

Gear Refurbishment, An Economical Approach for Aerospace Overhaul & Repair

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American Gear Manufacturers Association



TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

A program to repair gear teeth was initiated for AlliedSignal's Power by the Hour customers. Repair turnaround times were becoming more critical as the availability of new gears for the gas turbine engine overhaul and repair depot became scarce. We decided to partner with Air Gear Industries International because they are an FAA/JAA approved repair facility and have had considerable experience in the refurbishment of aerospace gearing. Most other gear manufacturers did not want to participate because of the paperwork and liabilities involved in obtaining FAA approval for FAA repairs. Also, because of the small number and variety of gears, it would not be economical for a production facility to participate in this program.

Power gears of AGMA quality Q11 - Q13 were chosen to begin the program because the need was greatest and it would be the most rewarding even though it would also be the most challenging since minimum stock removal would be paramount to a successful rework. A number of gears from the Coast Guard fleet of helicopters were reviewed and based on knowledge of the manufacturing stock removal, blueprint case depth, and Material Review Board actions, it was concluded that most of the gears were reworkable. Working together with Air Gear, an acceptable procedure for rework ensued including the establishment of inspection requirements. The refurbishment procedure was often more involved than just reprofiling the gear teeth. It also included honing, chrome plate and regrind of bearing journals, and unbolting and rebolting of two gears. In addition, a marking procedure for tracking and repair limits had to be established. A 150 hour or 1000 cycle engine test was also required before final approval could be issued.

To accommodate AlliedSignal's requirements for quality and delivery, Air Gear used their specialized grinding machines which they had developed for gear refurbishment. These machines can be dedicated for individual parts and be available and ready whenever a part is received. With a long term commitment from AlliedSignal, Air Gear could justify dedicating these machines to the work at hand.

With the success achieved in the Coast Guard program we have gone forward onto the regional fan jet program, the ALF 502/507 engine which has even more stringent requirements for gear tooth stock allowance and profile tolerances. A variety of accessory gears are being reviewed for refurbishment considering that Air Gear is having success with reworking splined shafts by cutting off the splined end and EB welding on a new one.

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Power reduction gears for the LTS 101 engine family are subject to end load wear because there are two stages of single reduction and because the gearboxes have a long and narrow shape as shown in Figure 1. The first stage provides a 4:1 reduction ratio for an input speed of 37,000 rpm through an 18 pitch gear set. The second stage ratio is 1.5:1 which further reduces the speed to 6,100 rpm output through an 8 pitch gear set.

During development and on into production both helix angle changes and ribbing have been applied. However, both a variety of customers and increases in horsepower requirements had more than kept pace with our ability to maintain the proper uniform load distribution required for each application. In addition, the idler gear of the two stage reduction is also a mechanical torque meter which uses the thrust differential between the two helical gears to register torque through a piston at the shaft centerline. Helix angle variation affects the system friction which in turn affects the torque meter reading. This change, therefore, affects the calibration curve for the engine. Needless to say, the customer is not pleased with changes of this nature. The resultant end load wear manifested itself as frosting and sometimes spalling which started at one end of the tooth, see Figure 2, and worked it's way across usually in a triangular flag shaped pattern.

During 1994 & continuing to the present time, an AlliedSignal overhaul facility located in Greer, SC was being used for the LT101 engine programs. The Coast Guard was the main customer being serviced for the LTS101-750-B2 engine used on the HH65a Dolphin helicopter. During this time the company had it's hands full producing the AGT1500 engine for the Army's Abrams M1 tank and the ALF502 engine for the BAE 146 commercial jetliner. Meanwhile the plant in Williamsport was producing engines for MBB / KHI, Aerospatiale, Piper, Bell, Cessna and Piaggio as well as the Coast Guard. Both plants were operating at near capacity and were hard pressed to supply production and overhaul with all the parts that were required.

The overhaul facility recognized the problem and began searching for other alternatives; namely some type of refurbishment program and the gears being replaced were stored without scrapping since in many cases the parts were rejected but not damaged beyond repair. During a visit to the facility, the sub-contractor saw the rejected gears and entered into discussions with overhaul personnel for consideration of repair. A number of gears

were sent back to Arizona where they were inspected for wear and stock availability for rework.

A choice had to be made between beginning the refurbishment program with power reduction or accessory gears; The reduction gears were chosen for two reasons: 1. The customer would be delighted since the cost of a refurbished gear would be less than a new one especially if we zero timed it in the *Power by the Hour* Program. 2. Power gears of aircraft quality AGMA 11 - 13 were most in need as well as being the most rewarding financially for the customer. If this proved successful, accessory gears would easily be added.

The *Power by the Hour* concept was started with the Coast Guard. AlliedSignal owns the repairs and the Coast Guard pays an hourly rate. It was tried for a year and then the price was adjusted for FOD damage and other events that were beyond the realm of normal maintenance. A seven year contract is now in progress.

The first step was to inspect the gears visually to determine which might be repairable; Gear tooth distress was by far the major reason for reject. The main concern was pitted and spalled gears. Previous experience had shown that pitting could be up to .007 inches deep and that grinding away the surface tended to cover it up as well as making the pit area smaller. This type of pitting is a subsurface phenomenon with the depth below the surface of distressed area difficult to ascertain. It was decided to just scrap pitted and or spalled gears. The remainder of surface distress cases including wear, end loading, frosting, and scoring were acceptable candidates for rework.

The first gear to be visually inspected was the torquemeter idler which contains both a coarse pitch and the larger diameter, fine pitch gear. Of the fifteen gears reviewed, all fifteen of the coarse pitch gears were considered reworkable and, seven of the fifteen fine pitch gears were considered reworkable. The prospects for rework were excellent and we would start with the coarse pitch gear since it would have the most stock left for rework. This further reinforced the decision to go with power gears first. Reworking by regrounding the gear teeth was the only solution to the refurbishment problem and minimal stock removal was critical. The sub-contractor assured us that their experience in this area would be equal to the task and the refurbishment program was born.

The major steps required to qualify this program were then established as follows:

1. Determine the minimum measurement over wires, stock allowance, for rework. This requires knowledge of the following:
 - a. Case depth versus hardness as manufactured. A surface hardness of 60HRC minimum was required for "zero" timing to insure adequate operational life.
 - b. Stock allowance for original manufacturing.
 - c. Material Review Board, for blueprint discrepant parts, actions for this part number.
 - d. Stock allowance for rework. This will be over and above MRB limits.

1. Establishment of an acceptable "Rework Procedure" by Air Gear. This required a review of the overhaul manual to determine all possible rework conditions for each part. For example, bearing journal repair etc.
2. Identification procedure of test parts to pre-empt improper assembling of these parts into production engines. (Repair Development Engineering number is supplied by AlliedSignal)
3. Inspection of refurbished parts.
 - b. This required some paperwork changes on the part of the contractor since both companies did not have the same inspection equipment. As an example, Hofler machines used at the contractors plant contained their own tolerance bands built in for involute and lead charts. The sub-contractor uses Fellows equipment and overlay templates had to be made for their inspection.
1. Test requirements for acceptance. We required a total of 1,000 hours of testing for acceptance. To expedite the program a 150 hour in-house test was initiated and followed by three *lead the fleet* engines for the Coast Guard to reduce the overall length of time required. A 150 hour engine test is equivalent to approximately 1000 hours of field operation because of increased time spent at high power levels. AGMA 911-A94, Annex B offers an excellent discussion of Aerospace Gearbox test and Mission requirements.
2. A marking procedure to be used at the sub-contractor to keep track of refurbished hardware and to identify the number of reworks.
3. Final acceptance of Air Gear for licensed refurbishment of AlliedSignal Engines gears by part number.

For the eight or coarse pitch gear the carburized case depth range is 0.028 - 0.040 inch per blueprint. This is the case depth range to reach a hardness of 50HRC. For operational purposes, we are interested in the minimum case depth to 60HRC. Fielding a part at this surface hardness level was considered satisfactory for operational longevity. A review of as hardened case depth records showed that a 0.028 inch case depth curve crosses 60HRC at 0.018 inch. Figure 3 shows the hardness versus depth traverse for the test sample gear teeth that accompany the production parts in the furnace. The as manufactured maximum stock allowance per specification is 0.006 inch per side and another 0.002 inch was used for MRB action, which is for parts that are not to blueprint but are still acceptable for operation. This left $(0.018 - 0.006 - 0.002) = 0.010$ inch. Other factors not yet accounted for include tolerance on the hardness and depth measurements, a desire to minimize operational backlash, and the actual measured data points which start at 63HRC but could have been 62HRC or 61HRC. The additional stock for refurbishment was limited to ~ 0.001 inch below the MRB limit.

For the torque-meter idler gear the overhaul manual defines areas other than just the gear teeth for inspection and rework, these include the bearing journals, the body fitted bolts, and the adjoining surfaces for fretting wear. Figure 4 shows an isometric view of the torque-meter idler gear along with a simplified tabulation of the basic rework procedure including numbered circles representing the rework areas on the gear. Some views of typical gear tooth patterns are also shown. The actual rework sheet for this gear is shown

in the Appendix A. Table I is a listing of the gear tooth inspection results both prior to and after refurbishment for a typical gear. Figure 7 shows the Fellows involute charts for comparison; The Hofler has tolerance bands which are printed in red if the actual trace is not to blueprint. The Fellows chart has the inspection template superimposed on it for ease of visualization.

The subcontractors rework procedures were accepted and the first gears were refurbished. The engine test was acceptable and three sets of gears were identified for *lead the fleet* and installed into Coast Guard aircraft. After 1,000⁺ hours all gear sets looked fine and Air Gear was certified for refurbishment of the torqueometer idler gear.

The output gear followed since it also was of the same coarse pitch. The fine pitch torqueometer idler gear followed shortly after because it was in short supply and was the remaining gear from the assembly. Some of these gears were acceptable without rework but Greer found them to be noisy during the engine acceptance run. They requested that the sub contractor regrind the teeth on these gears even though no rework was required. LT101 gears are now shipped directly to the sub-contractor for inspection and disposition which is more cost effective and reduces turn around time for the customer.

The success of this program led to a search for other candidate gears. The ALF502 Turbofan reduction gears were considered because of surface distress caused by high oil temperature operation. The ALF502 reduction gears were originally designed in the 1970s are made from SAE9310 carburizing steel which is the standard of the Aerospace industry. At an operating temperature of 350°F, the material starts to lose its hardness which leads to wear and surface distress. For certain applications a higher operating temperature material is required. The upgraded ALF507 engine contains reduction gears made from EX53 "Pyrowear" carburizing steel which doesn't soften until 450°F. Some customers prefer to refurbish the SAE9310 gears for economy of operation. The reduction gear system is a star type planetary configuration, see Figure 5, comprised of an input sun gear, which is splined to the power turbine, driving seven planet gears which in turn drive an internal ring gear. The ring gear is splined to the turbofan. The transmission provides approximately 7,500 horsepower at a turbine speed of 17,500 rpm which is reduced to a fan speed of 7,600 rpm. The sun and planet gears were considered for rework while the ring gear did not exhibit signs of surface distress because the concave curvature of the teeth increases the contact area to reduce the operational compressive stress to 90,000 psi as compared with the sun gear mesh of 130,000 psi.

The procedure for qualifying the ALF502 reduction gears is the same as for the LT101 reduction gears and again pitting or spalling was excluded as candidates for rework. The pitch is 10.8 and the corresponding case depth range is 0.018 - 0.028 inch. The minimum case depth curve of Figure 6 shows a crossing point of 60HRC at 0.011 inch depth and again the traverse is of the sample test gear teeth that accompany the production lot in the furnace. The as manufactured maximum stock allowance for this gear is 0.005 inch.

Consideration of stock allowance for refurbishment is more involved for the planet gear than for the sun gear. There are two different blueprint part numbers for the planet gear with each one having a different range of tooth thickness. Tighter control was required for the sun-seven planet-ring gear mesh to improve load sharing as compared with a single gear mesh. It was also desired to have the same total range of stock allowance on the planet gears for manufacturing purposes. By having two different planet gear part numbers, both requirements could be achieved. Table II is a listing of this geometry. A stock allowance of 0.002 inch was established for refurbishment of the sun gear.

A requirement of the assembly is that only planets of the same dash number may be built into the carrier or housing. If a -24 planet is reworked within the blueprint tolerance on tooth thickness, it will remain a -24 gear and if not, it is allowed to become a -23 gear. Creation of a third dash number for the planet gear was not desirable so the smallest value of blueprint tooth thickness was maintained for the -23 gear. This meant that the stringent requirement for tooth lead, involute, spacing, index and runout had to be maintained with a minimum amount of stock allowed for repair on both loaded faces of the idler gear. To further complicate matters, the planet gear bores may require a chrome plate repair because of wear in which case the bore must be located from the gear teeth. The planet gear assembly is comprised of a threaded pin onto which two bearings and a gear are press fitted. The assembly is held together by a lock cup and nut. Since the bore is the datum surface, any machining error will be reflected in the tooth characteristics.

The sun gear also requires a lengthy repair since the teeth are silver plated and the gear contains a damper ring that needs replacement. The gear is then check balanced and re-balanced if necessary. The sun and planet gears may then be *zero* timed and re-identified as a new set upon assembly.

During development of the rework procedure the inspection equipment needed to be re-calibrated to provide the eight microinch finish required on both the sun and planet gears; Checks are required at three axial locations to verify uniform honing and a honed gear was supplied to the sub-contractor for this purpose as a reference. Involute and lead data also required inspection machine synchronization between the two companies and The machines had to then be re-calibrated for acceptance. Long roll involutes are used with numerous points being identified. Overlay templates for both involutes and the crowned sun gear lead are now the inspection masters used to check charts at the sub-contractors plant.

When these issues were resolved, acceptable gears were submitted and subjected to a 1000 cycle engine test run in October 1997. The gears looked fine after test and Air Gear is now qualified to refurbish these gears also.

Air Gear International Inc. is an FAA/JAA repair station equipped strictly to repair gears, shafts, splines, and related components for the Aircraft/Aerospace industries. The restoration of parts is a combination of proprietary development as well as proven repairs