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QA PROCEDURE FOR ASSEMBLY, TESTING AND AIRWORTHINESS CERTIFICATION OF A HIGH SPEED ACCESSORY GEARBOX

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Abstract: *Every Type approved Line Replaceable Unit (LRU) of a Combat Aircraft undergoes a stringent Quality Assurance plan during production, assembly and acceptance testing (ATP) for obtaining airworthiness certification. The traceability of the materials used for the aircraft components and International Standards imposed for testing are well documented for every aircraft system. Strict geometrical tolerances are imposed during manufacturing processes and the inspection cleared components are assembled with an approved assembly procedure documents. Then the assembled units are subjected to an Acceptance Test Procedure (ATP) comprising of several tests to confirm its functional performance. Depending on the performance of the system with respect to the acceptable limits on parameters, the airworthiness certification is awarded for aircraft fitment. In the present paper, a comprehensive QA procedure adopted for obtaining airworthiness certification for a high-speed accessory gearbox is presented. The paper dwells in detail the basic specification and functions of the gearbox, quality control activities for some critical components such as gears and casings, assembly practices and Acceptance testing carried out on the gearbox.*
Keywords: *Accessory gearbox, Airworthiness, Kit clearance, Acceptance testing*

1. INTRODUCTION

The Quality Assurance procedure for Military aircraft gearboxes differ largely from those followed for automobile and other applications. As these gearboxes operate in high altitude and extreme environment conditions, QA procedures play a vital role in achieving the high reliability required for aircraft applications. A newly designed aircraft system undergoes an exhaustive Qualification Testing (QT) procedure based on International Aircraft Standards such as MIL, DTD, AIR standards etc. After successful qualification testing, the Airworthiness authorities accord type approval to the aircraft system. The type approved aircraft system undergoes stringent quality requirements during production, assembly and acceptance testing for the Flight clearance and fitment on the aircraft.

1. 1. Aircraft accessory gearbox

Aircraft Accessory Gearbox used in Military aircrafts form a part of the Secondary Power System (SPS), which draw on engine power to supply their client accessory systems (Mark Davies, 2002). The secondary power requirements of the accessories include hydraulic, electrical and pneumatic systems. The accessory gearbox discussed in the present paper is a light weight gearbox transmitting 185 kW power at a rated speed of 16810 rpm. The gearbox draws secondary power from the main power plant through a Power-take off shaft (PTO) and supplies it to three accessories namely two Hydraulic pumps and one Integrated Drive Generator (IDG) as shown in Fig.1. A Jet

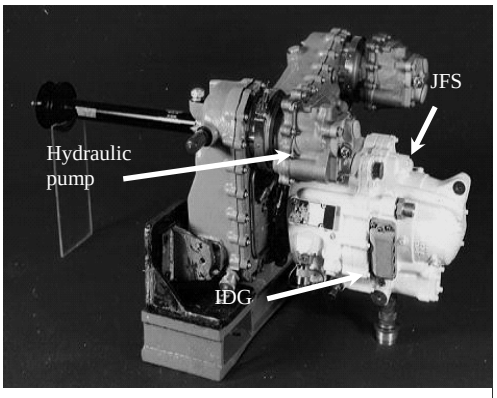

Fig.1. Aircraft accessory gearbox

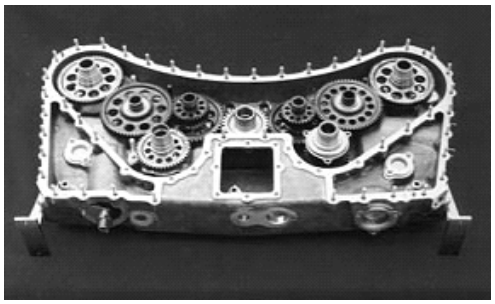
Fig.2. Main casing of accessory gearbox

Fuel Starter (JFS) is connected at the starting gear train pad of the accessory gearbox.

The gearbox has twin functions, one to start the main power plant of the aircraft through the jet fuel starter and the other to run the accessories mounted on it to cater to the

hydraulic and electrical requirements of the aircraft. The gearbox consists of main casing and cover casing as shown in Fig.3 and Fig.4.

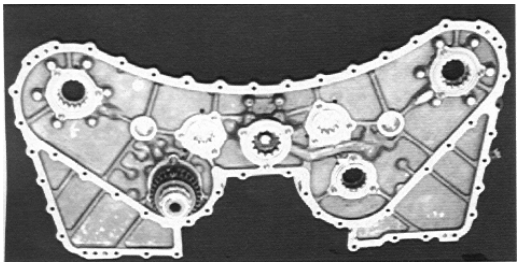

Fig. 3. Cover casing of accessory gearbox

The casings are made out of Magnesium alloy to AIR 3380 specification. It is a thin walled casing with wall thickness less than 6mm and incorporates mini-core oil galleries for catering to the lubrication requirements of gears, bearings and seals. Lubrication jets are provided on the main and cover casing of the gearbox at different locations to ensure proper lubrication. The gearbox also provides health monitoring systems such as magnetic chip detectors, hot oil temperature and low oil pressure warning switches.

2. QA PLAN FOR ACCESSORY GEARBOX

The Quality Assurance plan for the accessory gearbox broadly consists of 100% inspection of all the components such as casings, gears and other critical components with the coordination of the airworthiness authorities. The functional performance of the assembled gearbox is ensured by subjecting it to acceptance testing as per International Aircraft standards. The Quality Assurance procedure carried out on casings, gears including kit clearance and gearbox assembly procedure are described in the following sections.

2.1. Quality control of casings

The QC activities start right from the preparation of the mould for the main and cover casting of the gearbox. The shape and positions of the cores are checked for given geometry by using templates to avoid sagging during curing process. During the casting, samples are taken to check the chemical composition, grain size and mechanical properties of cast magnesium alloy. Once the casting cools to room temperature, it is knocked out of the mould, core holes cleaned and the cleaned castings are identified with a melt batch number. The same details are also punched on the sample test bars for traceability. A thorough radiography test of all the sections of the casting is carried out as per MIL-STD-2175 and ASTM E 155 standards. Subsequently a fluorescent dye penetrant test is also carried out as per ASTM E 165 standard to identify surface defects which are difficult to identify by radiographic methods. A fluoride anodizing treatment is given to the casings to prevent it from galvanic corrosion as per MIL-M-3171C. After the machining process the casings are inspected for their dimensional and geometrical tolerances through Co-ordinate Measuring Machine (CMM). The inspection cleared casings are then subjected to a painting scheme as per DTD 5567, 5580 standards and a coupon test carried out to evaluate the painting in coordination with quality assurance authorities.

2.2. Quality control of gears

Straight tooth spur gears have been used in the present accessory gearbox. As the pitch line velocities are of the order of 70 m/sec, these high speed and precision gears conform to DIN Class 5 standards (Dennis Townsend, 1992). These gears are made out of low carbon case carburised electro slag refined steel with nickel and chromium as the major alloying elements. Type certification of the material is the first step in ensuring the quality of the gears, which is based on the mechanical test properties such as yield strength, ultimate tensile strength, percentage elongation in length and hardness. The type approved material is forged to achieve maximum strength for the gears. The forged blanks undergo normalizing process followed by case carburising and tempering to achieve the required hardness for machining. The gears are manufactured and case hardened to about 800^{o}C followed by oil quenching. Sub zero treatment is carried out to curtail the percentage of retained austenite. Gear grinding followed by lapping ensures that the gears follow the prescribed Quality Class. Temperature, time and atmosphere are the most critical parameters that are monitored during the above processes by the certification authorities.

Power rating of gears depends upon surface durability which is a function of compressive strength which in turn is directly proportional to hardness (Gitin Maitra, 2000). Hence the accessory gears are case hardened to around 60 HRc to withstand higher load, and have higher endurance limit. To avoid reduction in fatigue strength due to notch measurement of hardness on gears, standard coupons are used. The test coupon is subjected to the same process as described above for the gears. The coupon is subjected to indentation until to a depth where the hardness reduces to 50 HRc from the surface to record the effective case depth for the gears (Dennis Townsend, 1992). Decarburization of the gear surface has the potential of causing differential wear rates and ultimate failure. Hence the gears are checked for any de-carburisation by Nital etching. Once the coupon satisfies the design specifications, the gears undergo inspection for transmission and composite errors (Gitin Maitra, 2000). The vital checks on tooth such as profile error on individual gear tooth and lead error is then carried out on these high precision gears. The composite errors on the gears are evaluated by a double flank test where the total composite error is contained within specified limits. On completion of the above process the gears undergo Phosphating to improve their oil retention capabilities. All these processes are meticulously documented for achieving Quality certification.

2.3. Kit clearance for components

Verification of the inspection documents called Kit clearance for the components ensures traceability and prevents components with non-conformance from entering into the gearbox. The Kit clearance is carried out by airworthiness authorities inspecting both manufactured and bought out components of the gearbox. The above certification is issued after thoroughly pursuing the quality records such as chemical analysis report, heat treatment card, mechanical property test report, NDT report and final inspection reports such as dimensional and geometrical tolerances for the casings. The authorities also scrutinize type approval certificate for the gear material, heat treatment card, inspection report on coupon and error checks on gears to confirm that they satisfy the quality norms as stipulated in the drawings. Based on the confidence achieved on the perusal of the above records, Kit Clearance certificate is issued for clearing the items for final assembly.

2.4. Gearbox assembly procedure

The assembly procedure begins with the cleaning of components to prevent Foreign Object Damage (FOD) in the gearbox. This is carried out by subjecting the casings, gears and other components to ultrasonic cleaning at a frequency of 33 kHz for about 5 hours. Visual examination is then carried out on the casings to check for interconnections between the pressure and scavenge lines, surface damage and proper finishing of the components to ensure smooth assembly. Pressure checks are then carried out on the core lines of the main and cover casing to proof pressure of about 15 bars, to ensure that the minicore galleries of the casings withstand the lubrication oil pressure with no leakage at the blanks of gear casings. On completion of pressure checks, the lubrication oil jets in both casings are calibrated for the minimum oil flow as per design specifications at room and elevated temperature of 65^{o}C. Jets that do not conform to the minimum flow requirements are inspected and replaced.

The next step in the assembly of the gearbox is the preparation of subassemblies for different gear train stages. Spacers to the correct thickness and geometrical tolerances are assembled to prevent any longitudinal movement of the gears during running condition. The subassemblies for relief valve, lube filter and Aerostatic valve are carried out and performance check conducted to evaluate the performance as per design requirements. On completion of these activities, final assembly of the gearbox is carried out with special fixtures. The assembled gearbox is then subjected to break-in wear test for 30 hrs at an input speed of 6000 rpm. This test assesses the bedding pattern of gears and collection of contamination in the lube system. The gearbox is then subjected to external pressurization through compressed air to check the leakage in the interfaces of the gearbox. Finally a tag is issued by the quality assurance group to clear the gearbox for Acceptance testing.

2.5. Acceptance test procedure for accessory gearbox

The acceptance tests on an accessory gearbox are carried out to verify the Flight worthiness of the gearbox under simulated operating conditions. These tests check the performance of the gearbox under given conditions and verify the absence of manufacturing and workmanship related defects (Mark Davies, 2002). About 48 cumulative hours of testing is carried out at different conditions of load, speed, and position. These tests are categorized as Motoring, Performance record, Starting sequence and Attitude test. During these tests various parameters such as input speed, torque, speed at all accessory drive pads, lubrication system pressure, temperature, flow rates, oil leakage and vibration parameters of the gearbox are recorded. The acceptance tests are coordinated through quality assurance authorities. The motoring run test, performance record test and starting sequence test are carried out on a specially developed test rig discussed below.

2.5.1. Acceptance test rig

The Acceptance test rig for Accessory gearbox as shown in Fig.4 is used for Motoring test, Performance record test and Starting sequence test.

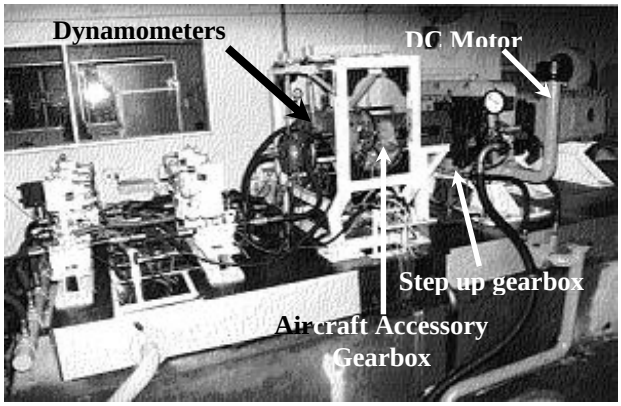

Fig.4. Acceptance test rig for accessory gearbox

The test setup consists of a 250 kW DC motor coupled to a step up gearbox of gear ratio 1: 9.3. The output of the gearbox is coupled through the PTO shaft to the Accessory gearbox. This shaft is capable of taking large misalignments both in radial and axial direction generally prohibited in the drive lines of transmission systems. The prime mover, which has a maximum speed of 2375 rpm, can be incrementally controlled through a microprocessor based thyristor drive system with high acceleration rate capabilities. The step-up gearbox is provided with its own independent lubrication and cooling system and has appropriate emergency alarm indications to ensure safe operation. The accessory gearbox in mounted on its frame and held in position at three points, through mounting brackets at LH and RH one each on the port and starboard side. The third mount is through a tie rod anchored to the

top of the gearbox frame. All the three mounts simulate actual mounting on the aircraft SPS bay. On the output pads of the accessory gearbox three water brake dynamometers capable of applying loads up to 60 kW at 11500 rpm is fitted. On the fourth pad a hydraulic motor is used to simulate the jet fuel starter. In order to simulate the drive through JFS pad a separate hydrostatic drive system with electro-hydraulic controls has been installed.

2.5.2. Motoring run test

In this test the accessory gearbox is run from zero to 100% of its rated speed up to and including 125% of its rated speed with and without accessories mounted on the gearbox. This test is carried out at Acceptance test rig with speed increments of 500 rpm and the bearing temperatures are allowed to stabilize at each speed. The motoring test is carried out for about 17 hours with one third of full loading on the accessory gearbox and the parameters are recorded.

2.5.3. Performance record test

This test is carried out on the acceptance test rig, determines the performance of the accessory gearbox by power extraction from the accessories at different PTO shaft input speed ranging from 9000 rpm to maximum rated speed. Full load is applied on the accessory drives of the gearbox through the water brake dynamometers simulating the power requirements of the accessories mounted on the gearbox. This test is carried in two stages, the first test is called as coasting up where the input speed

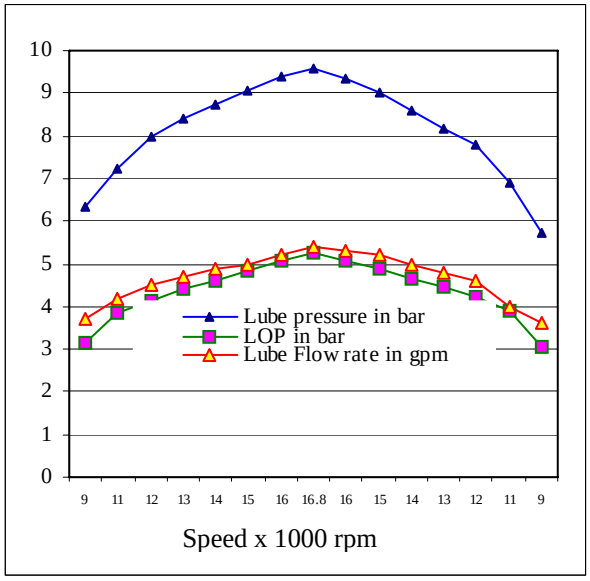

Fig.5. Performance record test result

is varied from 9000 rpm to rated speed and the second test is called as coasting down where the input speed is varied from maximum rated speed to 9000 rpm. A minimum dwelling time is allowed at each speed increments for lube parameters to stabilize. The health of the gearbox is monitored by recording the vibration peak values corresponding to the fundamental running frequency. The first four harmonics are also observed in the frequency domain for trouble shooting. The noise level is also recorded in addition to lubrication oil leakage at the drive pads and lube oil parameters. This cycle is carried out for one hour, with a total of 25 cycles for each gearbox. On completion of 25 cycles of test, an oil sample is tapped from the gearbox for carrying out SOAP analysis. A typical test result for one cycle of performance record test for the accessory gearbox is shown in Fig.5.

2.5.4. Starting sequence test

The objective of this test carried out at acceptance test rig is to evaluate the performance of the accessory gearbox subjected to periodical loading associated with the starting drag torque of the accessories, along with their inertia and the mass moment of inertia of the engine rotor. All the three water brake dynamometers simulating the accessories are fitted and the accessory gearbox is accelerated by the hydraulic motor mounted at the JFS pad to the cut-off speed of the starter and subsequently decelerated to zero speed. The time for the starter to achieve the cut-off speed is noted down in addition to the lube parameters and vibration in the gearbox. Each gearbox is subjected to starting sequence test for 25 cycles.

2.5.5. Attitude test

The Attitude test rig shown in Fig. 6 is used for the validation of the self contained lubrication system of the accessory gearbox at different aircraft attitude and maneuvering conditions.

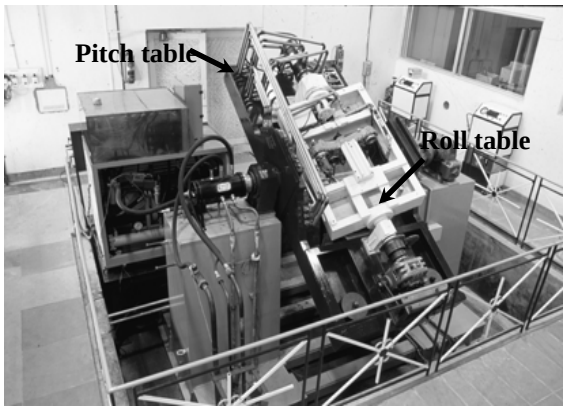

Fig. 6. Attitude test rig for accessory gearbox

The test rig consists of a pair of vertical columns on which a horizontal table is mounted to simulate the pitching motion of the aircraft. Inside the horizontal table, an inner table is provided to simulate the rolling motion of the aircraft. The accessory gearbox is installed on the rig and subjected to different pitching and rolling motions simulating aircraft motions at different input speeds. The lubrication oil parameters such as pressure, flow rate, temperature and vibration parameters are recorded for

different speeds at various loading conditions provided in the approved Flight test schedule. The gearbox is mounted at the center table of the attitude test rig and run at three different speeds upto the maximum rated speed. The power input is through one of the accessories mounted on the gearbox. At each speed the gearbox attains 19 different roll and pitch positions. The low oil pressure warning at inverted conditions of the gearbox is recorded. The duration for each cycle is about one hour with a total number of 5 cycles for every gearbox.

2.5.6. Strip examination

On completion of the Attitude test, the gearbox cover is stripped and the following checks are carried out.

- Bedding pattern of gears
- Evidence of scoring or scuffing marks on gears
- Scoring, pitting, galling and brinelling in bearings
- Runners of dynamic carbon seals for traces of carbon graphite
- FOD inside the gearbox
- Metal particles on Magnetic chip detectors

On close visual examination, if the condition of the gearbox is found to be satisfactory, then the gearbox is reassembled and further pressure check is carried out. Then the gearbox is released for final post performance record test.

2.5.7. Post performance record test

After strip examination, a one hour post performance record test is carried out on the accessory gearbox to ensure satisfactory performance. The parameters are compared to the earlier performance record test discussed in section 2.5.3.

3. DOCUMENTATION

On completion of the acceptance testing on the accessory gearbox, a comprehensive document is prepared which contains the following details:

- Test article configuration for the gearbox
- Kit clearance report
- Calibration report for test rig sensors
- Pressure check and jet calibration reports
- Break in wear test
- Acceptance tests and their results
- Strip examination observations
- SOAP Analysis report

4. FLIGHT CLEARANCE

The above comprehensive document is submitted to the airworthiness certification authorities for clearance. The certification authorities scrutinize the test results and compare them with the acceptable limits set for both lubrication and vibration parameters. The lube oil SOAP analysis results and the particle trend in ppm are also analyzed. If the results are well within the given limits, acceptance tag is issued. In case of deviation from the limits, rectification on the gearbox is suggested and the ATP is repeated. Once acceptance tag is issued, the deliverable gearbox is declared airworthy and dispatched for aircraft fitment.

5. CONCLUSION

The overall quality assurance procedure followed for an aircraft accessory gearbox is discussed in detail. This test procedure ensures satisfactory performance of the gearbox during flight trials. The record of these tests provides benchmark for future overhaul and health monitoring of the gearbox. Although 48 hours of acceptance testing discussed in the present paper relates to a newly developed gearbox, there is a scope for reduction in number of test hours after successful flight trial performance. Normally, standard proven accessory gearbox for a fighter aircraft undergoes less than 10 hours of acceptance test. The type of test differs depending on the design and reliability requirements.

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