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ELECTRO-MECHANICAL ACTUATORS FOR HELICOPTER BLADE FOLDING APPLICATION

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ABSTRACT

A viable blade fold system is needed on shipborne helicopters to reduce the overall dimensions of the aircraft and so enable high density storage.

Current conventional blade fold systems are hydraulically powered and considerable advantages could be achieved through electrical blade folding systems.

This paper describes two electro - mechanical actuators: one actuator to index the rotor head prior to the blade fold operation, the other to fold the main rotor blades. The rotor indexing actuator is a two - speed actuator where the change of speed is achieved without the need of an electronic control. The blade fold actuator is particularly interesting, being a single motor, multi - function actuator, which provides the structural fulcrum around which the blade hinges and automatically unlocks/locks, folds and spreads the blades.

INTRODUCTION

Shipborne helicopters, because of the environmental and logistical conditions under which they operate are invariably stored below the flight deck. To enable maximum utilization of space and ease of handling the main rotor blades and the rear part of the helicopter tail section are folded.

In order that the folding / spreading operations, even under the most arduous environmental conditions, be achieved with the maximum efficiency, it is necessary that the folding/ spreading sequence be performed automatically.

To achieve this requirement it is necessary that actuators be permanently installed on the helicopters. To avoid excessive penalties it is obviously necessary to keep the weight of these actuators as low as it is practicable and to this end electro - mechanical actuators seem more suitable than the conventional hydraulic ones. In addition electrical actuators have considerable advantages in terms of maintenance and servicing.

Presented in this paper are two electro - mechanical actuators which can be used in a helicopter blade folding system. The first actuator is one used to index the rotor head prior to the blade fold operation, the second is an actuator used to fold and spread the main rotor blades. Both actuators have been designed and developed by Microtecnica S. p.A. Turin.

ROTOR INDEXING ACTUATOR

The function of this actuator is to index the main rotor head and to hold the rotor in the final position prior to folding of the blades. The folding sequence normally requires that as a first operation the rotor is driven to a precise position in order to allow the blades to be folded without any interference with the helicopter structure.

The equipment basically consists of a linear actuator driven by a small D.C. motor and a rotary actuator unit driven by a 200 V 400 Hz electric motor. The function of the linear actuator is to engage or disengage the rotary actuator's output shaft with the gearbox of the main rotor. The rotary actuator drives the helicopter main rotor. A brake in the electric motor holds the rotor in the final position.
A sectional view of the unit is shown in Fig. 1.

In the design of the rotor indexing actuator the following requirements have been particularly considered:

- very high positional accuracy
- high actuation speed
- simplicity of control
- low power consumption
- low weight

The weight and the power consumption have been kept to a minimum by use of a high-efficiency gear reducer. The requirements of high positional accuracy, high speed and simple control have been satisfied by using a two-speed actuator. The output shaft of the actuator rotates at high speed for most of the travel required to index the rotor. As the final position is approached, the speed is considerably reduced, thus allowing a very precise stopping of the rotor.

The change of speed of the actuator is obtained by changing over two phases of the electric motor power supply, without the need of an electronic controller. This change over results in the reversal of the direction of rotation of the motor, which in its turn results in a reduction of the actuator's output speed.

Figure 2 shows a schematic of the compound epicyclic gear train, the function of which is to reduce the output speed when the direction of rotation of the motor is reversed.

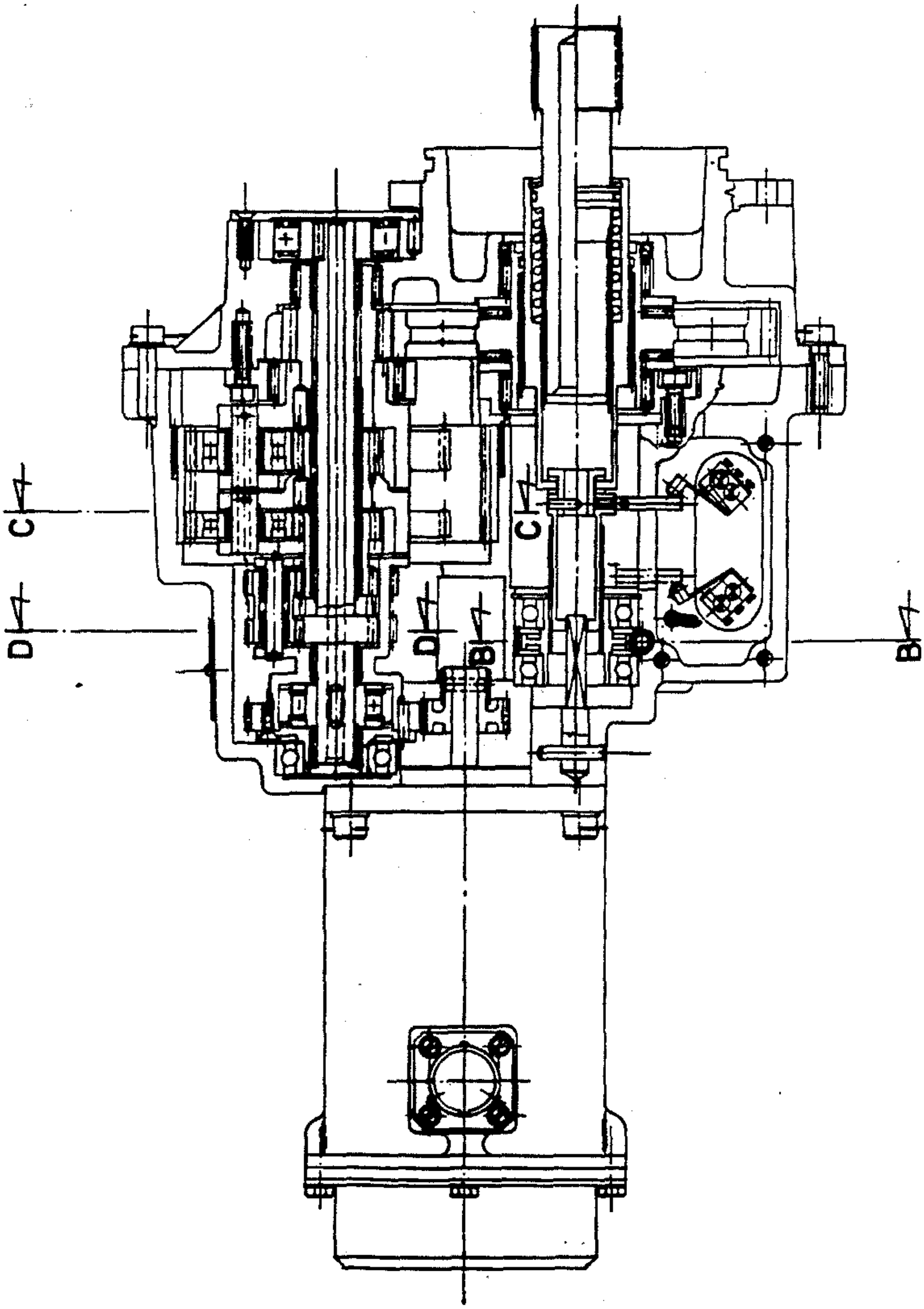

Fig. 1 - Rotor Indexing Actuator

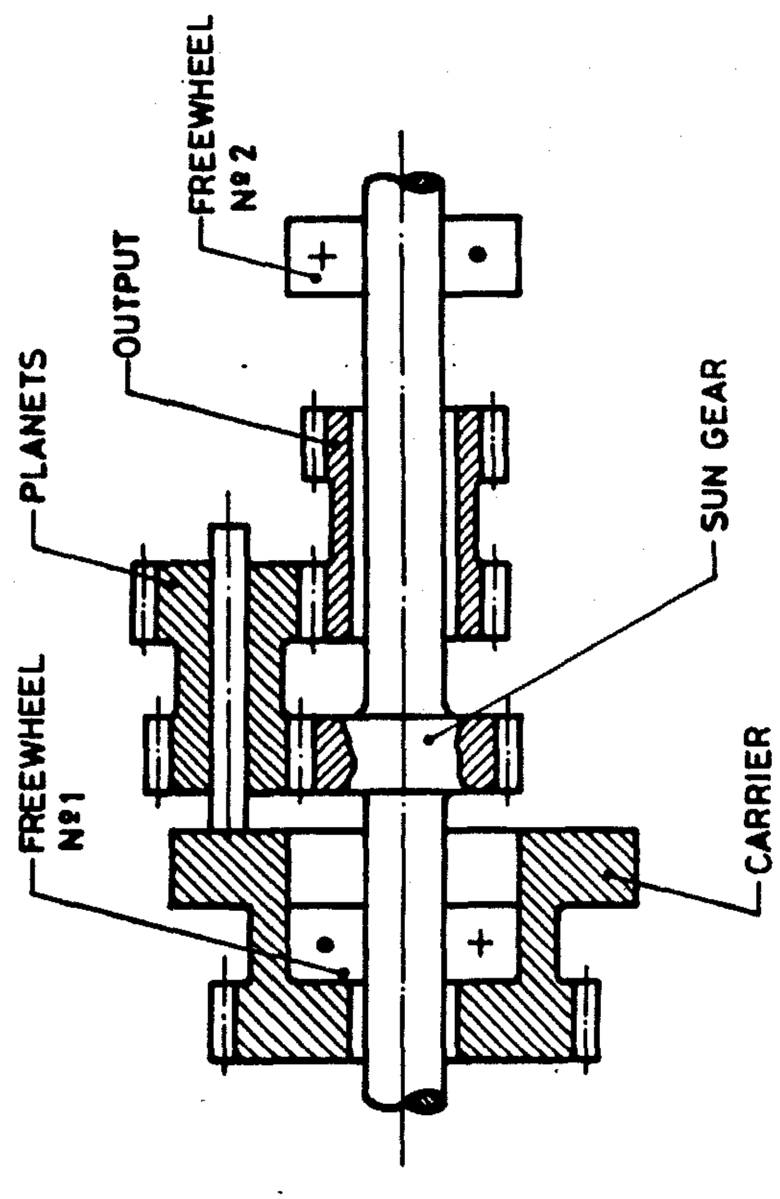

Fig. 2 - Compound Epicyclic Gear Train

When the carrier, which is connected to the motor, rotates in counter-clockwise direction, it also drives the sun gear. There is no angular velocity of the planets and therefore the output is driven counter-clockwise at the same speed of the carrier. When the carrier rotates clockwise the sun gear is clamped by the freewheel 2 and the output rotates counter-clockwise at a speed equal to 1/12 of the speed of the carrier.

Therefore, by changing the direction of rotation of the carrier, the output motion is always in the same direction, but at two different speeds, one being 12 times lower than the other.

The main characteristics of the rotor indexing actuator are summarized as follows:

- Maximum indexing time	60 s
- Positional accuracy	± 0.3'
- Power consumption	1.5 kW
- Mass	6 kg

BLADE FOLD ACTUATOR

The Blade Fold Actuator is an electro-mechanical actuator whose functions are locking / unlocking and folding / spreading of the blades of the main rotor of the helicopter. Each folding blade requires an actuator. The actuators are identical in construction, completely interchangeable between blades it being necessary only to adjust the limit switches according to the angle of rotation required for each blade.

The actuator is schematically shown at figures 3 and 4. It comprises basically an electric motor (C), a gear train (H), a differential gearing (B), two linear actuators (L) and two geared rotary actuators (A). Other features include an overload clutch (I), an emergency mechanical stop (D) and the provision for manual operation in case of loss of electric power.

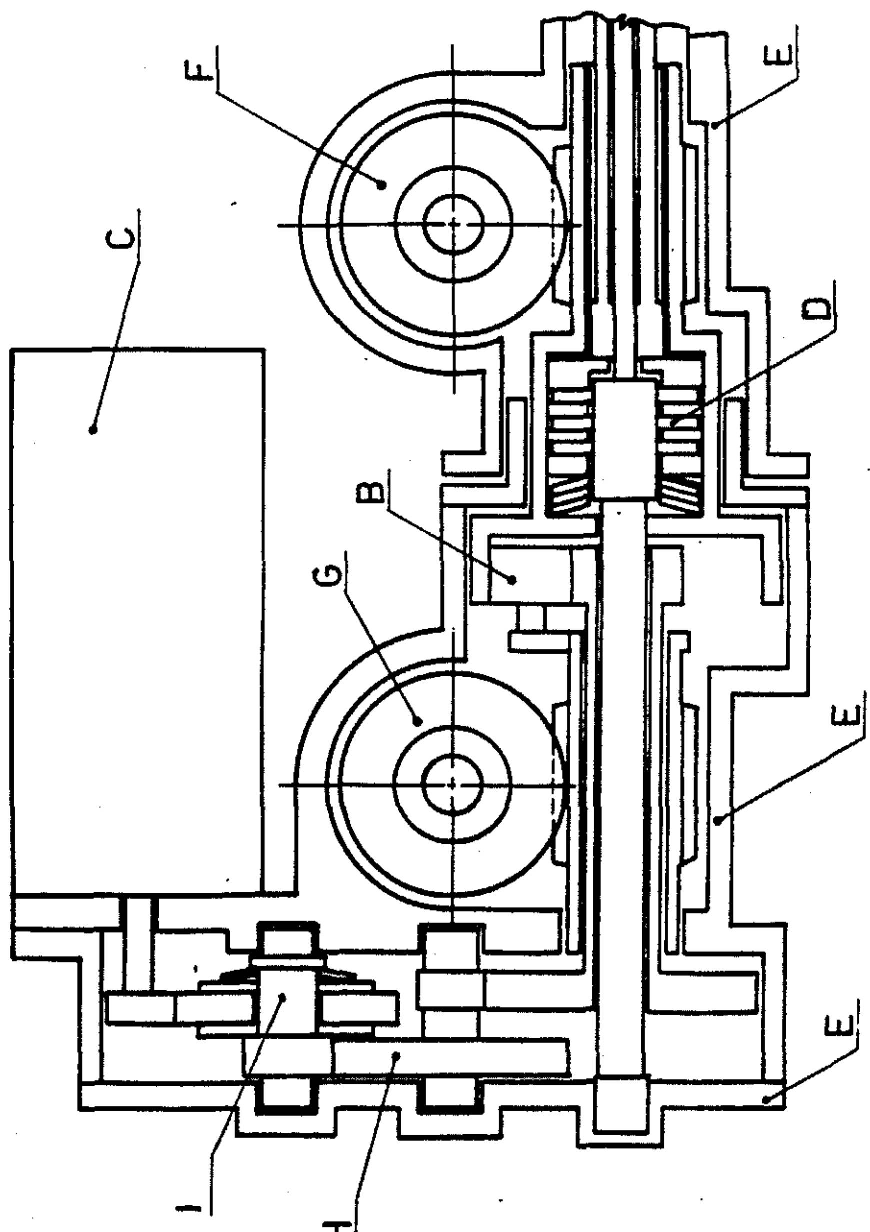

Fig. 3 - Blade Fold Actuator (plan view)

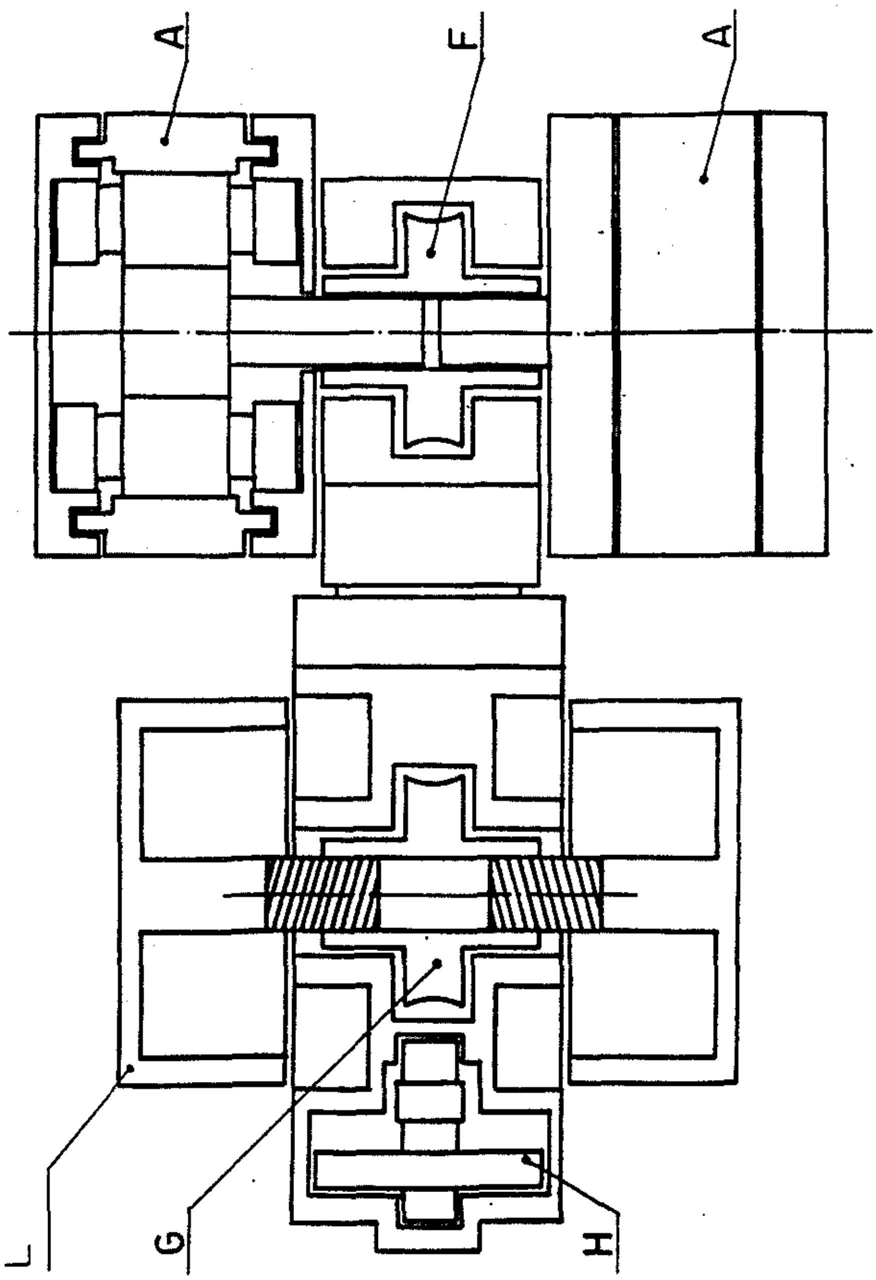

Fig. 4 - Blade Fold Actuator (lateral view)

What is particularly interesting in this blade fold actuator is the fact that it is a multi-function equipment, being both a functional and a structural device. Functionally it locks and unlocks the folding portion of the blade by means of a linear actuator and folds and spreads the blade by means of a rotary actuator. The two actuators, linear and rotary, are driven by the same electric motor. Structurally the blade fold actuator provides the fulcrum around which the blade hinges and also the only link between the fixed and the folding portion of the blade.

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 and by use of a common electric motor and differential gearing (B). In this gearing the sun gear is connected through the gear train (H) to the electric motor , the carrier through a worm - wheel coupling (G) to the linear actuators and the outer ring, through another worm - wheel coupling (F) to the rotary actuators.

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 electro-magnetic brake fitted into the motor.

The spreading sequence is similar: as soon as the electric motor is started, the electro-magnetic 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.

The most innovative feature of the blade fold actuator is the use of geared rotary actuators. It is worth few words to discuss the rationale which led to the choice of this type of actuator for this application. In the design phase the following constraints had to be taken into consideration:

- extremely high loads on the blades during folding / spreading sequences
- relatively low electric power available
- severe space limitations
- necessity of minimizing the weight of the equipment, as it was to be permanently installed on the helicopter.

Given these requirements, the use of geared rotary actuators was the natural choice since they have the following characteristics:

- very high load capability compared with overall dimensions
- high overall efficiency
- capability of providing both the actuation of the blade and of performing the function of a structural hinge.

The following is a description of the function of the geared rotary actuator, as illustrated in Fig. 5.

A geared rotary actuator uses 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 pihions (six) 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 (18). 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.

The planetary pinions are thus subjected only to torque loads. Detailed as follows are the design and performance parameters of the rotary actuator:

- Total ratio	54.25
- Efficiency for power flow from input to output	0.73

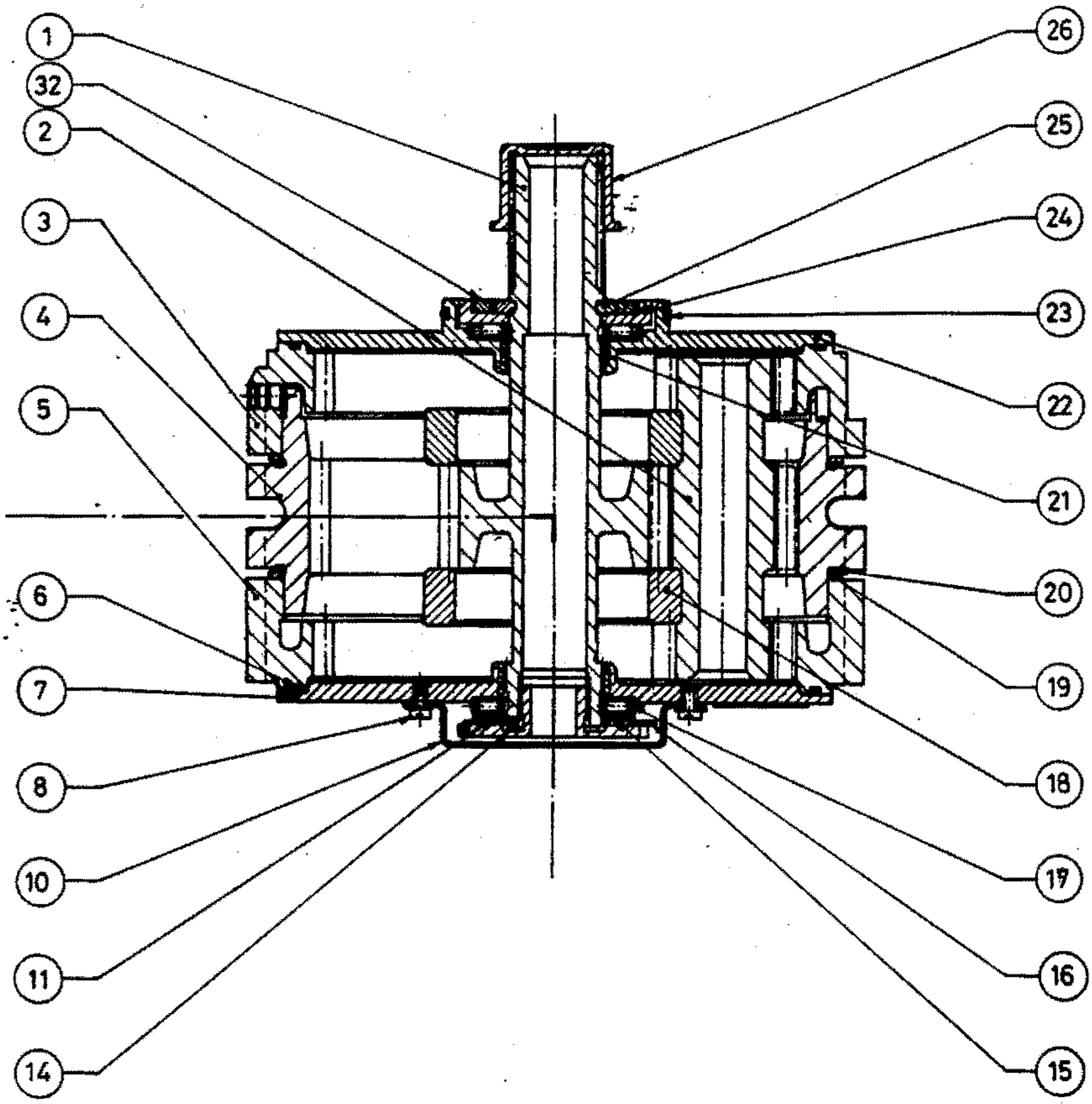

Fig. 5 – Geared Rotary Actuator

–	Efficiency for power flow from output to input	0.67
–	Maximum dynamic output torque	3500 Nm
–	Maximum static torque	7500 Nm
–	Ultimate torque	10500 Nm

Performance of the complete blade fold actuator are summarized below:

–	Rated torque	5400 Nm
–	Maximum torque	7000 Nm
–	Maximum folding / spreading time (including pins locking / unlocking)	50 s
–	Power consumption	700 W
–	Total mass	17 kg