

The Maintenance & Engineering Model of ZFL, an approved instrument in the field of further development and improvement of helicopter components

Hans W. Weber
Peter Richter
ZF Luftfahrttechnik GmbH, Germany

Abstract:

ZF Luftfahrttechnik (ZFL) has been engaged in maintenance, repair and overhaul of dynamic helicopter components for almost 40 years.

Comprehensive support of these functions does not only include workshop activities, but also continuous development and improvement of these components.

The basic concept was and still is to operate helicopters over their complete utilization cycle economically, with the correct technological standard and operational equipment and to ensure as well as improve the reliability in operation.

This paper is intended to describe the variety of technical events resulting from the basic concept as well as the maintenance model developed by ZFL.

By means of concrete examples it will be shown that it is possible to significantly improve DOCs, decrease spare parts requirements, increase TBO cycles and to improve reliability aspects by using a special policy, integration of design and development capabilities and logistical analysis models within the maintenance process.

Among other things, it will be shown how it was possible to increase, for instance, TBO cycles by up to 300 % or 400%.

Furthermore, it will be demonstrated that even by the development of complex repair procedures - despite extensive qualification and acceptance activities - the need of spare parts can be reduced.

1.0 Introduction

There is hardly anything which does not have to be or cannot be improved. Helicopters are one of these things and - in particular - their dynamic components. As it often happens, however, aspects to be improved become evident only in the course of utilization and - as we all know - because helicopters stay much longer in use nowadays than originally intended. Partly obsolete and inefficient technologies are thus carried along for decades.

The bitter consequence: operating costs, servicing and spare parts costs are not in line with the state of the art.

All the more painful for each operator, as helicopters and their components have to go to the workshop for maintenance, repair and overhaul in scheduled and unscheduled cycles. To be objective, we have to admit that even the most advanced aircraft cannot neutralize external effects.

Wear, corrosion, vibrations, structural loads and damage caused, for example, by inexpert handling cannot be completely avoided.

Therefore, the obvious thing to do is to make a virtue of necessity, i.e. to integrate continuous development and adjustment to modern technical and economic conditions as well as operational changes in this field.

This integration is only possible, if repair and overhaul are not isolated as workshop-related subjects, i.e. only focussed on disassembly, assembly, exchange and repair of parts.

This is the foundation of the maintenance & engineering methodology put into practice in the ZFL plant. This methodology basically aims at ensuring safe and economical operation of helicopters over their complete utilization cycle, providing them with the correct equipment in line with the technological standard, as well as improving the reliability in operation.

I will demonstrate this by presenting to you the maintenance activities for dynamic components in the ZFL plant, our ideas and how they are put into practice.

2.0 Basic elements of the ZFL Maintenance & Engineering Model

On the basis of the philosophy presented to you in the introduction, the following primary challenges and targets are envisaged (Fig. 1):

- ◆ **Reduction of DOCs through**
 - Reduction of spare parts requirements
 - Increase of TBO cycles
 - Reduction of repair and overhaul costs
 - Use of efficient production and repair procedures
- ◆ **Further development**
 - on the basis of weak-point analyses
 - to increase reliability in operation
- ◆ **Adjustment to new operational requirements**
(keyword: mission equipment)

Fig. 1: Basic targets of the ZFL Maintenance & Engineering Model

Obviously, many different aspects must be dealt with to reach these goals. The most important disciplines which are subject to continuous improvement are shown in the following graph (Fig. 2):

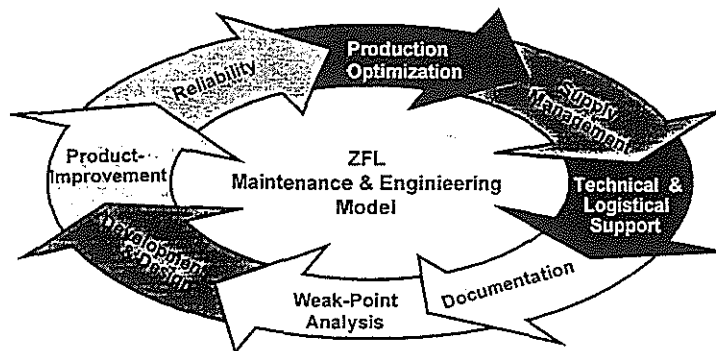


Fig. 2: Work spectrum of the ZFL Maintenance & Engineering Model

In pursuance of the primary objective of operating an aircraft over the complete utilization cycle according to modern safety and profitability criteria, the challenge consists in having to deal with widely varying technologies and methods in order to develop and apply an integrate process methodology.

Only this will make it possible to use the most advanced technologies and know-how for older helicopter models, too.

In fact, many aspects of the resulting technology spectrum (Fig. 3) to be processed by our team of engineers are identical with the requirements to be met by new development of a dynamic component. This is documented by the following, by no means complete, list (Fig. 3) of a wide variety of technical knowledge required.

- | ◆ Practice-oriented spectrum | ◆ Theoretical spectrum |
|---|--|
| <ul style="list-style-type: none"> - Production technologies <ul style="list-style-type: none"> • surface hardening • galvanic processes • bonding procedures - Bearing technology - Tribology - Sealing technology - Jointing: e.g. electron beam welding | <ul style="list-style-type: none"> - Design - Stress analyses - Aerodynamics - Flight mechanics - Metallurgy - Vibration technology - Logistic analyses |

Fig. 3: Examples of the technology spectrum to be processed

However, the decisive parameter is the fact that the whole of this interdisciplinary know-how can be used for the benefit of the product. The concentrated effect of said technical knowledge is therefore of great importance and has stood its test in daily work.

This philosophy is institutionalized in our company in different programs known under the designations **LEP** (Laufzeit-Entwicklungs-Programm = Lifetime Extension Program), **AZI** (Analytische Zustands-Inspektion = Analytical Condition Inspection) and **On Condition Maintenance**. At present, these programs are applied to the CH-53G, MK 41 Sea King, MK 88 Sea Lynx and BO 105 helicopter models.

3.0 Examples of realization of the above targets

3.1 TBO increase of various dynamic components

The TBOs of the dynamic components are of great importance for the operator and have a direct effect on the operating costs and utilization cycles.

In view of this fact, the whole range of dynamic components of, for instance, a cargo helicopter used by the German Armed Forces was included in the LEP.

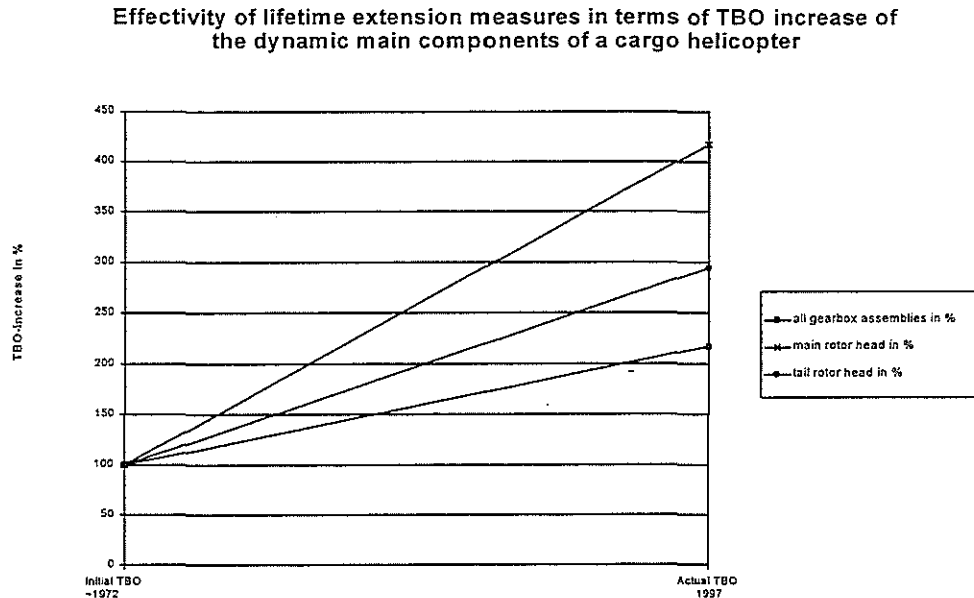


Fig. 4: TBO increase of dynamic components of a cargo helicopter

As can be seen from this graph (Fig. 4), the modifications carried out under this program were instrumental in achieving substantial increases of TBOs.

To describe all measures contributing to this improvement would be taking things too far. The main rotor head of said helicopter will therefore serve as an example for further explanations.

This modification concerns the highly susceptible sleeve and spindle assy bearings (Fig. 5) which according to an analysis of the relevant repair data turned out to be an important weak point. These bearings often caused untimely failure of the sleeve and spindle assemblies so that even shorter TBO cycles could not be achieved.

A test program was therefore initiated and furnished proof that the stack/preload bearings could not withstand the loads at this location, i.e. quick oscillating movements under high centrifugal forces and strain loads.

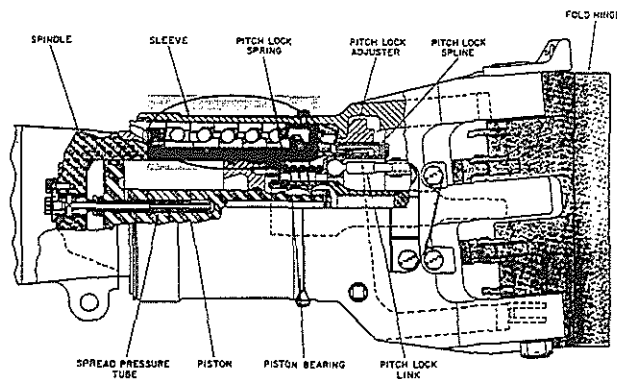


Fig. 5: Modified sleeve and spindle assy stack/preload bearings

The failure was preprogrammed as, due to manufacture and design, the loads could not be distributed evenly to all bearings. All loads acted on one or two bearings only and caused damage to them before long.

On the basis of this knowledge, specifications were generated for suitable bearings capable of coping with this load spectrum. These specifications were generated in cooperation with a renowned bearing manufacturer.

Main modifications concerned the material sector and seat design and were achieved by reducing the manufacturing tolerances and better matching of the bearings.

After thorough testing and acceptance, this improvement was put into practice and has been carrying out its function very satisfactorily since that time.

Untimely repairs are now an exception.

From many modifications carried out in this sector we came to realize that „it is usually not a revolutionary modification which must be developed to bring about a significant improvement, but rather an individual solution tailored to the load spectrum in question or, generally speaking, to the factors that count“.

Due to this and other similar improvements, untimely repairs could be minimized and the TBO of the main rotor head could successively be increased by 400 %. In addition, the reliability aspects could be improved.

3.2 Reduction of spare parts requirements

If a product is to be operated under modern technical and economic aspects, special importance must also be attached to the spare parts requirements as a central block of repair costs.

This will be documented by means of two topical examples which brought and will bring about a significant reduction of the spare parts requirements for the cargo helicopter fleet concerned. The first example is the practice-oriented variant of our work, whereas the second one is rather a description of the theoretical requirements to be met by our Maintenance & Engineering Model.

3.2.1 Development and application of innovative repair procedures

The following example will show that - despite the costs involved - even complex development activities including extensive theoretical and practical acceptance work can drastically cut the spare parts costs.

Due to wear and environmental effects, the applicable repair tolerances of a vital component of the rotor head were exhausted and further rework was no longer possible for strength reasons.

Scrapping of a great number of very expensive components was under discussion, but we decided in favour of an intensive search for a new repair procedure.

Several procedures were theoretically checked for suitability.

Finally, we decided in favour of an attempt to replace the non-repairable component section (Fig. 6) by a new section to be added by means of electron beam welding.

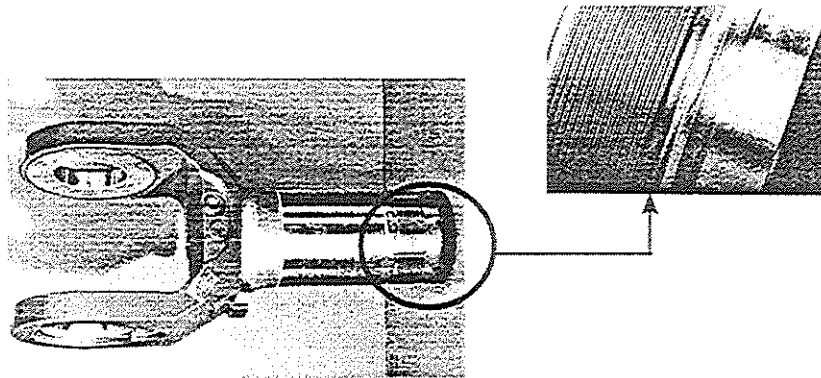


Fig. 6: Spindle; repair section

In cooperation with Lufthansa, we developed an electron beam welding method suitable for the component made of titanium alloy (TiAl6V4). Extensive pretesting was required for development of the welding parameters and put into practice in the course of test welding /2/ (Fig. 7) on the original component. Metallurgical analyses /2/ (Fig. 8), stress analyses and fatigue tests were and are being carried out and will soon be completed.

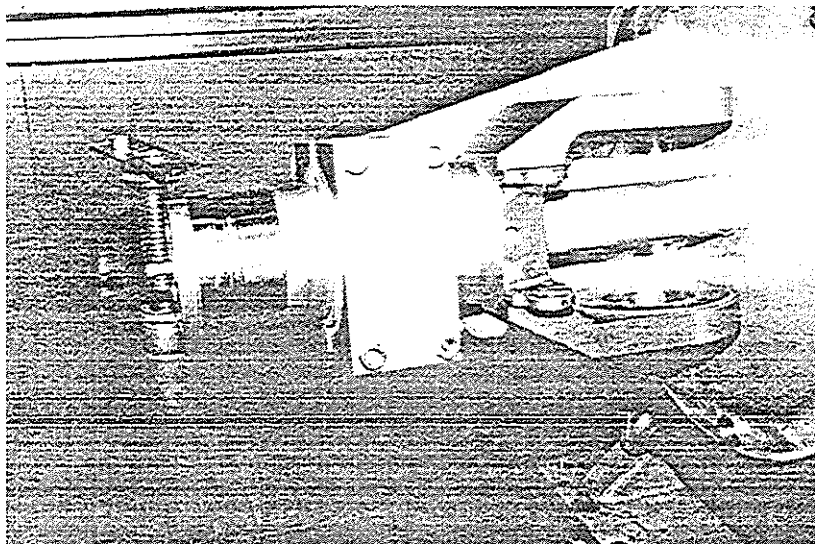


Fig. 7: Electron beam test welding

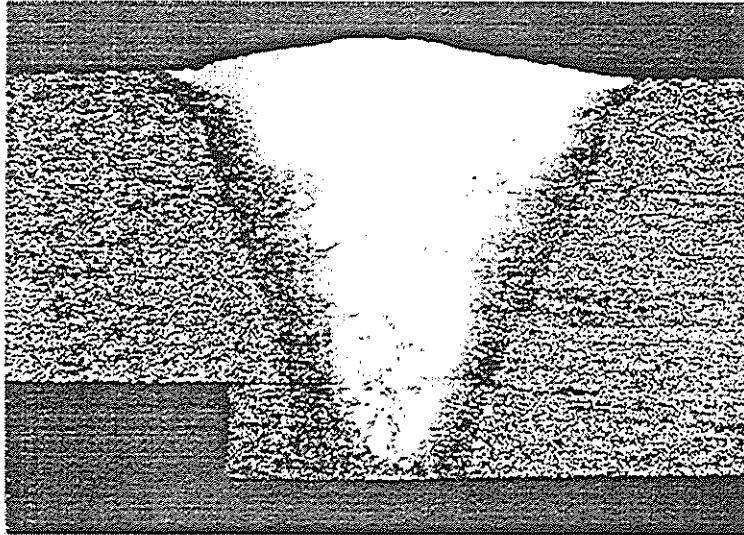
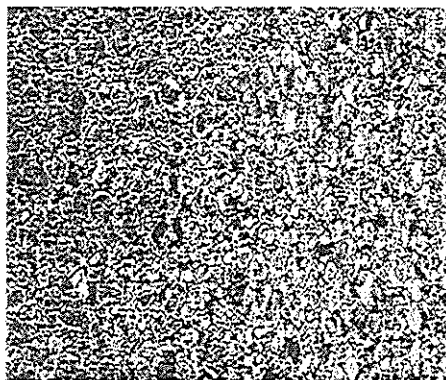
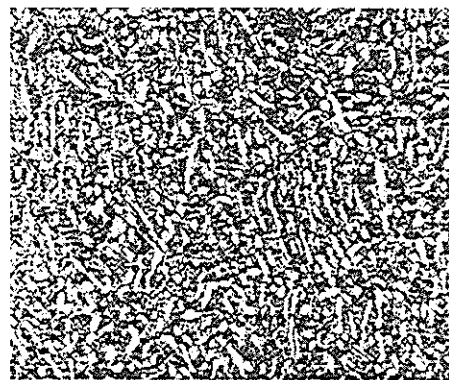


Fig. 8: Section through the welded-on area

The microstructure of the test weld can be seen from Figs. 8 and 9. The desired results were obtained both with regard to homogeneity and grain size.



Welded-on material:
Magnification x 200, etched



Spindle:
Magnification x 200, etched

Fig. 9: Structural comparison spindle vs. welded-on material

In view of the results so far obtained, the project is expected to be successful both from the technical and from the financial side.

The purchase of a new part as a replacement for the damaged one will not be necessary and the repair costs will only amount to approximately 15 % of the price of a new part.

If on the basis of these facts a forecast is made for the failure rate to be expected over the next 10 years, savings to the amount of approximately DM 20 million will result for this component only, even if allowance is made for the development and acceptance costs.

3.2.2 Decrease of DOCs by revaluation of the Component Retirement Times (CRTs)

The cargo helicopter model in question used by the German Armed Forces is a derivative of comparable models operated, for example, in the U.S.A. Until recently, the German operator went by the CRTs specified for said models by the design authority and applied them also for his own fleet. All of a sudden, a highly precarious situation was created by the recalculation of the CRTs for the dynamic components of the U.S. versions /8/, which had become necessary due to a changed mission spectrum.

As a result, the CRTs were drastically reduced for almost all high-quality components such as upper and lower hub plate, control horn, rotating swashplate, pressure plate, stationary swashplate, tail rotor hub, main gearbox housing, etc. (see Fig. 10).

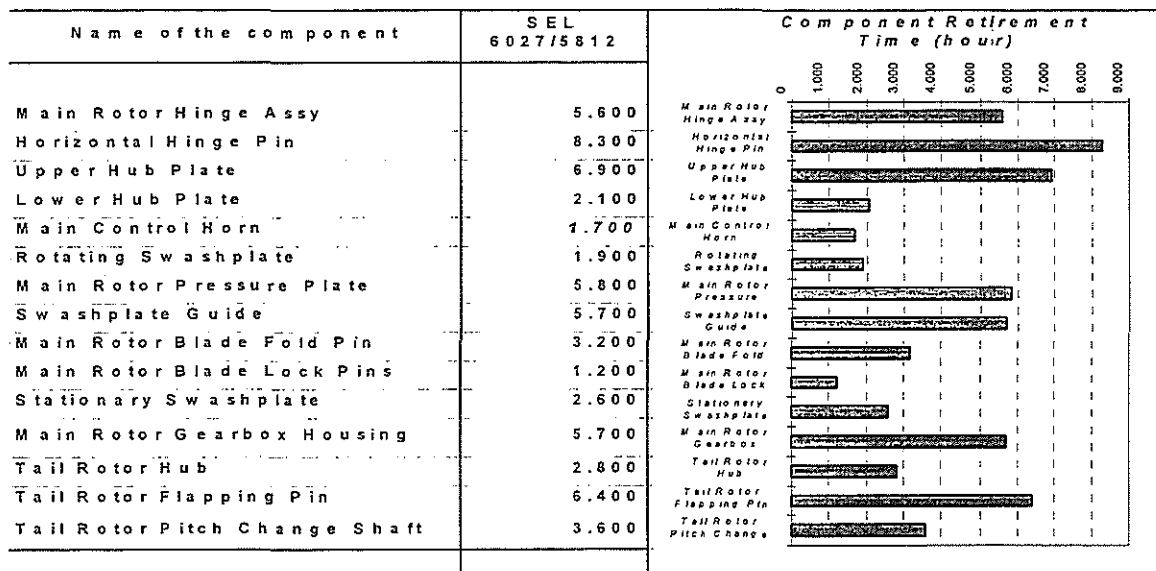


Fig. 10: List of the new CRTs

As a result, the purchase of new components valued at several hundred million DM came up for discussion. The usual procedure of simply adopting the CRTs therefore had to be abandoned. The only way of avoiding the untimely purchase of said spare parts was the concretization and revaluation of the CRTs in accordance with the German mission spectrum. On the basis of the stress analyses and flight test data kindly made available to us, the damaging parts of the load spectrum were analysed and isolated for all dynamic components concerned.

These were compared to the well-known flight spectrum of the helicopter used in Germany. The damaging flight maneuvers which would not occur with 100 percent certainty, for instance towing and in-flight refueling, were then eliminated. The CRTs to be used for this helicopter as a first approach to the solution were calculated on this basis /5/.

An exemplary calculation for the Main Rotor Control Horn can be seen from Fig. 11.

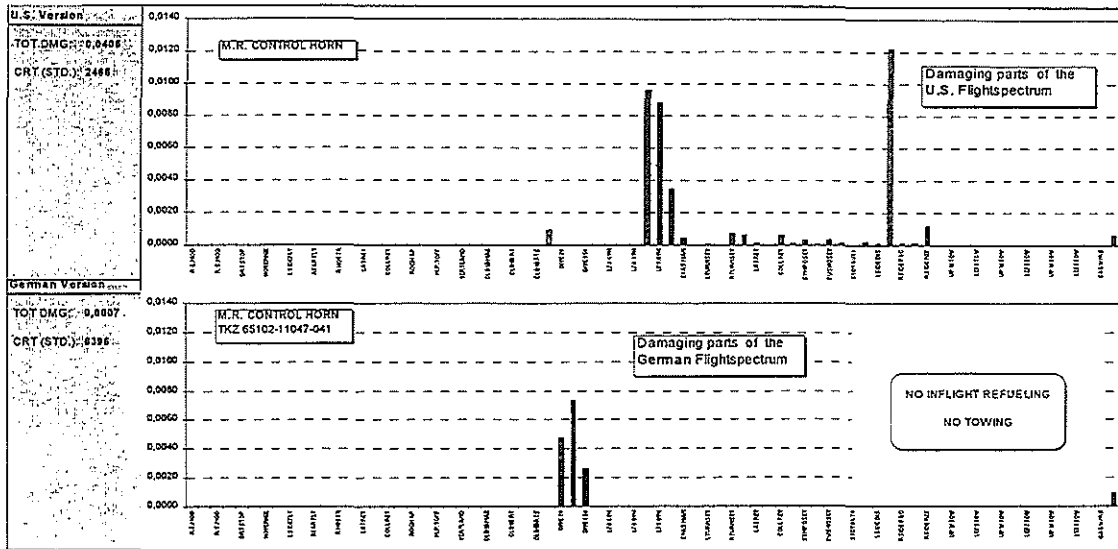


Fig. 11: CRT recalculation; damaging parts of the flight spectrum

The next step required the characteristic of deterioration (damage) for every individual part to be analyzed with reference to the respective flight maneuver.

To quote an example: the load on the control rod is a function of the flying speed. If, however, the German helicopter is flying the same maneuver, but at slower speed, recalculation is possible on the basis of the flight test data and the actual detrimental portion can thus be established. This procedure was, however, only applicable when such load fractions had actually contributed to loading a component part. Other loads that were only conditionally dependent on the flying speed, such as maximum mast bending moments as found during certain maneuvers, could only be put in concrete form by validating the time fractions for this maneuver. Fractions of centrifugal force are mainly determined by the max. possible autorotation speed which, among other things, is in turn influenced by the maximum gross weight (mass) of the helicopter.

Combinations of these cases made the calculation even more complex because the determination of the reference tension to be applied was, of course, even more extensive.

The comparison of all CRTs [7] specific for the German helicopter with the CRTs recommended above for the U.S versions may be noted from figure 11A.

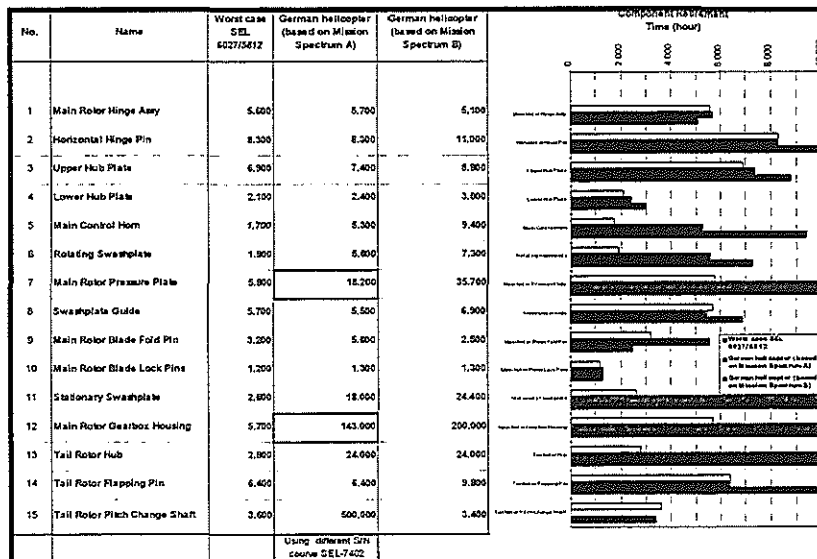


Fig. 11A: CRT comparison German vs. U.S. version

Additional synergetic effects may result from flight-physical interrelationships which are yet to be examined. In this regard the analysis will focus on influences of and dependence on mass (gross weight), autorotation speed (revolution of the rotor disc) and load factor.

To further substantiate these „provisional CRTs“, additional flight tests will be carried out for special and possibly damaging flight maneuvers, whose results will then be taken into account.

This program presented in a few words, although very complex, turns out a success already now. In our opinion, buying new dynamic components will therefore mostly not be necessary any more or, in the worst case, only at a much later and better manageable date.

3.3 Improvement of reliability aspects exemplified by ultrasonic inspection of the spindle

The sleeve and spindle assemblies of all H-53 helicopters operated worldwide must be subjected to an ultrasonic inspection every 50 hours according to the manufacturer's instructions to examine, among other things, the spindle area for cracks.

According to the ultrasonic inspection procedure, the test instrument is adjusted by means of a calibrated sample prior to the measurement. This usually ensures that even small cracks are detected in time. Not in this case, however.

As in the case of the aforementioned electron beam welding tests, spindles were found to have an unusual microstructure.

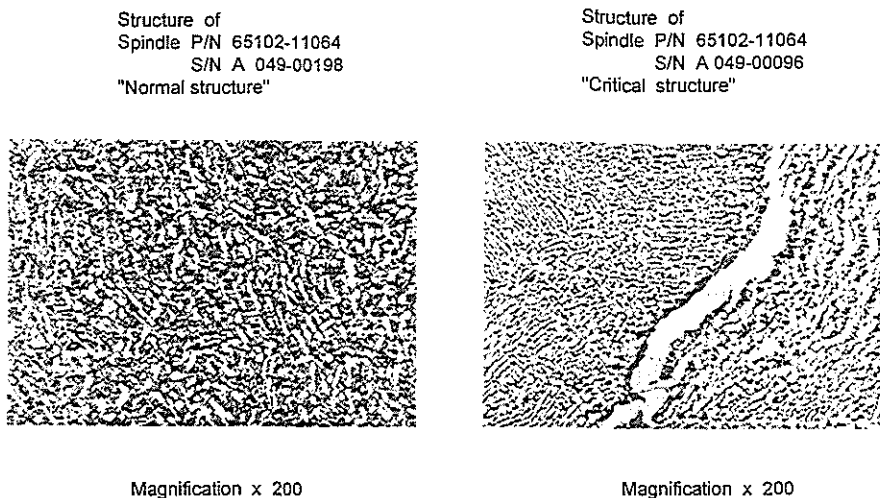


Fig. 12: Differences in spindle microstructure

Further investigations immediately started showed that, in addition to the rising uncertainty regarding the mechanical properties of these components, the high ultrasonic echo damping proved to be a risk factor. In the case of this microstructure, a crack could not be detected by means of ultrasonic inspection, as the grain size corresponded to the wave length of the ultrasonic echo. An extremely high damping was the result /1/.

In parallel, we also informed the design authority and extensive fatigue tests were started at our request.

In addition, all operators worldwide were informed about these facts by the design authority at our recommendation.

In view of the higher ultrasonic echo damping of said spindles we developed a nondestructive test method for inspecting the whole fleet. The mechanical properties of the spindles in question turned out to be acceptable. However, due to the fact that potential cracks could not be detected by means of ultrasonic inspection on spindles in installed condition, over 50 sleeve and spindle assemblies and spindles had to be quarantined for safety reasons.

4.0 Summary

Our customers ask for comprehensive maintenance of dynamic components and will do so increasingly in the future. For DOC optimization, increased utilization cycles, adjustment to new operational requirements, continuous product improvement is required.

In our opinion, this objective can only be reached by means of a comprehensive strategy which in our company is based on the integration of different disciplines such as development, design, logistics, production technologies, etc. in the maintenance process.

From the results so far achieved and from the response of our customers it can be concluded that the Maintenance & Engineering Model put into practice by ZFL will be instrumental in reaching this objective.

Increased TBO cycles, reduced spare parts requirements and the optimization of reliability parameters are reasons enough for further utilization and refinement of the described methodology in our company.

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