IN-SERVICE CRACKS GROWTH IN SHAFTS OF AIRCRAFT STRUCTURES UNDER SIMULTANEOUS ROTATION OR TORSION AND BENDING

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Several cases of aircraft shafts failures produced in service under bending-torsion condition were studied. There were three situations of the mode I, III, and mixed I/III failures of shafts depending on the shear stress value. Various mechanisms of cracks development which caused structure failures in service under combined bending-torsion are discussed.

INTRODUCTION

In-service failures of shafts subjected to rotation or torsion and bending are the results of various causes. Most typical situation develops in the case of fast fracture under torsion when shear stress limited the section resistance to static stress.

Shafts fatigue fracture are developed, as a rule, throughout a section of the same diameter as other sections have, and the fracture surface has the main orientation in the perpendicular direction to the shaft's axis. The difference in mode I and III influence on the crack growth must be known to classify a cause of a shaft's failure.

In the recent paper are analysed several cases of shafts fatigue and static fractures occured in various aircraft structures. The dominant role of the bending in the high cycle fatigue is demonstrated. The well-known mechanism of steps developing in fracture origin, which are usually used to classify fatigue fracture, is discussed in the case of static fracture under rotation.

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HYDRO-HINGE OF YAK-42 AIRCRAFT

The structural component was manufactured from Cr-Ni-Mo steel, having Yield stress and Ultimate stress 1500MPa and 1800MPa respectively. Its failure has developed throughout a section of the transition from cylindrical to spherical parts of the component, as shown in Fig.1. The fracture surface, placed near the component face, had roughed relief with wear marks oriented along the ring traces. Traces were the result of mixed processes of a metal fracture and tearing between produced surfaces. There were two zones of various features on the investigated fracture surface.

First zone "I" placed directly near the component face, Fig.1. This slightly destroyed zone had flat dimples oriented along component face with scarce appearance of their depth. There were oriented dimples on the surface of the second zone "II" with usually observed depth appearance for the material of middle plasticity. The macro-boundary between these two zones correlated to the transition from flat to deep in the direction toward the centre of the shaft.

The discovered sequence of fracture surface features reflected the fatigue crack growth process in the case of cyclic torsion without evident bending (1). This process realised in the low cycle fatigue area of loading. The fracture surface developed as a result of pores creating and growing along the circular direction under torsion, as shown in Fig.2. Pores had small sizes in the radial and axial directions, but the size in the circular direction under the torsion is very high. The pores volume have increased under the mode III cyclic loads from torsion. An increment of crack propagation in the radial direction took place at the moment of several pores coalescence. The developed crack have no evident opening in the direction of rotated component's axis. That is why dimples are not expressive in their depth direction, being in parallel to the component's axis. Fast fracture develops under the bending mode increasing. That is why the volume of plastically deformed material increases, and dimples deep increases too.

Investigation revealed that the main cause of component failure was its malfunctioning because of seizure in its hinge part. The shear stress from torsion exceeded the material's shear Yield stress in each cycle of the component's loading. That is why it was true low cycle fatigue fracture under shearing.

FRACTURE OF THE MI-17 N70914 HELICOPTER'S SHAFT

It was the shaft from the same Cr-Ni-Mo steel that failed 20.03.93 in flight at Siem Reap. The helicopter had flown 1287 hours to that time. Fracture surface was developed in the perpendicular plane to the shaft axis. There were oriented shearing traces on the investigated damaged fracture surface produced under the shaft's rotation. There was oriented composition of the material structure from the plastic deformation process near one part of the fracture surface, and another part of the fractured material was without any features of this process. There were steps along the border between the fracture surface and component face in the part of not oriented material's structure.

Fractographic analyses discovered oriented dimples in local places which were free from the shearing damage for both parts of structured and nonstructured material. There were dimples depth variations in both fracture zones from near to plain to rather deep for deformed and nondeformed material's parts respectively. Hence there were various values of tension from bending during fracture development through the shaft. The tension value was near to zero around the origin place. The microtunneling process developed under torsion, as shown in Fig.3. That is why steps were formed in the place of origin. The fast fracture in the last part of the shaft was developed under compression from the bending. The combination of compression from bending and shearing from torsion have produced the material oriented deformation.

So, it was high level of the static load from the torsion with small value of bending that caused fast fracture through the shaft. Wrong flight operation of helicopter was the cause of the static fracture of the shaft.

SHAFT OF OIL PUMP OF TVD-10B ENGINE

The shaft of the oil pump failed in transverse direction across a keyway designed to place a key joining the shaft with pump gear. The component had flown 768 hours or 730 flights from the last repair. The shaft was manufactured from the Cr-Ni-Mo steel with Yield stress and Ultimate stress 1200MPa and 1600MPa respectively. The fracture process had next features, as shown in Fig.4. The fatigue macro-lines have S-shaped form. There were two zones without lines placed at the keyway, having an area between them in the form of a tongue with very roughed relief. Several steps were seen around of the fracture surface.

The performed fractographic analyses under scanning electron microscope discovered next fracture features. There were small dimples on the fracture surfaces in two zones without macro-lines. It is correlated to static or repeatedly-static fracture. The first part of fatigue fracture was developed from the corner with place of origin shown by arrow in Fig.4. It was small crosspiece between shaft surface and zone of static fracture that fatigued under combination of tension-shearing from bending-torsion respectively. The crack trace laid not exactly in plane. That is why there were two places of a new crack initiation near to the shaft surface as shown by arrows in Fig.4. Origins were placed on the shaft face because there were maximum of stress concentration from the bending-torsion.

Therefore, the fracture process of the shaft was developed in the next consequence. The static fracture zones were created first and a big stress concentration was introduced. The highest stress existed around of the shaft face from the bending-torsion loading. The crack growth rate along the face under this loading was higher than for any place in the depth direction from the face. That is why the crack front had S-shaped form. This was the same situation as shown for the steps formation in Fig.3, but in the case of cyclic loads.

So, it was not only the torsion that produced fatigue fracture. The bending can not be only one to produce the fatigue fracture too. That is why the bending-torsion can not initiate static fracture zones from the keyway because of the highest stress at the shaft face. Therefore the fatigue fracture can be initiated only after the static fracture was developed. This static fracture should be discovered during repair when a key was introduced into the keyway.

To confirm this conclusion the crack growth period was calculated by the number of macro-lines. The regularity of their formation correlated to the regularity in cycles of pump working. It was shown that one line forms by one flight (2),(3). There were nor less than 100 flights of the engine with working pump during fatigue crack growth. It is near to 13% of the shaft durability after the static zones were introduced during repair. This estimation is in a good accordance with the well-known phenomenon for a low level cyclic load in the high cycle fatigue when fatigue crack develops from the stress raiser.

CONCLUSION

The mode I crack opening under shaft bending-torsion played the dominant role for in-service fracture developed by high cycle fatigue. The mode III crack opening are dominant in the case of quasi-static or low cycle fatigue failures. The shearing is the driving force for failures after the ultimate shear stress was exceeded in local volumes of shafts.

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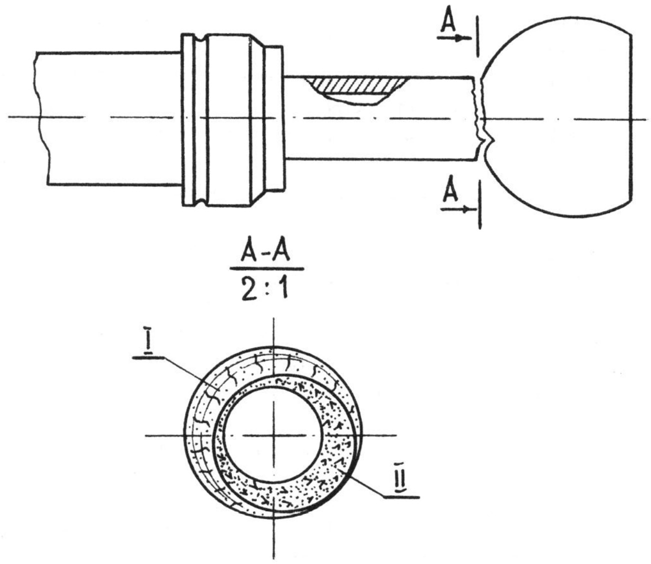

Figure 1 Overview on the fractured shaft, and schematized fracture surface with (I) fatigue and (II) static fractured zones

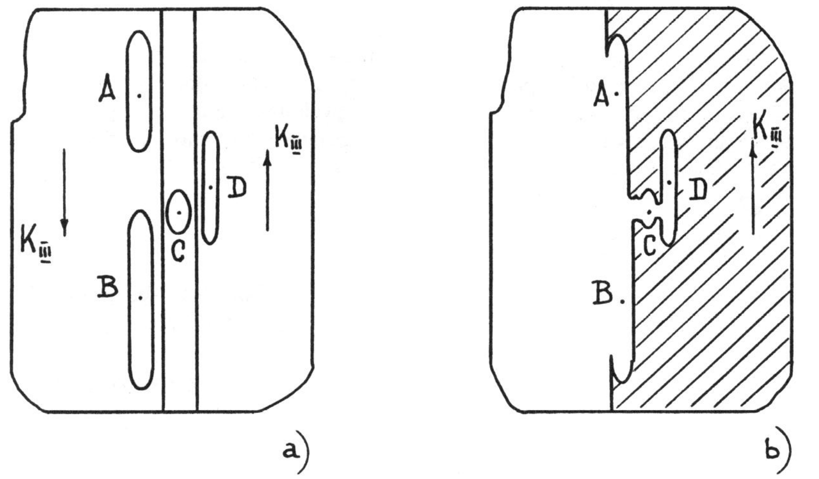

Figure 2 Schemes of the fracture process developing under torsion cyclic loading (a) before and (b) after pores coalescence, courtesy from (1)

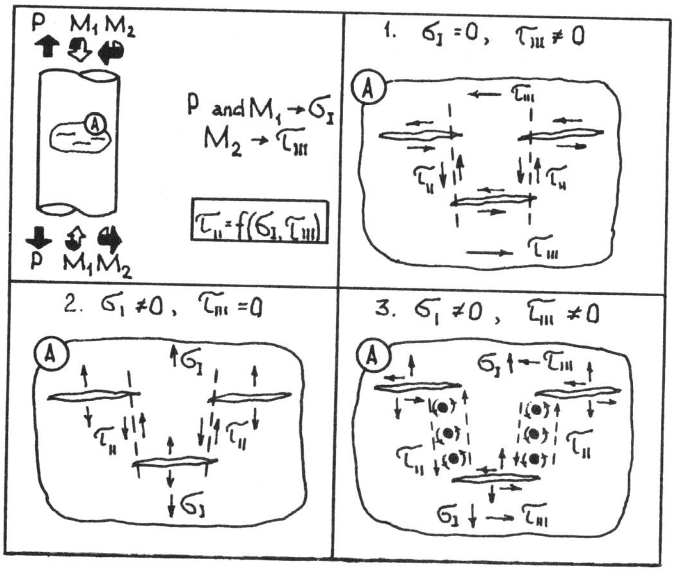

Figure 3 Schemes of fracture processes produced similar patterns under various biaxial tension-torsion loads for (1, 2) static or (3) fatigue fracture cases

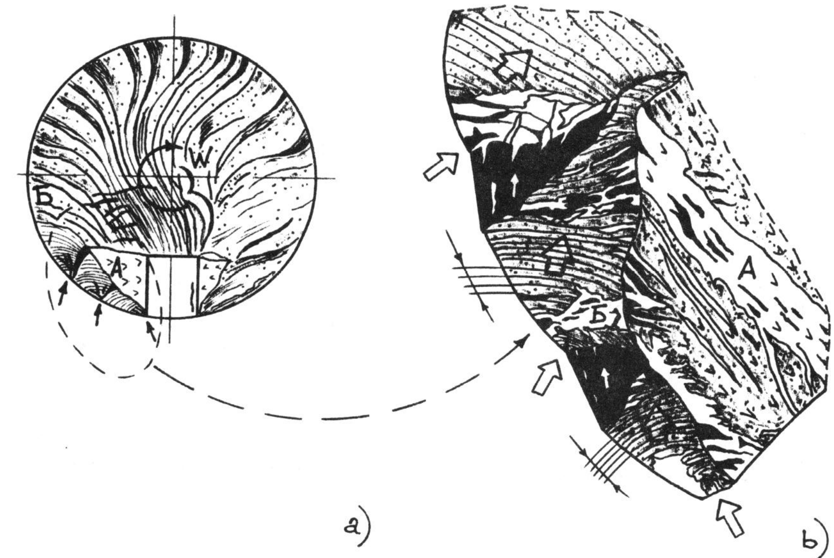

Figure 4 Fatigue surface of shaft (a) with static fracture "A" zone, and (b) magnified initial zone of the fracture surface with origins pointed out by arrows