THIRD EUROPEAN ROTORCRAFT AND POWERED LIFT AIRCRAFT FORUM

Paper No 1

IDS - AN ADVANCED HINGELESS ROTOR SYSTEM *)

W. JONDA, H. FROMMLET

MESSERSCHMITT-BÖLKOW-BLOHM GMBH

GERMANY

*) work sponsored by the German Ministry of Defense (BMVg)

September 7-9, 1977

AIX-EN-PROVENCE, FRANCE

ASSOCIATION AERONAUTIQUE ET ASTRONAUTIQUE DE FRANCE

Abstract

In the following, the INTEGRATED DYNAMIC SYSTEM with its modules is described, pointing out its advantages compared to other systems.

The integration and modularisation of the subsystems render a compact design possible with good maintainability, reliability, lower weight and lower Life Cycle Costs (LCC)

1. Introduction

The hingeless rotor of "System Bölkow", as used on the BO 105 helicopter, has simplicity of construction and otherwise unobtainable flying and handling qualities as its main characteristics.

In place of the flapping and lagging hinges of articulated rotors a flexible blade design of fiberglass is substituted. The only bearing is for blade pitching motion which supports the blade in the stiff titanium rotor hub. This construction allows very high control and trimming moments on the one side, and a drastic reduction of moving parts on the other, thus making the rotor "System Bölkow" competitive with most modern design, especially if the service requirements of the new elastomeric bearings are considered.

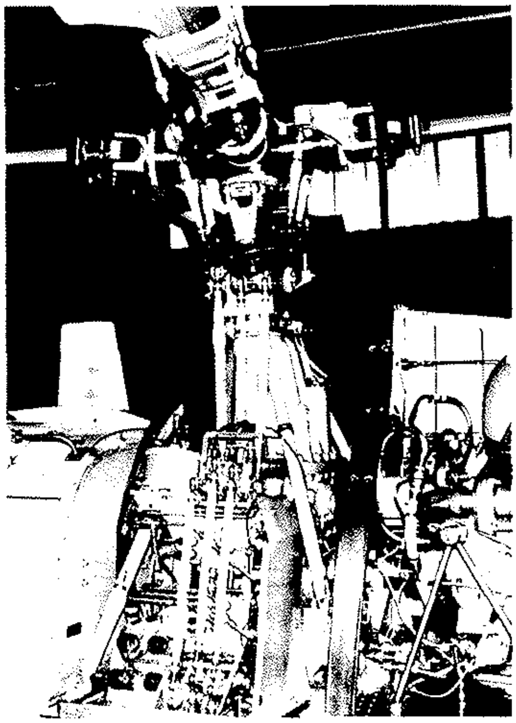


Figure 1. Dynamic System BO 105

The BO 105 rotor head is supported by the drive shaft of the three stage planetary gear box.

On the outside of the drive shaft are the controlrods and the mixing lever, which are operated over the swash plate by a dual hydraulic unit.

The power is supplied by two engines.

The further development of this rotor system must aim at retaining the major advantages of the hingeless rotor, while bringing further improvements to the already excellent charasteristics of the rotorsystem in such areas as:

- life cycle costs
- maintainability
- reliability
- weight
- space requirements

To this and the following steps are to be taken:

- Modular Integration
- Complete modularisation of subsystems, with subsystem interchangeability without any adjustments, as is practiced in modern engine design.
- Structural compactness with a minimum of single parts.
- Multiredundant condition monitoring and fault-diagnosis system

Over the past years numerous IDS studies were conducted at MBB. Fig. 2 shows an early design concept with a 2 stage gear box and a spur-gear collector stage.

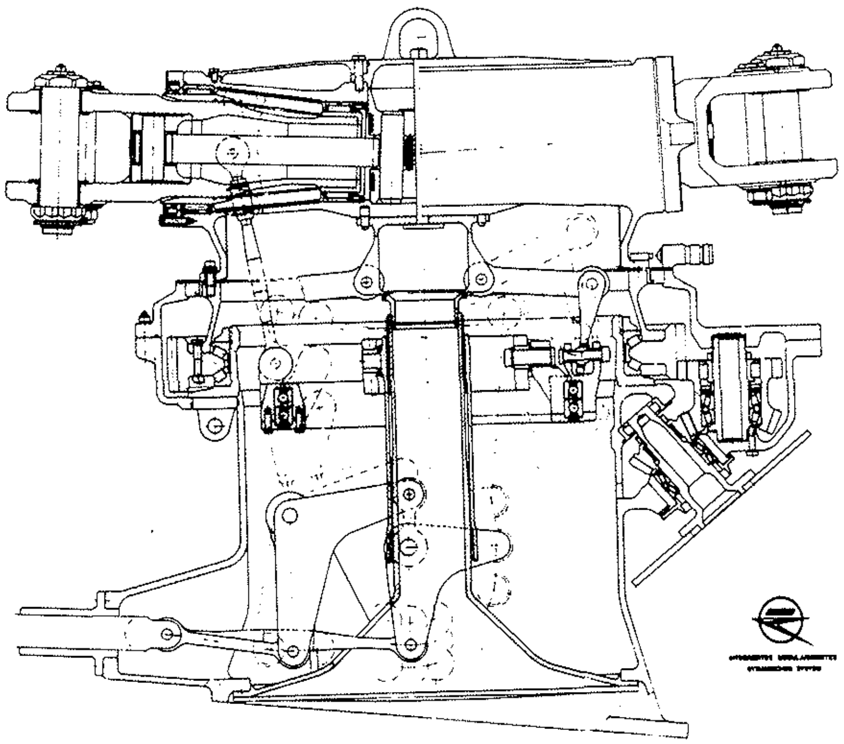


Figure 2: Possible IDS concept

2. IDS, the Integrated Dynamic System

The goals outlined in the introduction can be realized by a properly designed IDS system as described in this paper. The proposed rotor system consists of the following modules:

- rotorblades
- rotorhead
- main transmission
- upper controls
- controls hydraulic unit
- auxiliary systems

Fig. 3 illustrates the construction and the differences between IDS and a conventional rotor system such as:

- Connection of the rotorhead direct to the gear box, thus no drive shaft
- the double ball bearing for the collector gear
- arrangement of the upper controls inside the gear box and rotor hub
- attachment of the hydraulic unit direct to the gear box
- 2 stage gear box with a spiral bevel collector stage with high reduction ratio

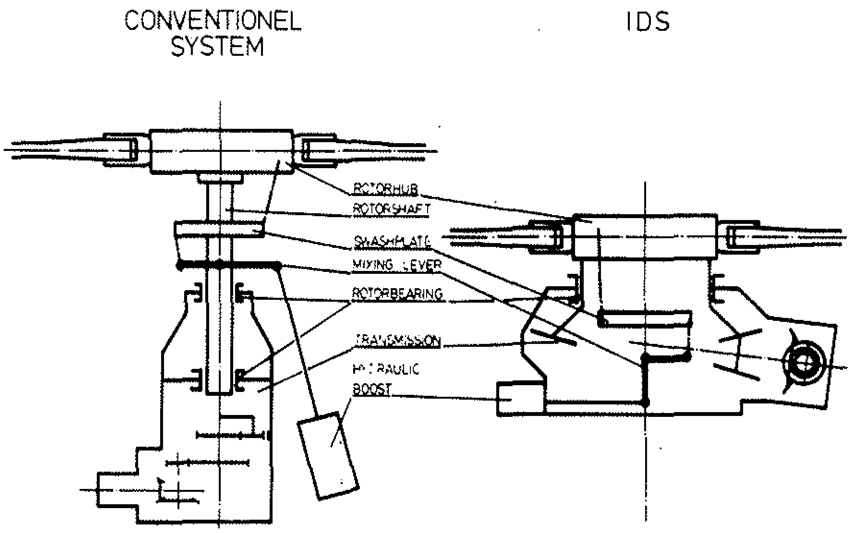
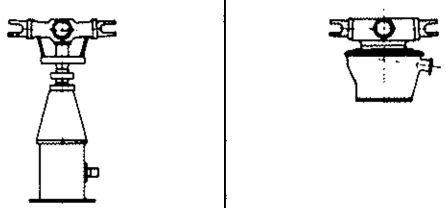


Figure 3: Comparison Dynamic system conventional/IDS

By means of the integration and modular construction a number of important advantages could be achieved:

- reduced number of parts (see Fig. 4) results in lower costs, reduced weight as well as improved reliability. Especially the reduced number of bearings should be noted. Since their failure is governed by the laws of statistics, a reduced number of bearings means an improvement in reliability.
- protection of the internally arranged control parts from environmental influences, mechanical damage and ballistic damage.
- lubrication of all gears and bearings, including rotorhead and upper controls, by the same lubrication system. The oil lubrication and protection from outside influences results in significant improvement in the life span of control bearings in comparison to conventional systems.
- use of the lubrication as carrier of informations for the condition indication system of the gear box, rotorhead and control system

SIMPLIFICATION BY INTEGRATION



	CONVENTIONEL	INTEGRATED
NUMBER OF GEARS FOR MAINROTOR AND TAILROTOR DRIVE	16	8
NUMBER OF DRIVE SHAFTS	7	5
NUMBER OF BEARINGS FOR MAINROTOR AND TAILROTOR DRIVE	26	15

Figure 4: Comparison IDS/Conventional System

- short control paths through attachment of the hydraulic unit directly to the gear box together with the possible connection of the hydraulic unit to the lubrication system.
- exchange of complete modules, as well as single components without special adjustment requirements
- reduction of the vulnerable area through the lower hight of the unit.
- lower loads on the rotor components as illustrated in Fig. 5. In Fig. 5. the difference in transmission ratio for the control and trimming moments of conventional and IDS systems is shown:

  conventional:

  The flapping moment produces a bending moment in the rotor shaft, which is transferred to the gear box housing as force couple.

  IDS:

  The flapping moment is taken up directly at the flange of the rotorhead and the results as couple moment directly in the mainbearing. This means a reduced load on the rotorhead and short load transfer paths.

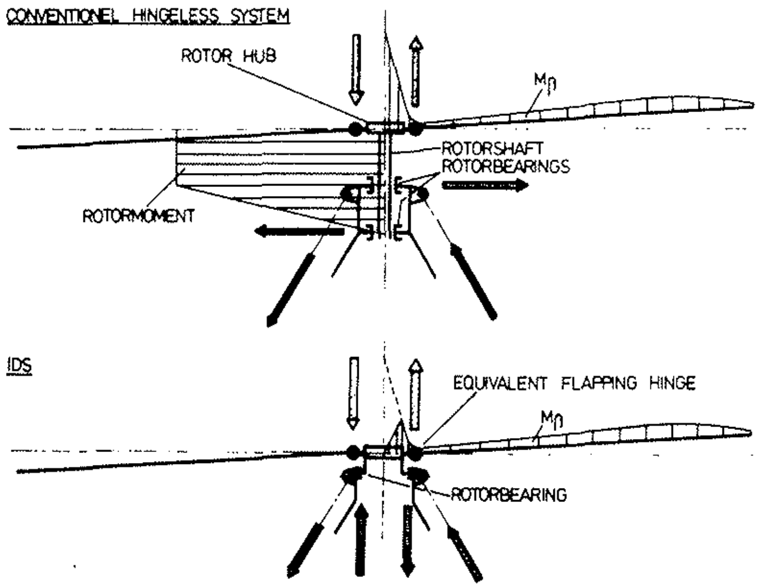


Figure 5: Control moments transfer to airframe

3. Design of the IDS

The IDS and its modules are presented in Fig. 6. The study was conducted for a helicopter of 4,5 ton class an normal rated power of 2x5oo kw for the gear box.

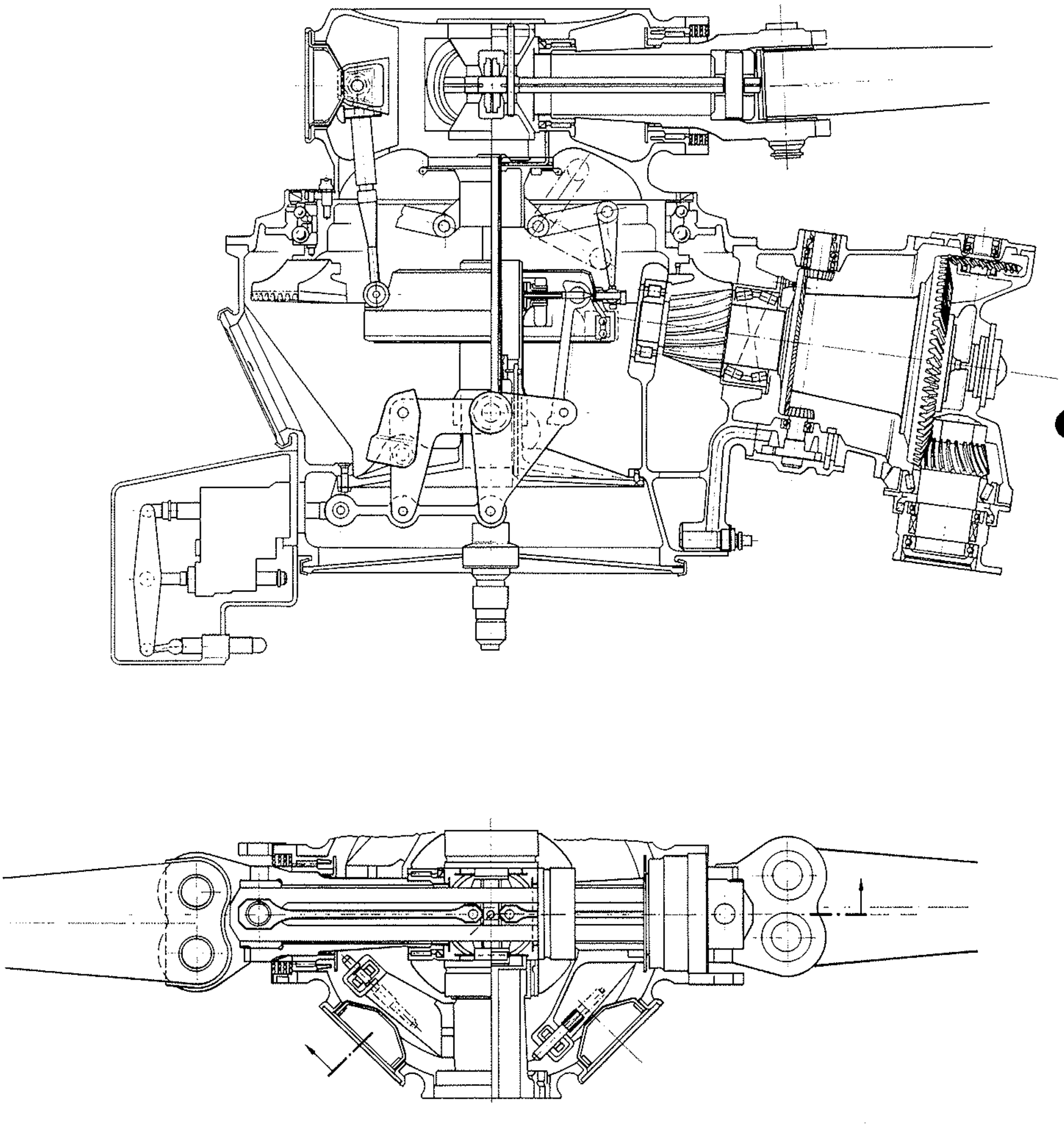


Figure 6 : Integrated Dynamic System

3.1 The Rotorblade

The last 1o years have proven that rotorblades of composite construction are superior to other blade designs. Thus the blades for the IDS are of composite material. Here the 15 years of experience available and the latest technology are combined to achieve further reduction in the life cycle costs of the blades.

3.2 Rotor hub

Similar to the BO-105 the flexible rotorblades are attached to the inner sleeve of the rigid rotorhead. The shear loads are transferred from the inner sleeve to the hub by means of pitch change bearings. The center piece of the rotorhead is a circular housing with stub arms for attachment of the inner sleeves and a large flange for attachment to the rotor bearing installed in the gear box.

Some technical details are:

- roller bearings for blade attachment
  retention of the centrifugal forces by steel laminated tie bars connected to the rootend attachments of each blade pair.
- the coning angle is built into the blade attachment which results in aeroelastic advantages on the one hand, and allows the use of one single tie bar for each pair of blades on the other, without subjecting them to torsional loads with cyclic control inputs.
- Centering by means of a narrow centrally located strap for each arm
- attachment of the pitch horn at the inner sleeves between the roller bearings
- the lubrication of the roller bearings by transmission oil which is fed to the inner bearings and is moved outwar by the centrifugal force.
- sealing of the bearings on the inner side by a conventional shaff seal plus deflector ring, and on the outer side by a new developed flexible elastomeric seal which allows torsional motion.
- return of the oil through the control rod holes in the bottom of the center piece.
- 4 service and inspection ports on the side.

For the production of the center piece several methods can be used. These methods, being under investigation are:

- titanium alloy
  - . α-β forging
  - . β forging
  - . centrifugal casting

production of [illegible] forgings is the lowest risc method, but requires the largest effort in machining. Centrifugal casting is the most promising method in production costs.

- composites
  - production of the center piece of composite material promises further reduction of costs and a significant weight saving

3.3. Transmission

For two a engine version the designs shown in Fig. 7 were investigated, with number 5 being selected. (fig. 7.,8.)

- 2 stage transmission
- input bevel gear stage
- spiral bevel collector gear stage with a reduction ratio of 6.5
- tailrotor drive from the collector stage
- auxiliary drive from the intermediate shaft (between input stage and collector stage)
- common duplex ball bearing for rotor and collector gear
- a circular oil sump, into which oil is scavanged from the center of the transmission in order to prevent loss of oil when opening the bottom inspection port
- dual redundant oil circuit
- 2 oil coolers directly attached to the transmission
- gear box attachment by 4 struts connected on the upper and lower end part of the housing opening of inspection ports by quick disconnectdivice on the sides and on the bottom

Three different types are under investigation for the rotor bearing:

- duplex ball bearing with two rows of different size balls
- duplex roller bearing
- combined bearing with one row of balls and one row of tapered rollers

In a test which is now in progress the best type will be determined. Based on current results it appears that the duplex ball bearing will be best.

3.4 Controls

The upper controls (swash plate, control rods, sissors and mixing lever) are located on the inside of the rotorhead and transmission. The bellcrancs are also serve as the mixing lever. The swash plate is lubricated through openings in the supporting tube and through two spray nozzles. The rod end bearings are spray lubricated. A new design for the rotating control rod was necessary to improve the effort for blade trakking. This new special mechanism allows the length adjustment without using tools or removal.

3.5 Hydraulic system

The hydraulic system is designed as a self contained unit and forms an integral part of the transmission. The dual hydraulic system has dual redundancy. The control input can be located in front or below, depending on the requirements of the airframe

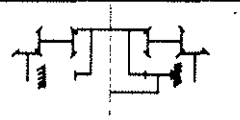
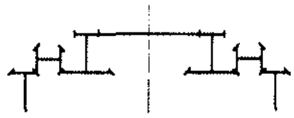
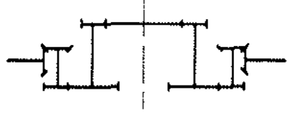
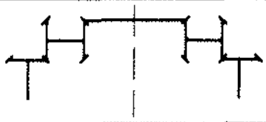
VERSION	SCHEME	WEIGHT	NUMBER OF GEARS (MAIN ROTOR DRIVE)	NUMBER OF BEARINGS (MAIN ROTOR DRIVE)	NUMBER OF SHAFTS (MAIN ROTOR DRIVE)
1 CONVENTIONEL PLANETARY TRANSMISSION WITH ROTORMAST 3 STAGES		100%	14	23	6
2 IDS TRANSMISSION WITH PLANETARY STAGE 3 STAGES		105%	14	20	5
3 IDS TRANSMISSION WITH SPUR GEAR COLLECTER STAGE 3 STAGES		115%	11	19	6
4 IDS TRANSMISSION WITH SPUR GEAR COLLECTER STAGE 3 STAGES		118%	11	17	6
5 IDS TRANSMISSION WITH BEVEL GEAR COLLECTER STAGE 2 STAGES		93%	7	13	4

Figure 7: Comparison IDS Transmission

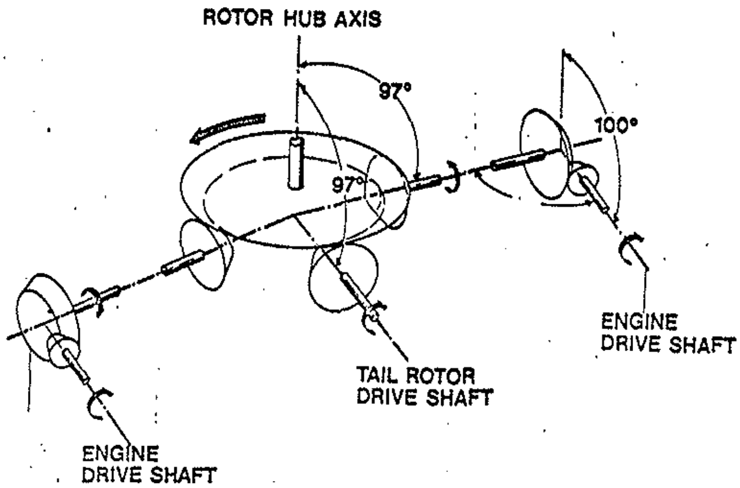


Figure 8:gear box schematic

5. Maintenance

Through the completely sealed arrangement sand, dirt, humidity, salt water and other adverse environmental effects are kept clear from the critical components. This protection and the built in oil lubrication provide the system with a significant reduction in wear compared to other rotor systems.

In addition the structural robustnes made possible through the IDS and reduced loads on components (for example the center piece with the flange retention) result in high MTBR and subsequently lowered maintenance requirements.

Since any defects which might occur will be indicated by the condition monitoring and fault diagnostics system, an on condition overhaul concept is possible for the entire dynamic system.

5.1 Blade tracking (Fig. 10)

The easy access to the rotating control rods is made quite sure by 4 quick opening access ports on the rotorhead. The locking mechanism can then be unlocked the length of the control rod adjusted by means of the special mechanism, and locked again without the requirement of tools. A moveable membrane cover prevents the entry of foreign objects.

5.2 Modul Change

The individual modules are built in such a way that they can be interchanged under field conditions, without the need of calibration or adjustment. The hydraulic boost, the upper controls and the blades can be changed without removing any of the other modules.

It should be noted that the upper control module can be exchanged without removing the rotorhead, as usually necessary with other rotor designs. As shown in Fig. 11 the quick opening access ports is removed from the transmission, and the quick disconnect joints of the control and sissors are unlocked. Then the lower transmission cover is removed, the hydraulic lines and the supporting tube are disconnected. Now the control modul can easily be lowered out of the housing by means of the integral lowering mechanism built into the system.

5.3 Change of the rotating control rods

The control rods and control bearings of the IDS demonstrated by test to have more than five times the life span of externally located control rods. This is the advantage of their completely protection and continuous oil lubrication inside the transmission housing. The drastically higher MTBR for this components results in a much lower necessity for inspection and removal.

Neverteless the access ports on the rotorhub and the transmission housing provide an easy removal and replacement of the control rods as shown in Fig. 12.

6. Condition Monitoring-And Fault Diagnostics-System

The condition monitoring and fault diagnostics system for the IDS gives a major contribution for the improvement in reliability and resulting LCC reduction.

It will provide the maintenance personel on ground with the possibility to find and localize faults on any component of the dynamic system without disassembling it. On the other hand it will also give the pilot an early warning of a possible malfunction of a component in flight by indication of type and location.

This is accomplished by periodic inspection and continuous condition monitoring and or registrating time history of the monitored parameters, and comparison with the rated values.

Warning is given if either a preset level is exceeded, or the rates of the values exceeds a preset gradient.

Special attention is given to:

- all gears
- all bearings
- control rods and joints

To achieve this target the following means will be used:

- oil as information carrier

continuous monitoring	periodic monitoring
. magnetic plugs (for ferromagnetic particles such as bearing and gears)	. oil analysis
. oil filter for non ferrous metallic and non metallic particles	
. oil pressure	
. oil temperatur	
. oil level	

Some of these monitoring systems are already used in transmissions however the incorporation of the control system and rotorhead is new.

- measurement of structure borne sound and comparison with the original levels and frequencies to detect anomalies in gears. (periodic monitoring)
- measurement of vibration to diagnose bearing anomalies. This can be achieved by means of accelerometers which determine the high frequency vibration and compare it with the original conditions.
- visual inspections (direct and borescopic) will be used to determine the type and severity of the indicated unnormaly by removing the inspection ports provided.

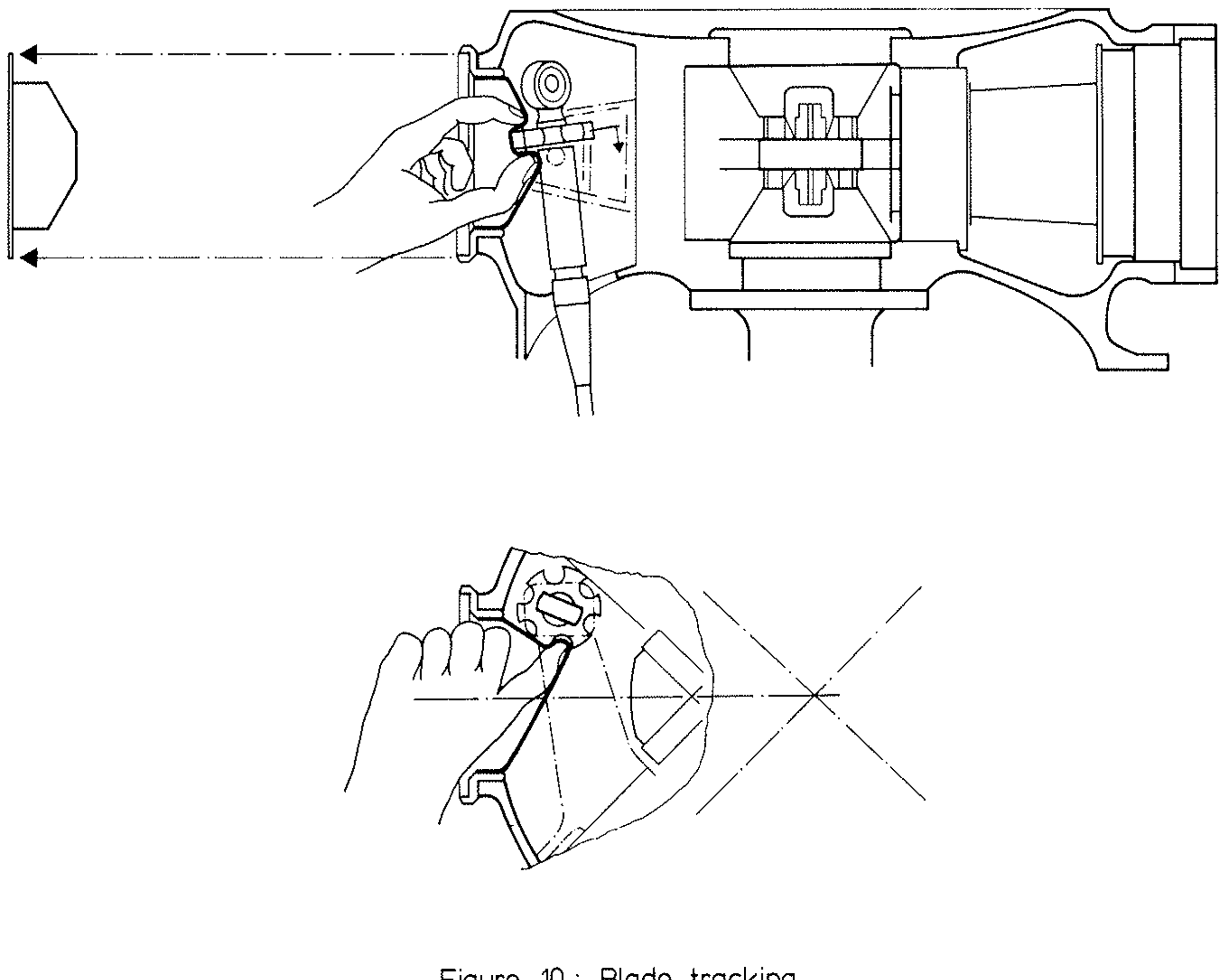


Figure 10 : Blade tracking

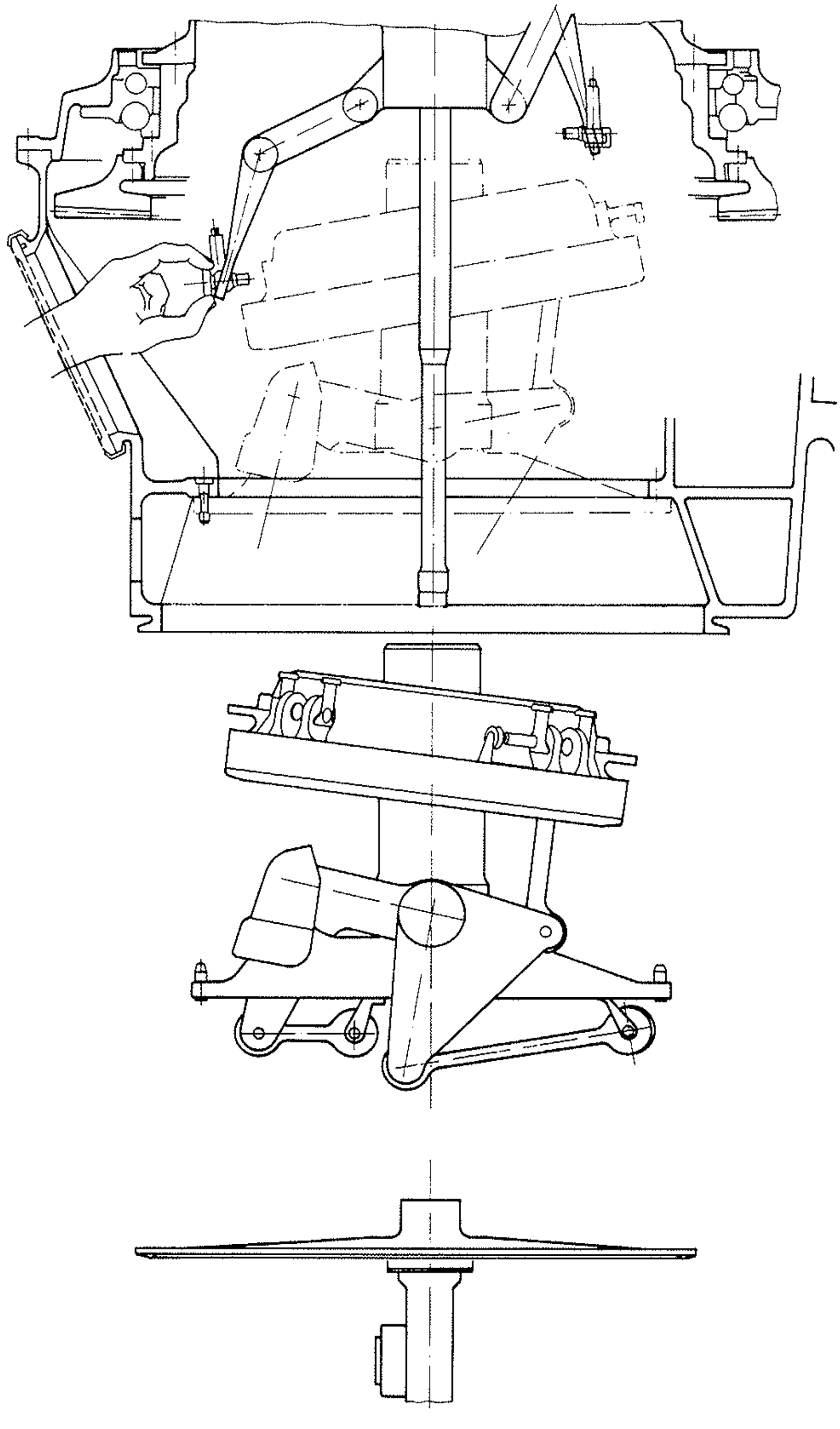


Figure 11: Exchange upper control module

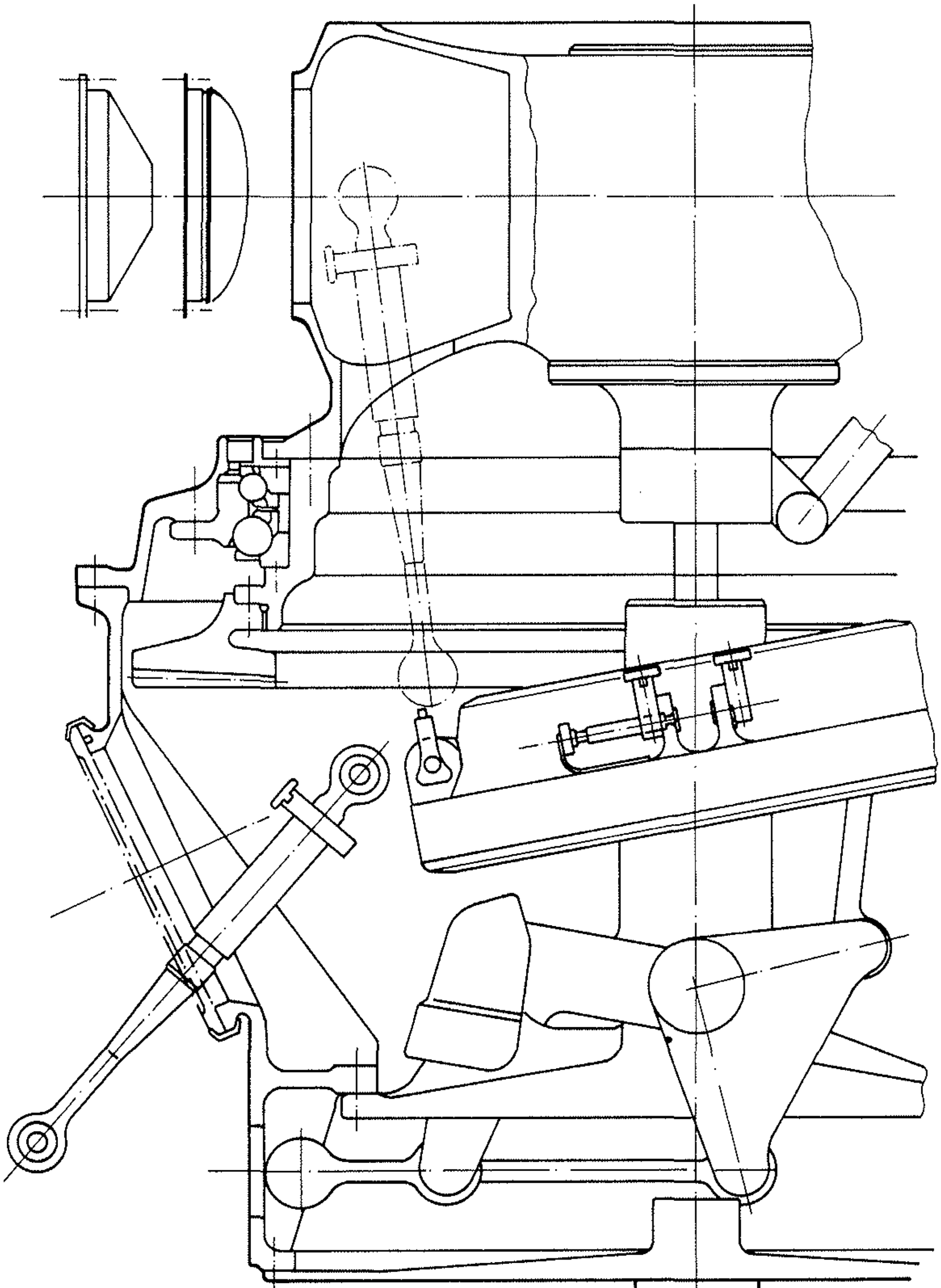


Figure 12: Exchange rotating control rod

7. Critical Development Areas

The targets in the development of the Integrated Dynamic System can only be achieved, if attractive solutions for all critical areas of this system can be proven.

. ACCESSEBILITY

The integration of important main components such as main transmission, rotorhead, rotorblade, uppercontrols and hydraulic boost unit with its drastic possible advantages, some problems could be expected, which are mainly in the accessibility of the components.

This subject is not as severe as it originally appears, because the necessety to visually inspect and exchange parts in this system is reduced by having a high MTBR for all components. Additionally the system arrangement is designed in a way to ensure optimum interchangability and accessibility of all components in order to have in any case low maintanability effort.

This is achieved by using a high degree of modularisation for all main components, similar to that, what latest turbine engine concepts offer and by using quick disconnects. The individual modules are manufactured and calibrated to ensure, that a modul change does not require any adjustment, rigging or calibration procedure or tools.

It can be shown that, though this system has a high degree of integration, the effort man hours to interchange components, to perform inspections or to adjust for example the length of the control rod for blade tracking is smaller than for existing designs.

This is also valid for most of the important accessories such as hydraulic pumps, gererators and cooling fans.

. SPIRAL BEVEL GEAR WITH HIGH REDUCTION RATIO

Until now the combination of a high reduction ratio (IDS = 6.5) in one spiral bevel gear stage with a shaft angle smaller or equal to 90° is not applied.

Besides the possibility to calculate and manufacture the gears, the critical points of such a design are the stiffness of the supporting structure.

The reason, why until now such a design is not used in current transmissions, is due to the large diameter when using a standard arrangement.

The result would be large gear deflections and as a consequence low life at comparable weight, or high weight to achieve the required stiffnes at attractive life time.

In case of the IDS, where the large gear is directly attached to the large diameter rotor bearing low weight and small deflections (high life time) are resulting.

The investigation and calculation of MBB and Zahnradfabrik Friedrichshafen, which will manufacture the transmission module indicate, that this solution offers a progress also in transmission technology combined with an acceptable risc and will give advantages in simplicity, number of parts and weight compared to other concepts.

. MAIN ROTOR BEARING

The main rotor bearing has to fulfil two functions. First: transfer the control and trim moments from the rotor to the airframe and second: support the main gear.

Only if such a design is working perfectly the advantages of the IDS can be realized. Until now 3 different kinds of bearings are proven in a test rig. Due to test results being already available a life time of a minimum of 3000 h could already be demonstrated.There are further tests with other configurations under progress which are expected to result in even higher bearing lifes.

8. Results and Conclusions

The IDS is a major step to improve the effectivenes of helicopters. The chances to achieve all possible advantages are very high, because all steps which were done until now inclusive testing of critical components have shown the expected result. The results being already inhand indicate that there is still ample potentials for further progress.

Because of the impossebility to get actual numbers of the important criteria such as:

- costs (LCC)
- weight
- safety
- maintanance/reliability

for judgement and comparison upon standard systems, these criteria were splitted into subpoints, which can be considered being representative for the main characteristics mentioned before, and for which an estimation is possible.

LIFE CYCLE COSTS:

- NUMBER OF PARTS
- NUMBER OF CLOSE TOLERANCE DIMENSIONS AND INTERFACES
- OPERATION-/LIFE-TIME OF ALL COMPONENTS
- INSPECTION CYCLES
- MTBR
- POSSIBLE ENVIRONMENTAL INFLUENCE
- RIGGING AND CALIBRATION FOR EXCHANGE WORK
- CONDITION MONITORING SYSTEM
- COMPLETE DIAGNOSTICS SYSTEM
- OIL SYSTEM
- MAINTAINANCE REQUIREMENTS

WEIGHT:

- NUMBER OF PARTS
- VOLUME AND SURFACES
- TRANSMISSION DRIVE PATH LENGTH
- NUMBER AND SIZE OF OIL RESERVOIRS
- OIL COOLER SIZE
- NUMBER OF ATTACHMENT POINTS TO FUSELAGE

SAFETY:

- PROTECTION AGAINST ENVIRONMENTAL INFLUENCE AND FOREIGN OBJECTS
- NUMBER OF EXTERNAL OIL LINES
- VOLUME AND SURFACES
- STRESS LEVEL
- FAIL SAFE DESIGN
- CONDITION MONITORING SYSTEM
- DIAGNOSTICS SYSTEM
- OIL SYSTEM

MAINTAINABILITY/RELIABILITY

- DEGREE OF MODULARISATION
- INTERCHANGABILITY UNDER FIELD CONDITIONS
- NUMBER OF PARTS
- CONDITION MONITORING
- DIAGNOSTICS SYSTEM
- INSPECTION PERIODS
- NUMBER OF ATTACHMENT POINTS TO FUSELAGE

were chosen.

Results show, that for military applications as well as for civil ones a large potential of further advantages is available.

In 1974 a research program was initiated. It is planned to qualify the complete system in flight tests beginning 1979.

The program status as of today is:

- Preliminary design and selection of individual components and of the whole system, layed out for a 4 to 5 ton class helicopter, is complete.
- Design of individual modules as well as of the integrated system is under progress and will be finished in 1977.
- Design of the experimental helicopter for flight tests and the test stand for the tie-down test is expected to be completed by end of 1977.
- Experimental static and dynamic tests for critical components such as:

  Rotor bearings
  Pitch links
  Pitch link bearings
  Rotor blade root end
  Rotorhub

  are under progress and will be finished in 1978
- Manufacturing of the prototype was already initiated and will be finished in 1978.