Computed Tomography as a Nondestructive Test Method for Fiber Main Rotor Blades in Development, Series and Maintenance.

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Abstract

The main and tail rotors of helicopters are made more and more out of fiber composite materials because of their increased stiffness and strength to weight ratio compared to metallic structures. The earlier helicopter division of MBB, now Eurocopter Germany, has developed the first bearingless main rotor made of glass fiber reinforced materials within the 60´s. By the use of glass fiber reinforced materials the main rotor head of the BO 105 could be made without discrete flap and leadlag hinges. The newer helicopter rotor developments at Eurocopter Deutschland (ECD) have further simplifications of the rotors. The result has been that more and more functions have been integrated into the rotor blade structure, resulting in increasing structural complexity. Such complex structures of fiber composite materials, so e.g. the rotor blades of the EC135, can only be inspected restrictedly with the conventional NDT-methods, like ultrasonics or the conventional X-ray testing. Particularly at thick-wall, monolithic composites the conventional NDT-test procedures fail. The X-ray Computed Tomography (CT) as an imaging test procedure closes this gap. CT is especially suitable for applications involving spatial analysis, differentiation, material identification, flaw analysis and structural quantification. This is made possible by the good spatial resolution and the very good resolution of density of the CT- measurements. Subsequently the history of the CT at ECD, the measuring principle of the CT and the necessary technical equipment is described. The paper will be supported by examples, the usage of CT during the development of fiber-reinforced main rotor blades for optimization the manufacturing techniques. In addition the methodology of the qualification of test procedure for determination the quality of fiber reinforced helicopter rotor blade structures during the manufacturing in series is presented.

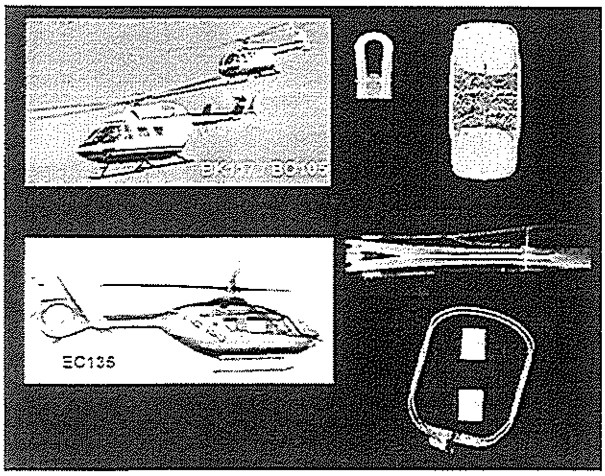


Fig. 1: Comparison of the complexity - BO105 with EC135 rotor blade -

History of the Computed Tomography at Eurocopter Deutschland

Computed Tomography is an radiographic NDT- method to locate and size planar volumetric details in three dimensions. A CT-scanner generates X-ray attenuation measurements which are used to produce computed reconstructed images of any desired part of an object. At the beginning of the 70´s Computed Tomography was developed for medical diagnostic. The inventors Hounsfield and Cormak have got for this the Nobel award for medicine in 1979. Already 1907 the German mathematician Johann Radon has put to this the mathematical foundation with the so-called Radontransformation. Since 1979 ECD has used conventional medical CT-scanners to test thick-walled composite materials of helicopter components. The CT was used as a complementary NDT-method during the destructive

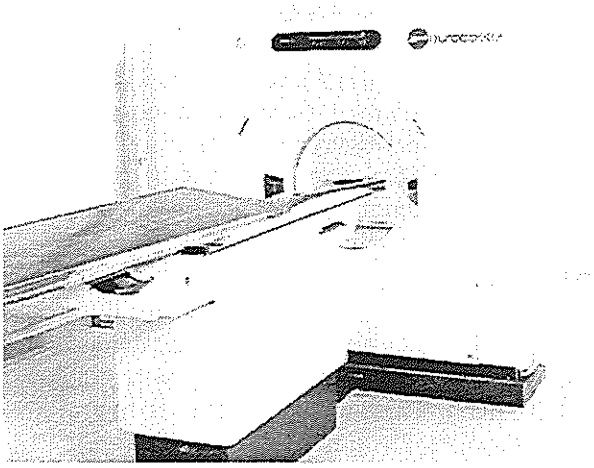


Fig. 2: ECD CT-Scanner

analyse the damage behaviour of the test specimen. Therefore it was possible to detect and knowing the manufacturing defects and anomalies inside the composite structure with their effects to the fatigue and the damage behaviour of the test specimen. Particularly during optimization of the manufacturing of the thick-wall, monolithic main rotor blade structures the CT could successfully show its applicability. In the period of 1979 to 1992 approximately about 4000 tomograms with 100 fiber composites components were performed by CT-investigation. For the examinations medical CT-scanners of the companies EMI (EMI 7020), General Electric Medical (GE 8800, GE 9800 and GE 9800 Highlight) and industrial scanners of the Bundesanstalt für Materialprüfung und -forschung (BAM) are used. Due to the good results, since 1993 ECD is using an own medical CT-scanner (GE HihLight Advantage) for development and quality control in the manufacturing process of composite helicopter rotor blades. The CT applied within the development of new rotors made of fiber composites, in the series production of main rotor blades for quality assurance and maintenance. Since the CT-investigations started, 2000 test specimens were examined with approximately 130 000 tomograms. Eurocopter Deutschland is the first helicopter company which is using extensively the CT as a non-destructive inspection method in development, series production and maintenance of helicopter main rotor blades.

ECD-CT-scanner

Equipment and capabilities

ECD uses a medical CT-scanner (i.e. Fig. 2). An alteration of the tube energy or a customisation of the image reconstruction algorithm was not carried out. The image files will be transferred to Windows-NT computers for further image processing.

Following demands had to be realized for CT-scanner selection:

- **Economy of the system**
  The test cost shall be only a small fraction of the manufacturing cost of the rotor blade
- **Good geometric resolution:**
  Delaminations of 0.20 to 0.30mm must be detectable
- **Good contrast resolution**
  Low fiber volume contents must be visible
- **Short examining times for a test specimen**
  Demand: 3 - 5 components per day
- **Standard inspections procedures of components**
- **Simple operation**
- **Daily availability of the system**
- **Response time of the service: 1- 2 days**

At the beginning of the selection of a CT-scanner usage of an industrial CT-scanner had been discussed. This would have the advantage that the scan techniques of X-ray transmission could be adapted optimally to the fiber composite material. A corresponding specification was worked out also. An industrial CT-scanner which fulfils the above requirements was not available as a standard system. The scanner must have been developed and built. The reliability and the desired simple operation of the CT-scanner could not be obtained during the CT-inspections of manufacturing in series for quality control. The high availability of the CT-scanner could not be guaranteed. The supply price of a corresponding industrial CT-scanner was three times higher than that of a medical CT-scanner. Decisive for the obtaining the medical CT-scanner were the positive experiences that ECD had made with medical scanners since 1978. The X-ray tube energy of 140 kV is sufficient to transmit

Performance parameter of the CT equipment
GE Highlight Advantage
Field size 96 - 480 mm
Image matrix 512^2
Slice thickness 1.5, 3, 5, 10 mm
Number of the projections:
up to 3600 at 360° scan
Reconstruction: 11 - 16 sec per slice
Scan- and reconstruction time for 100 slices:
approx. 20 min at 120 kV 170 mA
Scan- and reconstruction time for 100 slices:
approx. 40 min at 140 kV and 170 mA
the necessary cooling time of the X-ray tube extents here the scan- and reconstruction time
Type of X-ray tube: rotating anode
Power: max. 24 kV
Life time of the X-ray tube: approx. 40 000 shots
High voltage: 80, 120, 140 kV
Tube current: 10 to 200 mA
Focal point: 0.7x0.9
Detectors: 864
High contrast resolution: 0.38s mm @ 10% MTF
(2sec scan/120kV/200mA)
CT number scale: -1024 to 3071 Units
Composite materials:
E-glass: up to 2500; air -1000;
GFRP: up to 1400; CFRP: up to 500
Epoxy resin: ~ 150

GFRP-laminate of 50x50 mm up to 250x 60 mm by radiates to get images with a good quality for examination of the fiber structures. Primarily the short measurement- and reconstruction times (i.e. box above) supplies economical examining times. This is reached by the high performance of 24 kVA of the rotating anode tube ensuring a high photon flux. Newer medical scanners use X-ray tubes with a performance of up to 56 kVA. To get a good quality of CT-images it is necessary that the attenuation profiles must consist of sufficient numbers of photons measured at the detectors. About three components are CT-checked at the moment per day. For a check approx. 140 min. are required. The components are mostly scanned with a tube energy of approx. 140 KV/170 mA. For a CT- check with 120 slices approx. 40 minutes are necessary. This contains the scanning and the image reconstruction. The remaining 100 minutes are needed for the make-ready time, the image analysis and the documentation. Now a short note for the advantages of the industrial CT-scanner. The industrial CT-scanner is able to use various radiation sources . Components, made of materials of higher density, can be transmitted optimal. For high-resolution CT-inspections (spatial resolution of < 50 µm) 2-D and 3-D CT-scanners with micro focus X-ray tubes (250 kV) were developed. By comparison, industrial scanner has a 15 MV source to inspect objects up to 2.4 m in diameter. A summary of the application of industrial CT-scanners can be taken from the references [1,3,4,5,8]

Image database / damage catalogue and image analysing

After the CT inspection, all CT-images and evaluation reports will be stored by a NT-server on CD-ROM and archived into a juke box. The juke box stores 150 CD´s with approximately 150.000 tomograms. All data are accessible via the Eurocopter network. For image analysis the image processing software of the CT-equipment is used and on the NT-server the image processing tool Optimas® is available. For the support of the tester a damage catalogue was built up. This contains all relevant component defects and damage tolerance limits. A high software integration guarantees frictionless and simple operation and economical CT- inspections.

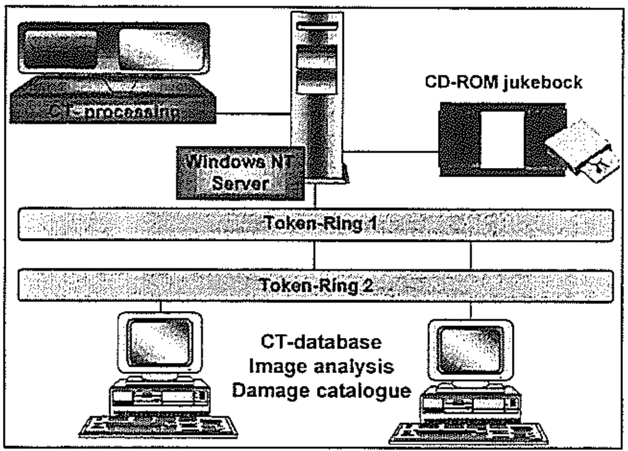


Fig. 3: CT-network

Measuring principle

Scanning and reconstruction

The measuring principle of the CT is described in this place briefly. Details can be taken from the references [2,4,5,7,13,16]. The CT-scanner reconstructs an image matrix (tomogram) that shows a two-dimensional cross-sectional image of the material distribution within the test specimen. As known, X-rays can penetrate matter. During the transmission of the X-rays through the object, they will be more or less strong absorbed on the basis of the interaction of the photons with the atoms of the matter. The X-ray loses therefore its intensity during its transmission through the object. The X-ray will be attenuated. The attenuation characteristics of the object indicated by the linear attenuation coefficient µ. The tomogram contains consequently an information about the local, material related distribution of the attenuation coefficient. Therefore structural differences in the material cross-section will only get visible if materials of various attenuating characteristics are available. Referring to the components of glass fiber composites means, that structure differences or defects are visible by the strongly different attenuation coefficient of glass fibers and epoxy resin within composites. The attenuation of X-rays is determined by the fact, that slices of equal thickness and equal material will absorb the same portion of the radiates (Lambert-Beer's law).

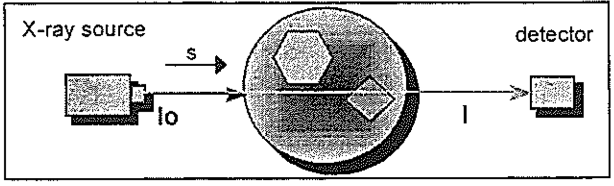


Fig. 4: Measuring principle of CT

If the X-ray hits by its way (s) through the object a region of material with high attenuation, it will locally lose more strongly of its intensity (I). For the local intensity change (I) is given by:

$$\frac{dI}{I} = mds. \quad (1)$$

If the equation is integrated and the local dependence of μ is taken into consideration, the local dependence of the X ray intensity is:

$$I(S) = I_0 \cdot e^{-\int_s \mu(s)ds} \quad (2)$$

The rest intensity of the X-ray, which is leaving the object, hits the detector. Simplified expressed, the detectors are scintillating crystal optics which the X-rays change into light. Light creates a voltage at the output of the post-connected photo multipliers (photocells with voltage gain) which is proportional to the intensity (I) to the transmitted radiation.

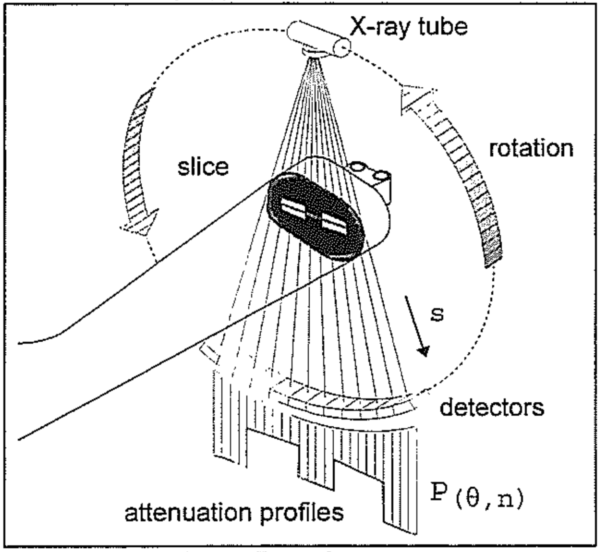


Fig. 5: Rotation scan

To create cross-section images the fan-shaped X-ray beam rotates around the object (360 °). From several projection directions attenuation profiles of $P(\theta,n)$ are measured. P is the projection value at the detector position n and θ the angle of projection. After normalising and logarithmic operation of the equations (2) the projection value is given by:

$$P(\theta,n) = -\ln\left(\frac{I}{I_0}\right) = \int_s \bar{\mu}(x,y)ds \quad (3)$$

$\mu(x,y)$ is the attenuation coefficient at the location of x,y within the object cross-section. By means of the filtered re-projection the projection values will be projected back along the X-ray path (s). The result is the distribution of the attenuation coefficients within the material cross-section displayed as an image matrix. Any attenuation value corresponds within the image matrix to a certain grey value. This makes the object cross-section gets visible at the display screen.

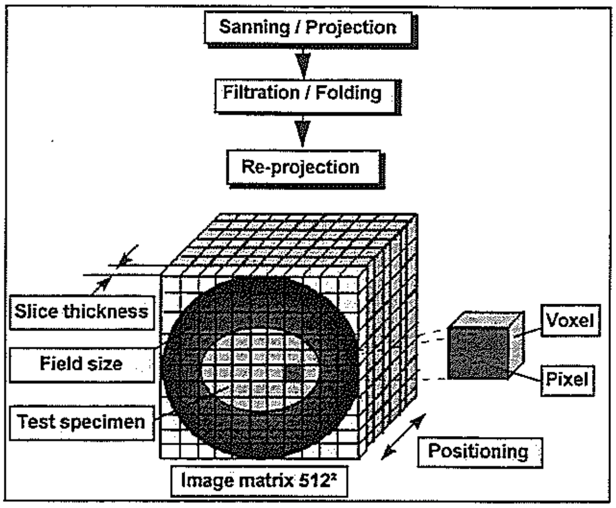


Fig 6: Scanning and image processing

Axial and volumetric tomograms

In reality, the pixel element represents a volume element within the image matrix. This results from the fact, that the X-ray beam passes through a cross-section slice with a final thickness. The less thick this CT-slice is the more details of the cross-section becomes visible. In general the fiber composite structures are scanned by an X-ray beam with a thickness of 1.5 mm. By stacking adjacent CT-slices of the test object, a three-dimensional image of the interior can be constructed by the computer. This is an stringent requirement for examine wavy laminates within fiber structures.

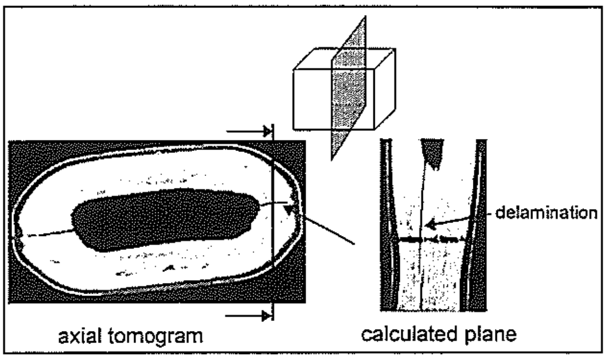


Fig. 7: Visualization of calculated planes

Quantification of fiber composite structures

By the representation of the material cross-sections by the attenuation coefficients the material cross-section is available as a data record. So the material qualities becomes quantifiable. The medical scanners do not use directly the attenuation coefficients but the so-called CT-number. This number was established by Hounsfield. The Hounsfield scale standardises the reconstructed attenuation coefficients (μ) to the linear attenuation coefficient of water at a photon energy of 73 keV.

$$CTn = \frac{\bar{\mu} - \mu_{Wasser}}{\mu_{Wasser}} \cdot 1000 \ [H] \qquad (4)$$

Therefore water has by definition the CT-number zero. Air has -1000 H, GFRP at 1200 up to 1400 H and CFRP approx. 300 up to 500 H.

Defect detectability

The normalisation of the attenuation coefficients by the CT-number has the advantage, that materials of fiber composites become comparable. The CT-numbers are represented at the screen as grey value distribution. One grey value has always the same CT-number, independent of the maximum attenuation differences of the component. Therefore visually and quantitatively comparable CT-images are obtained. This is a quite essential prerequisite to analyse the CT-images automatically by image processing analysis.

Resolution

In the Computed Tomography will be distinguished between the spatial (geometrical) and the density (contrast) resolution. In this paper the practical meaning of the resolution for the CT-check on fiber composites is presented. A closer description of the process engineering can be looked up at reference [5,7,13,16].

Spatial resolution

Spatial resolution is generally quantified in terms of smallest separation at witch two points can be distinguished as separate entities. The limiting value of the resolution is determined by the design and construction of the system and by the amount of data and sampling method. It must be distinguished between the spatial resolution within the scan plane (slice) and vertical to the scan plane dependent on the slice thickness. The spatial resolution affects the detectability of defects e.g. delaminations, fiber cracks or air pockets within fiber composites. The geometrical resolution within the scan plane is indicated by the MTF-curves.

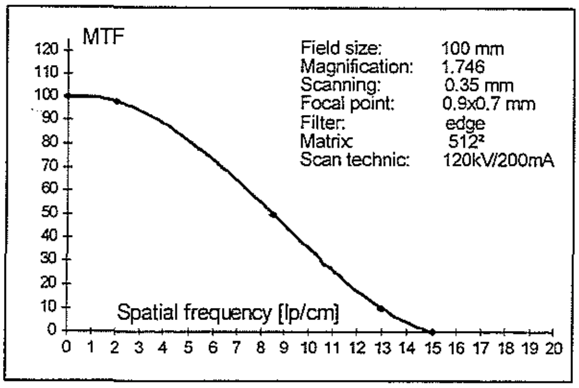


Fig. 8 MTF-curve of the GE HihgLight Advantage [6]

The MTF-curves describe the ratio of the contrast in the CT image to the contrast in the object with respect to the spatial frequency. The spatial frequency is the resolution value indicated at the threshold of 10% contrast difference. The ECD scanner reaches a value of 0.38 mm. A delamination with 0.38 mm can be resolved. By the good resolution of density delaminations of lower extensions may be detected. A calibration standard developed by ECD made of CFRP contains air-gaps, starting with 0.1 mm and increasing with 0.05 mm. The gap with 0.1 mm is still clearly visible.

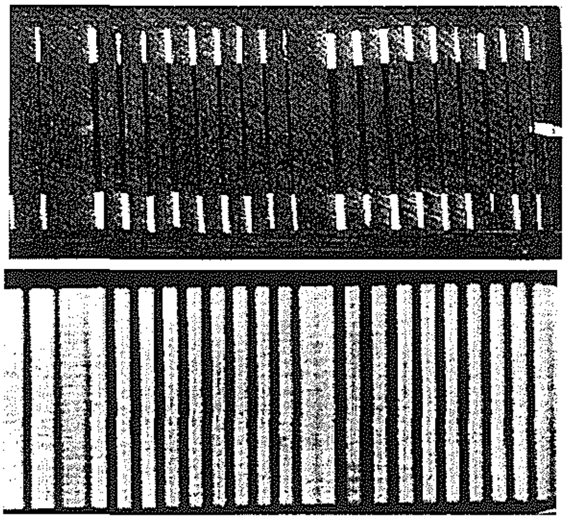


Fig. 9: Calibration standard, tomogram below

Why not establishing a higher resolution to detect microcracks into the fiber composites? Defect sizes less than 0.2 mm are detectable only by an industrial scanner which use a microfocus tube. This is possible on small samples and not on components which have the size of a main rotor blade (transmission cross-section up to 250x60 mm). A higher resolution is not essential because all strength relevant manufacturing defects and damages like delaminations are larger than 0.2 mm. Microcracks may not lead to a disastrous failure of the component. The main rotor blade is developed so, that damages must become indicated before failure - Fail Safe Principle-. The CT with medical scanners applies to this fact.

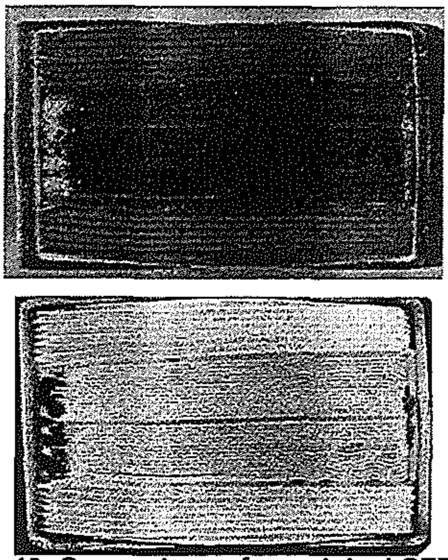


Fig. 10: Comparison of an original GFRP-prepreg cross-section with the tomogram

Contrast- or density resolution

The two Images (i.e.Fig. 10) show the good contrast resolution. Single laminates are recognised clearly. The grey values visible in the CT-images represent the attenuation differences (CT-numbers) caused by the local variable resin- and glass distributions.

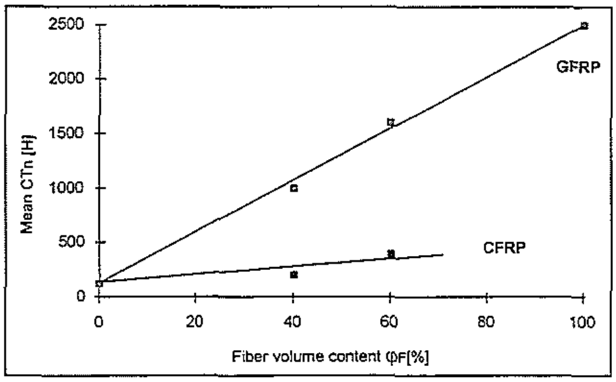


Fig.: 11 Correlation of fiber volume content and CT-number

This indicates a local unsteady distributed fiber volume content. The correlation between the CT-number and the fiber volume content is described briefly in the following. The characteristic material properties like the interlaminar shear strength, the modulus of elasticity and shear, the transverse contraction and the thermal expansion coefficient of a cured fiber composite are due to of the ratio of the mixture of fiber and epoxy resin.

The fiber volume content φ_F of fiber reinforced materials is defined as ratio of the fiber volume V_F to the complete volume of the laminate V_L, where V_F is the volume of the fiber and V_M is the volume of the epoxy matrix.

$$\varphi_F\,[\%] = \frac{V_F}{V_L} \cdot 100\% = \frac{V_F}{V_F + V_M} \cdot 100\% \qquad (5)$$

Measurements with GFRP and CFRP-fiber *samples with various fiber volume contents have* shown that there is a linear correlation between fiber volume content and the CT-number (i.e.Fig.11.),[2, 4]. Further examinations showed, that this will be only valid for small transmitted cross-sections. At larger transmitted cross-sections the beam hardening is noticeable [2,12,13]. However the resolution of density is sufficient.

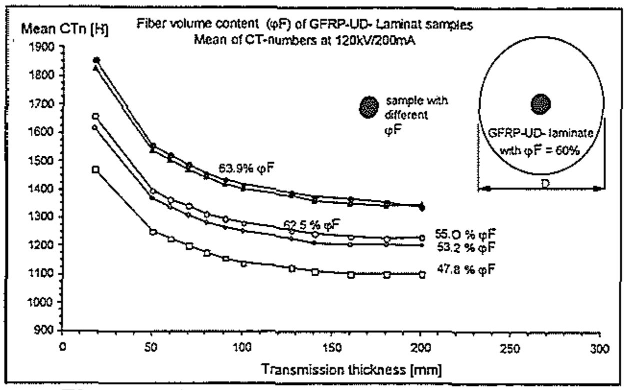


Fig. 12 Influence of the beam hardening on the CT number

Inside the components the difference of the fiber volume content is well measured (i.e.Fig.12). So comparative measurements on series components can be performed. The absolute measurement of the fiber volume content is not possible. Pores in the laminate or fluctuations in the glass composition can distort the value [2]. Serious process-, material alterations or manufacturing defects will be visible and quantifiable in the tomograms. Only the normalising of the attenuation coefficients allows the comparison of the series components with the master component (component without defects) by CT. The diagram (i.e.Fig.13) shows the differences of the standard deviations of the CT-numbers of a faulty CFRP-laminate (wavy fibers) to a defect-free

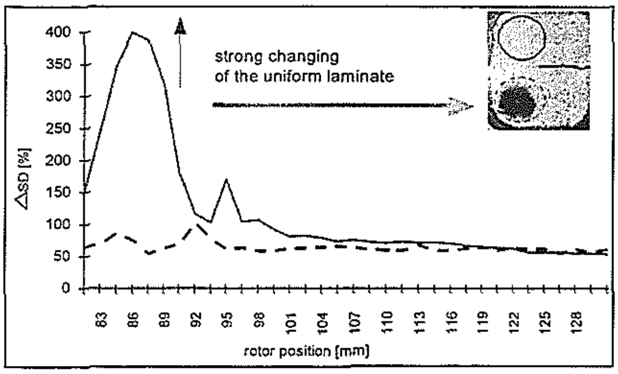


Fig. 13: Comparative measurings on a GRFP-laminate

laminate. The relative alteration, which indicates the defect within the laminate could be seen clearly. The standard deviation is a measure for the uniformity of the resin fiber distribution within a laminate cross-section.

Exemplary tomograms with defects within fiber composites

The following listing gives a summary of defects which could be within monolithic fiber composite structures:

- *Wavy laminates*
- *Fiber cracks*
- *Delaminations and debondings*
- *Curing cracks*
- *Air pockets and pores*
- *Nonuniformity resin and fiber distributions*
- *Foam fractures and deformations*
- *Shifting of structural parts*

Wavy laminates

Wavy fiber laminate structures are very harmful if they are located within high loaded zones. The fibers are only carrying loads if they are placed in the direction of load. In a wavy laminate the load will not be carried by the fibers, therefore the resin matrix has to take over more loads. As a result high shear stresses will be introduced into the resin matrix - the resin fails. The matrix will change so strongly that the fibers will have space for bending. The fibers break.

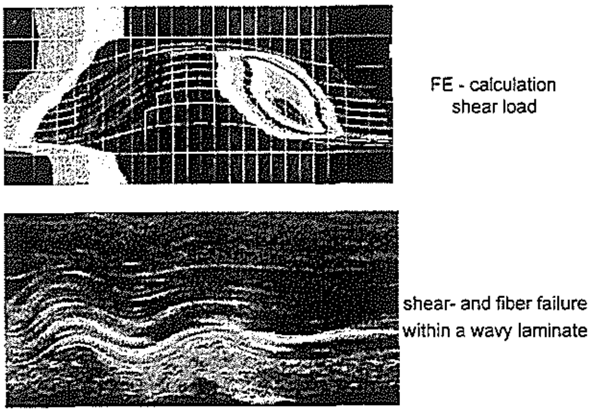


Fig. 14 Failure of a wavy laminate

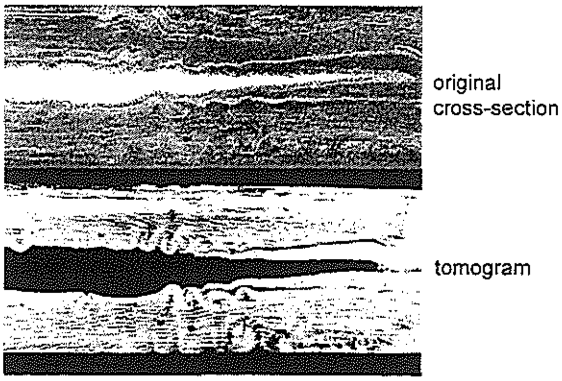


Fig. 15: Wavy GFRP-laminate

Fiber cracks

Fiber cracks are very difficult to detect in the tomograms. In the rotor blade neck cross-sections the fibers of the UD-laminate are placed in the rotor blade radial direction (direction of the centrifugal force). At this point the spatial resolution is equal to the minimum thickness (1.5 mm) of the X-ray beam.

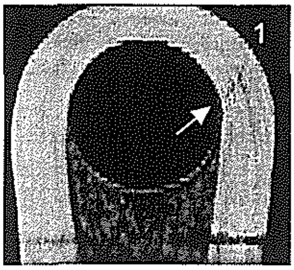


Fig. 16: Fiber crack in UD-loop after a dynamic fatigue test

Delaminations

Delaminations are detectable quite clear. The good spatial resolution in the scan plane (axial tomograms) defines here the limits of the detectability.

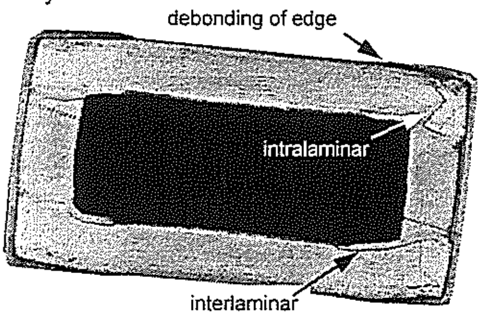
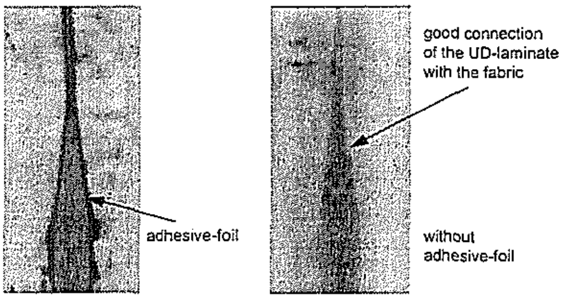


Fig. 17 Delaminations

Inspection of bondings and laminate transitions

An adhesive foil of a bonding becomes visible as the distribution of resin in the joint gap (area between the bonding parts). The compound quality (cohesion) between the bonding parts cannot be checked by CT. If it is possible the laminates should be manufactured so, that various prepreg laminates be cured together (polyaddition at the same time), so it is possible to obtain an integral meshing for the various prepreg laminates. If a good integral meshing is available the laminate transitions can be hardly recognised in the CT-images.



± 45 fabric cured and pasted with UD-laminate

± 45 fabric cured together with UD-laminate

Fig. 18: Bondings

Detectability of foils and films

Foils made of synthetic materials used in the production process can not be detected directly by CT. The attenuation which is caused by a foil corresponds to the attenuation by the resin matrix. Therefore they are not visible. A foil is detectable indirectly due to a stronger concentration of resin film on the foil.. Foils should contain elements which will absorb the X-rays to detect the foils better by means of CT. Here for the future the need for further actions is obvious.

Use and qualification of CT-inspection for helicopter rotor blades

The life cycle of a main rotor blade can last 20 years or more. The life cycle of the helicopter rotor blade is divided into three phases, the development, the series production and the operational phase with maintenance. In front of this background the CT must be seen as non-destructive test method in the application to the rotor blades. CT is used as a test method within all three life phases. For this purpose it is necessary to qualify the CT inspection for these applications. This starts during the development phase very early.

Helicopter life	Activity	State	Evaluation
Development	Design/Analysis prototype production *Destructive testing* + CT	Manufacturing defects Test damages Strenght / life time	Correlation Strenght / CT
Series production	CT Destructive testing	Production flaws Deviation from "Master"	Quality
Maintenance	CT Destructive testing	Operational damage	Degree of damage Residual strength

Fig. 19 CT on helicopter rotor blades

CT during the development

The fiber composite rotor blade is a component whose strength properties depends on the design and the production quality. The sizing and the manufacturing technology must be optimally co-ordinated [9]. Thin prepreg layers are inserted by hand into a blade mould. The mould must be filled with the prepreg layers so, that within each fiber laminate of the cross-section of the rotor blade the fiber volume content is 59%. The laminate cuts and the map to put the laminates into the mould must be arranged so, that an optimal filling of the blade mould is obtained. After closing the mould the component is cured under pressure and temperature. Nonuniform filling rates result in difference pressures in the mould. The prepreg layers can shift and wavy laminates with low-quality strength properties will be produced. These laminate deformations inside the fiber composite structure are usually not visible from outside. Only the CT makes wavy laminates visible.

Fig. 20: Manufacturing of the Tiger rotor blade

Optimization of the production process

The quality of the composite component depends on an optimal manufacturing process.

Earlier, in the prototype production the first manufactured helicopter rotor blades have been cut. Only in such way it was possible to get information about the inner distribution and set-up of the fiber laminate structures and to co-ordinate optimally the design process of the component and the productional process one to the other. Now the cutting of the components can be avoided by the use of the CT. This exhibits a great benefit if one considers that a rotor blade represents a considerable value. Each rotor blade will be CT-checked to detect production deviations after the curing process. The tomograms are visualising the manufacturing defects and deviations in the cross-sections of the fiber component. Sometimes surprising effects become visible by the CT which must be understood. Therefore an evaluation of the tomograms of new components and its information contents should always happen together with the engineers of mechanical design, production, structural and test. This guarantees an efficient interpretation of the tomograms and contributing to this, understanding the productional process. Therefore the production process can be optimized so, that the desired component qualities will be reached. During the optimization phase must be distinguished between obvious manufacturing defects like wavy laminates within high loaded fiber layers which will result in a failure of the component and production deviations within other less loaded composites. Also production deviations occur which can only be removed by considerable cost. The judgement of visible production deviations within the tomograms with respect to structural efficiency is not often possible.

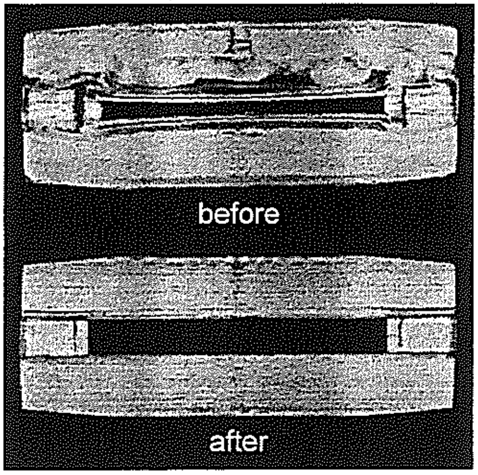


Fig. 21: Wavy laminates removed

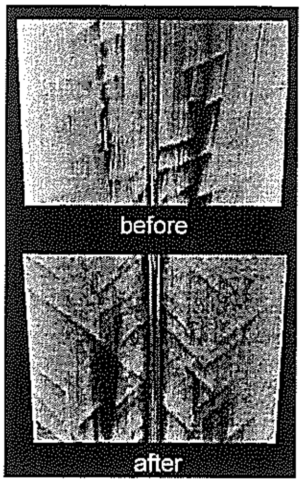


Fig. 22: Tapered laminates optimized

Destructive testing

Therefore components with production deviations are selected for test specimens for the destructive testing in a relatively early optimization phase. Special defined built-in manufacturing defects will be not implemented in the inner structure of the composites because these will never match the reality of the complex structures of a rotor blade. This could lead to false results of the fatigue tests. This approach has the advantage that the effect of the production deviation on the life time of the component can be judged relatively early. After that, the optimization process can be better co-ordinated. Special test rigs applies static and dynamic loads to the rotor blade. The test specimens are CT-checked before, during interrupts and after these fatigue tests. Therefore it is possible to judge the life time of the rotor blade in connection with the inspection of the external

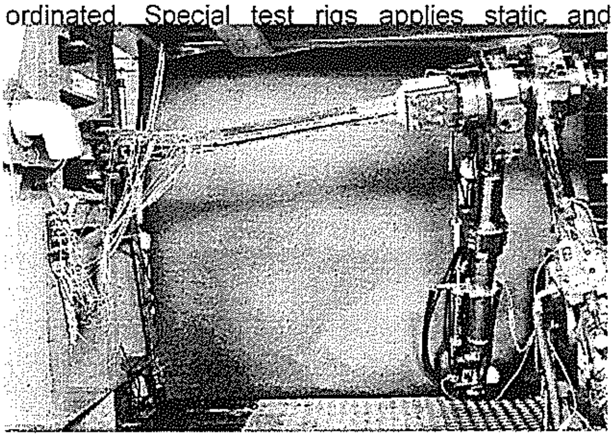


Fig . 23: Fatigue test of the EC135 flexbeam in the blade bending machine

interrupts and after these fatigue tests. Therefore it is possible to judge the life time of the rotor blade in connection with the inspection of the external visible damages and the change of stiffness of the component with the effects of the production deviation, detected by CT, inside the fiber composite structure. The destructive testing is also necessary, to evaluate the design concept of the rotor blade. Furthermore the rotor blade shall be proved its life time by static and dynamic fatigue tests according to the certification of FAR 27 requirements and the Special Conditions of the Luftfahrt Bundesamt.

Fig. 24 Fiber cracks and delaminations in a wavy UD-laminate

CT during the series production

Only by the tight combination of the non-destructive CT-inspection with the destructive testing, during the fatigue tests, the judging of the CT-tomograms can be guaranteed. This methodology qualifies the CT inspection as a non-destructive test method for the quality assurance of the rotor blade in the series production. From the knowledge's of the development- and certification tests a CT-test instruction procedure for inspection was created for the series inspection of the rotor blades. The CT-test instruction contains descriptions of defects with permissible defect limitations. If new production defects are discovered, the rotor blade with the new manufacturing defects will be stored for some time in a closed store until the design engineers will have decided whether a release can be given by theoretical analysis or not. If the manufacturing defects cannot be removed by theoretical analysis or repair, the proof can be furnished only by a destructive testing of the component to certify that the manufacturing defect does not have any life time restricting effects. The destructive testing makes no sense with a component with a defect which occurred for the first time. Therefore the rotor blade must be saved in to a closed quantity store and one has to wait whether the manufacturing defect will occur further on systematically. If the defect will be present still on course of production, all sources of errors are to be removed in the production. Now a destructive testing is economical and useful to assess the effect of the defect. If the proof of the fatigue test furnishes that the defect does not cause any life time reductions, the rotor blade will be released again for flying. If an early failure will occur during the fatigue test, all rejected rotor blades with these new defects will be declared to be scraped. The most prior-ranking target will be the removal of the source of the production defect for a defect-free delivery of the blade to the customer.

CT during operational and maintenance

During the operating time of the rotor blades these are checked usually by visual inspections to external damages. The CT will be used if unusual events have been occurred and rotor strains were evoked which were above the limit loads, by examples, like loading of non-rotating rotor by over-flight and gust loads, at slop landings or manoeuvres on the ground with power or by foreign object damages or accidents. At such events the CT is used for inspection of the inner structure of the rotor blade attachment on possible damages. A further application of CT is its monitoring support during the residual strength test of helicopter rotor blades. Rotor blades with very high flight hours are brought back from the customer and the residual strength is determined in the fatigue test in comparison with the new rotor blade. The rotor blade attachment is checked by CT at the beginning, during and after the fatigue test. By that it can be found whether damages have been occurred within the structure by operational loadings and their effect on the fatigue of the structure.

Conclusion

Since 1993 ECD is using continuously the CT within the rotor blade development, series production and maintenance. During the development of the Tiger- and the EC135-rotor the quality and the life time of the rotor blades became effected decisively by use of the CT. In the series production the quality of the rotor blades of the BO105, the BK117 and the EC135 is checked by means of CT and improved step by step. If used consistently throughout the development, production and maintenance CT can help increasing the quality and fatigue behaviour of dynamic loaded helicopter components made of composite materials. Future aims in the usage of CT will be the consolidation of the defect catalogue and the development of the image processing with the objective of half- and full automatic defect analysis.

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