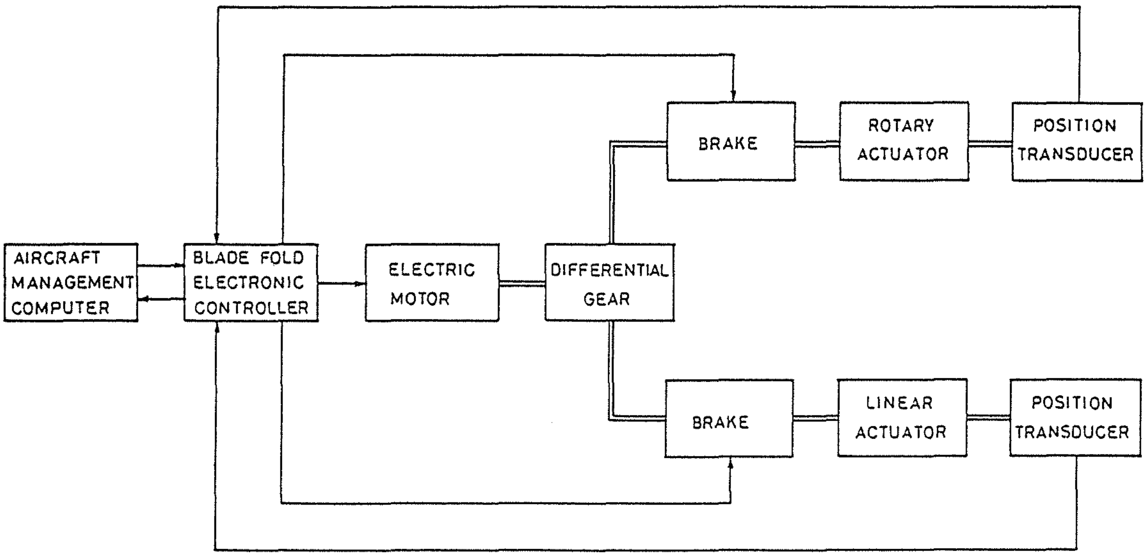

FIG. 5 SCHEMATIC OF AN ELECTRONICALLY CONTROLLED BLADE FOLD ACTUATOR

With the blade in the spread position the actuator locking pins are engaged and both brakes are engaged. Once the blade fold command sequence is activated, the locking pins brake is released and the motor starts to drive the locking pins through the differential gear. When the pins are approaching the retracted position, signalled by the linear transducer, the electronic controller gradually decreases the speed of the motor until at the point when the pins are fully retracted the motor is completely stopped. At this stage, the brake of the pins is engaged and the brake of the rotary actuators released. The motor now starts to drive the rotary actuators which move the blade towards the folded position. When the blade approaches the final position, signalled by the rotary transducer, the motor gradually decreases its speed and stops when the fully folded position is reached. At this stage, the rotary actuator brake is engaged and the folding sequence is completed. The spreading sequence is similar: activation of the blade spread command enables the release of the rotary actuator brake. The motor drives the blade until the spread position is reached.

At this stage, the motor stops, the rotary actuator brake is engaged and the linear actuator brake released. The motor then drives the locking pins to the fully inserted position. When this position is reached, the motor is stopped and the brake engaged.

3.4 <u>Proposal for a new blade fold actuator</u>

In fig 6 it is presented an outline of a blade fold actuator which could be utilized for new helicopters of the type of the NH90.

It retains the basic concepts of the EH101 actuator, i.e. single motor to perform two functions and geared rotary actuators which form the mechanical link between fixed and foldable portion of the blade.

In this application, the rotary actuators are on the centerline of the blade while the locking pin is placed on an orthogonal plane.

The arrangement shown constitutes a very compact and light solution for the blade folding system of the helicopter.

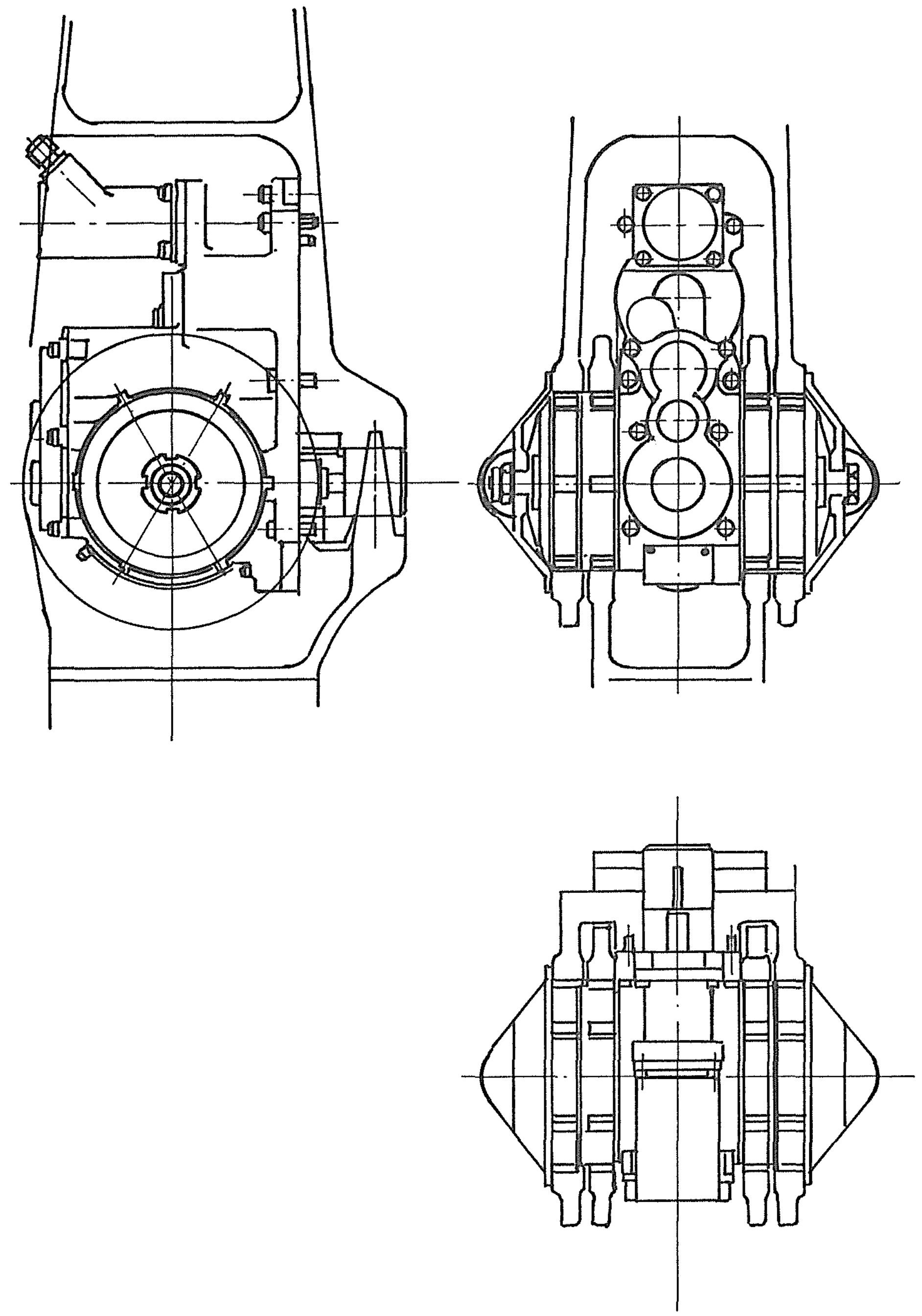

FIG. 6 PROPOSAL FOR A NEW BLADE FOLD ACTUATOR