2001173

International Conference on Shot Peening and Blast Cleaning.

REINTRODUCTION OF RESIDUAL STRESS BY SHOT PEENING FOR REJUVENATION OF AIRCRAFT LANDING GEARS

P.Parmeswaran*, S.V. Mate and M.S. Nadgir*****

ABSTRACT

Hindustan Aeronautics Ltd., Aircraft Division, Nasik has been engaged in the manufacture and overhaul of Russian origin fighter aircraft for the last 35 years. As on date the division has manufactured and overhauled over 1700 aircraft. The division deals with advanced aircraft materials and has precision machining, heat treatment and platingfacilities and extensive facilities for non-destructive testing. The division is also one of the few centers in India, which manufactures and overhauls Aircraft and Helicopter landing gears. The critical components of aircraft are load-carrying Bulkheads, Undercarriage, Wing spars, Control surfaces, Engine and Ejection system which requires advanced technology and precision tools for their manufacture.

The initial life prescribed by the manufacture for aircraft and landing gears are conservative due to uncertainties in the design analysis and life cycle testing at Certification stage. Mid life extension is therefore given through a very cautious and sound engineering judgement based on stress analysis, NDT and feed back received from operators.

Landing gears are long cycle accessories and involve a number of testing during manufacture and assembly, making use of special purpose test equipments and fixtures. Because of this, the manufacturing cost is often very high. Due to the above factors it is of prime importance to make maximum use of the landing gears in terms of the number of landings without compromising on flight safety.

Re-introduction of residual stress at mid life of landing gears by shot peening has been successfully employed in the development of

Rejuvenation technology and subsequent life extension of landing gears.

This paper deals with the shot peening process, measurement of residual stress and rejuvenation of landing gears for life extension.

INTRODUCTION

Aircraft Landings gears particularly those of military aircraft are designed for optimum weight. The main purpose of a fighter aircraft is to take off at the shortest possible time, fly and deliver the weapons. After take off, weight of landing gear, which account for 4 to 6% of the aircraft all up weight, is a penalty. An over weight landing gear reduces the armament or fuel carrying capacity of the aircraft. Hence, utmost care is taken to optimize the weight of landing gears.

Landing gears are so designed that, their TBO (Time Before Overhaul) and TTL (Total Technical Life) coincide with that of aircraft. While every care is taken to ensure this, it is always not possible to assign a common TBO and TTL for aircraft and landing gears.

The primary purpose of the landing gear is to facilitate movement of aircraft easily on ground while taxying, carry the aircraft weight during take off until it is transferred to the wings and to absorb the shock while landing. For military aircraft, the maximum take off and landing weights are specified. This is mainly because of the landing gear strength considerations. The maximum landing weight is of the order of 65 to 70% of the take off weight. The landing weight is brought down to specified limits by consuming the on board fuel and in emergency cases by jettisoning the unused stores and/or fuel dumping.

Most of the modern fighter aircraft have a tricycle landing gear consisting of a Nose Landing Gear (NLG) and two Main Landing Gears (MLG). The MLGs normally carry 90% of the aircraft static weight. Main landing gear can be of column type or beam type depending upon the configuration of wing.

CONSTRUCTION OF MAIN LANDING GEAR

The main landing gear consists of a main beam, wheel-turning unit, semi fork and shock absorber.The MLG main beam is a welded tubular structure consisting of upper, middle and lower units welded by argon arc welding. The upper unit is hinged to the aircraft fuselage by means of the main landing gear axle and rotates around the axle during extension and retraction of landing gear. The lower unit of main beam accommodates the wheel turning unit. The wheel turning unit has a pair of lugs for installation of shock absorber. The semi-fork for installation of main wheel swings in the wheel turning unit. The semi-fork has the second pair of lugs for installation of shock absorber.

The middle unit of main beam is also provided with two pairs of lugs, one for attaching the eye-end of actuating cylinder and the other for accommodating the bell crank of wheel turning mechanism. The inside cavity of main beam is used as storage chamber of air for pneumatic system. Material used is high strength alloy steel having UTS = 170 ± 10 kg/mm^2. External surface is zinc metallized as a corrosion protective measure. The general view of a typical MLG is shown in Fig-1

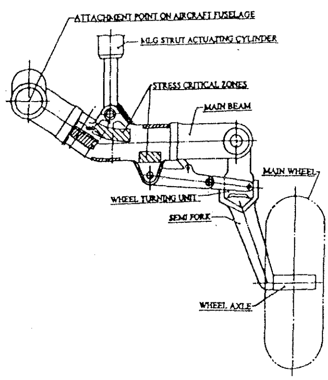


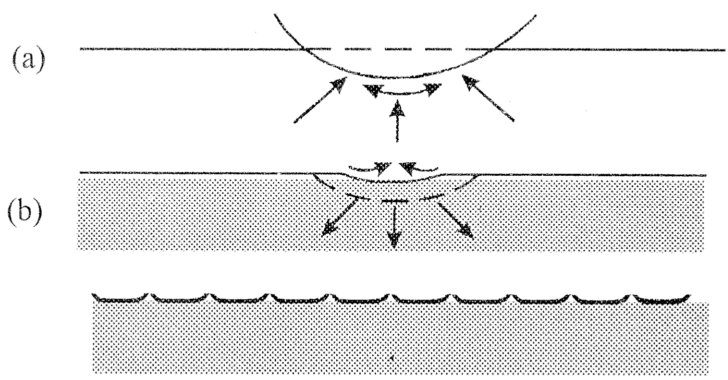
Fig. 1 MAIN LANDING GEAR STRUT

INTRODUCTIOIN OF RESIDUAL STRESS

After fabrication, residual stress is introduced on the surface by shot peening. Shot peening is a method of cold working is which compressive residual stresses are induced on the external surface layers of metallic parts by impingemnet of a stream of shot directed at the metal surface at high velocity under controlled conditions. It differs from blast cleaning in primary purpose and in the extent to which it is controlled to yield accurate and reproducible results. The major purpose of shot peening is to increase fatigue strength.

SHOT PEENING ACTION

When individual particles of shot in a high velocity stream impinge on a metal surface, they produce slight rounded depressions on the surface stretching it radially and causing plastic flow of surface metal at the instant of contact. The effect usually extends to about 0.13 to 0.25 mm but may extend as much as 0.5 mm below the surface. The metal beneath this layer is not plastically deformed (refer Fig.-2). In the stress distribution that results, the surface metal induces residual compressive stress parallel to the surface while the metal beneath has reaction induced tensile stress. The surface compressive stress may be several times greater than the surface tensile stress. This compressive stress offsets any service imposed tensile stress such as that encountered in bending and improves fatigue life of parts in service considerably.



(A) A HARD BALL PRESSED INTO A METAL SURFACE AT POINT OF GREATEST PENETRATION. NOTE THAT THE ORIGINAL SURFACE (DASHED LINE) IS STRETECHED (TENSION) INTO A SPHERICAL SHAPE BY THE FORCE ON THE BALL. RADIAL REACTION FORCES (BELOW THEBALL) ARE COMPRESSIVE AT THIS STAGE.

(B) AFTER THE BALL IS REMOVED, ELASTIC RECOVERY (FOR SPRING BACK) CAUSES A STRESS REVERSAL: SURFACE RESIDUAL STRESSES IN THE CAVITY ARE NOW COMPRESSIVE, RADIAL REACTION FORCES ARE TENSILE.

(C) CREATION OF NUMEROUS SMALL INDENTATIONS IN SURFACE, AS BY SHOT PEENING, FORMS A COMPRESSIVE RESIDUAL STRESS BARRIER THAT RESISTS CRACKING.

Fig.2 Demonstration of the principal of mechnically induced residual stresses.

Landing gear being a large component, shot peening is carried out in a special chamber. Polished steel balls of 3 mm diameter are used. Total weight of balls inside the chamber is maintained 20 to 25 kg. The balls are set into motion by compressed air of 3.5 to 5.5 kg/cm^2. The balls are inspected to ensure absence of scales, cracks, nicks, corrosion and other defects. The component to be shot peened is placed in the chamber on a special fixture which ensures rotation of parts in both direction exposing the surface uniformly and bombarded with steel balls for 25 to 30 minutes.

The residual stress can reach a level of about half the yield stress when the specimen is not strained during peening and coverage is adequate. These integrated effects are best measured by an Almen strip which is a thin steel strip (100 x 10 x 1 mm) clamped on the landing gear at critical zones. The residual compression causes convex curvature on the peened side and the arc height is taken as a measure of the degree of peening or stress level. A deflection of 2 to 3.5mm is considered as adequate for the landing gear to attain the desired residual stress level on the surface. Use of this method is a good process control for the peening operation but the basic translation from the arc height of the strip to fatigue life of the part must be done by test on the part itself. Exposure time must reach a definite point before maximum fatigue durability is realized. Longer exposure is of no particular benefit. The effect of variable air pressure is also noted to be rather ineffective beyond a certain limit.

MEASUREMENT OF RESIDUAL STRESS BY X-RAY DIFFRACTION METHOD

Though Almen strip is extensively used as means of process control, other different methods are used to measure the value of residual stress. Most common among them is X-ray diffraction method.

This method employes Bragg's law to estimate residual strains present in the atomic planes. In this method, a monochromatic X-ray beam of sufficient intensity is made incident on the atomic planes. The reflected beams from successive planes of atoms are observed. Bragg's law defines the condition for diffraction through the following equation:

$$n\lambda = 2d\sin\theta \qquad (1)$$

λ - Wavelength of incident X-rays

θ - Angle between incident or reflected beam and reflecting planes

d - Interplanar spacing

n - Order of reflection (n = 1,2,3,...)

The equation (1) shows that, if the wavelength of X-rays is known, the interplanar spacing d can be determined by measuring the angle θ. In presence of residual stresses, the d-spacing changes and this in turn results in shift in X-ray diffraction peaks. Therefore, this shift in diffraction peaks is a measure of residual stresses. Figure 3 shows the configuration generally followed for residual stress measurements.

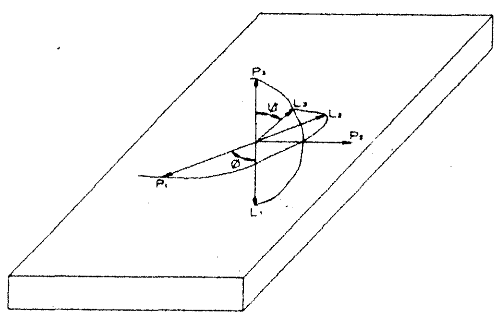


Fig. 3 Axial System fr Residual Stress Measurements

P_1, P_2 and P_3 refer to three orthogonal directions relative to the sample under investigation.

L_1, L_2 and L_3 describe the laboratory (or measurement) frame of reference.

The angles ψ and ϕ define the relationship between P_i and L_i axes.

ψ describes the angle between the specimen surface normal (P_3) and the direction of strain being measure (L_3).

ϕ denotes the angle between one of the principal stress axes (P_1) and the projection of the measured strain directon (L_3) on to the specimen surface.

In the widely used "Sin^2 ψ" method, diffraction measurements are made at several tilt angles ψ (. For the general case of two measurements at $\psi = 0^{\circ}$ and ψ_i (Fig.-4), Noyan and Cohen have given the following equation for surface residual stress σ_{ϕ}.

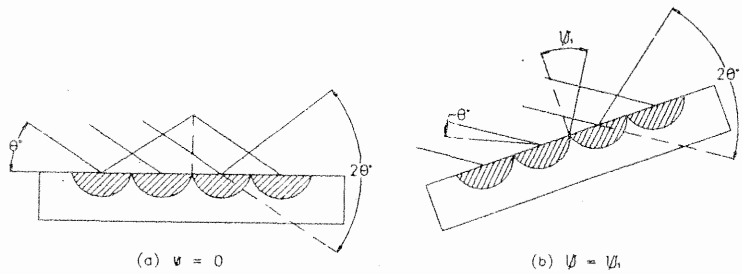


Fig.4 Sampling of Different grains inthe specimen by incident X-ray beam

$$\sigma_{\phi} = \frac{E}{(1+\nu)} \frac{1}{\mathrm{Sin}^2\psi} \frac{d_{\phi\psi} - d_{\phi\psi=0}}{d_{\phi\psi=0}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where, $d_{\phi\psi}$ is the interplanar spacing in the direction described by the angles ϕ and ψ

$d_{\phi\psi=0}$ is the stress free interplanar spacing value.

E Young's modulus of the material

ν Poisson's ratio.

The term $E/(1 + \nu)(\mathrm{Sin}^2(\psi)$ is constant and is defined as K.

Using the linear relationship given in equation (2) for surface residual stress, the lattice strain $\Delta d/d$ plotted against $\mathrm{Sin}^2\psi$ would produce a straight line whose gradient is a function of σ_{ϕ} ν and E. then,

$$m = \delta\varepsilon_{\phi\psi} / \delta\ \mathrm{Sin}^2\psi \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

$$\sigma_{\phi} = m / ((1 + \nu) / E) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

m is the gradient of a least squares straight line fit through the data points and $\delta_{\varepsilon\psi} = \Delta d/d$. Depending on the incident beam, energy and the material under study, the information on surface residual stresses with in a depth of 10-30μm is possible. For example in the case of Cr K_α X-rays, the depth of penetration in steel is of the order of 15 to 20 μm.

In the present study, the residual stress measurements have been made using a portable X-ray analyzer (RIGAKU STRAINFLEX MSF-2M) by IGCAR Kalpakkam. This is a back reflecltion type diffractometer with a 2θ scan range 140 to 170°.

REJUVENATION AND LIFE EXTENSION OF MAIN LANDING GEAR STRUTS

In order to study the effect of fatigue on landing gear, residual stress measurement was carried out on landing gears with different number of landings. Variation of residual stress with number of landings is given in Fig. - 5. Measurement was done on top surface and at depth 100, 200 and 300 microns. Variation of residual stress with respect to depth of layer in microns is given in Fig.-6.

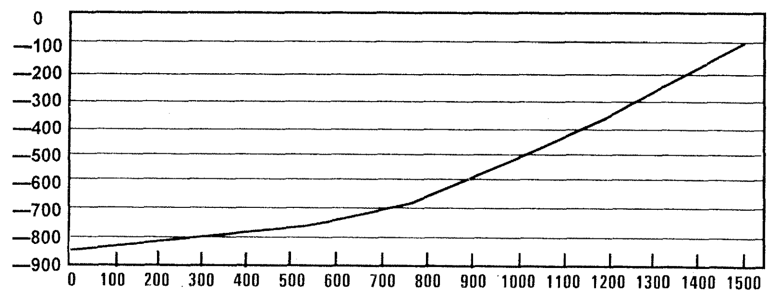


Fig. 5 Residual stess Vs No. of Landings

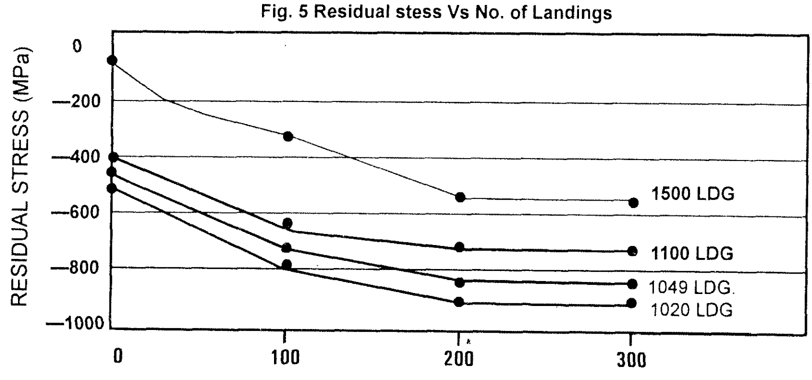


Fig. 6 Residual stess Vs Depth

It is seen from this study that during the process of exploitation of aircraft, the stress critical zones of MLG strut undergo fatigue damage and micro cracks develop on the surface. It is also seen that the depth to which the micro cracks develop is proportional to the number of landings. The process of rejuvenation involves in removing the layer of material, which has undergone fatigue damage. Though rejuvenation is a well-known process for certain other components, rejuvenation technology for main landing gear struts had to be developed indigenously by generating data.

DEVELOPMENT OF REJUVENATION TECHNOLOGY

The first step in development of rejuvenation technology was to develop data on residual stress on landing gears which have done 1000 to 1200 landings and determine the depth of fatigue damage. This experiment was done on a number of landing gears. From Fig. - 6 it is seen that the value of residual stress at a depth of 200 microns on used strut (1000 landings) is equal to that on the surface layer of new strut. Hence, it is concluded that the extent of fatigue damage is limited to the top 200-micron layer. It is also seen that as the number of landings increases, the depth of fatigue damage also increases. Hence it was concluded that, rejuvenation is to be done before 1200 landings.

FINALISED TECHNOLOGY

In order to remove the fatigue layer with micro cracks from the surface of MLG struts the stress critical locations were identified by detailed stress analysis of MLG strut. The technology consisting of the following steps has been developed.

1. Crack detection by Ultrasonic method to check for the absence of fatigue cracks and corrosion on internal surface. The internal surface is accessible for direct inspection only before welding during manufacture. Additionally as this cavity is used for storage of compressed air of pneumatic system at pressure 130 kg/cm^2 and presence of moisture beyond the permissible limits can cause

corrosion on the inner wall, a foolproof method of flaw detection is essential.

2. **Ultrasonic thickness measurement at stress critical zones:** MLG struts are taken up for rejuvenation only if they meet the requirements of minimum wall thickness at the stress critical zones. Minimum thickness required at various zones was specified based on stress levels at critical zones. Wall thickness measurement is carried out before and after rejuvenation.
3. **Tempering at 200 to 230°C for 12 to 16 hours:** MLG struts before taking up for removal of material from stress critical zone are tempered for removal of residual stress.
4. **Removal of surface material:** In order to remove the material upto 200 microns dept from stress critical zones, the area is marked by means of templates. Further a number of holes of diameter 2 to 4 mm are drilled in the marked area with depth to which the material is to be removed. Material from the drilled surface is removed until the drill marking disappears and then polished to merge with the main surface.
5. Magnetic crack detection paying special attention to the zones of rework and ultrasonic thickness measurement.
6. Low temperature tempering at 200 to 300°C for three hours followed by cooling in air.
7. Shot peening to introduce residual compressive stress with steel balls of diameter 3 mm, pressure 3.5 to 5.5 kg/cm^2 and time duration of 25 to 30 minutes.
8. Restoration of internal/external coating and painting.

LIFE EXTENSION RATIFICATION:

Main landing gear struts rejuvenated as per the technology developed were subjected to measurement of residual stress at critical zones and the values were found to be comparable with the stress values measured on new struts.

TABLE - 1
Residual Compressive Stress Measured at Stress Critical Zones on MLG Struts (Mpa)

Zone No	Strut after 1000 Landings			New Strut
	Before Rejuvenation		After Rejuvenation	
	On Surface	At Depth 200 μ	On Surface	On Surface
1	438	823	883	836
2	514	836	874	854
3	556	842	805	860
4	550	831	818	848
5	496	822	842	834
6	526	843	827	871

Stress calculation showed that adequate margin of safety was available for removing the material equivalent of 200-micron depth. Lifing Committee headed by Regional Centre of Mitary Airworthiness Certification (RCMA), Nasik has sanctioned life extension to rejuvenated landing gear struts.

CONCLUSION:

1. Induced compressive stress on external surface reduces with increasing number of landing as shown in Fig. - 5.
2. Life extension of landing gears is possible if rejuvenated at mid life by removing surface layer subjected to fatigue damage as per established technological sequence and by reintroduction of residual stress by shot peening.

FUTURE SCOPE:

Further life extension study for landing gears is proposed to be taken up on expiry of the extended life with full scale fatigue testing.

REFERENCES:

1. Aircraft Landing Gear Design

   By R.C.Cussions

2. Report on Residual Stress measurement by IGCAR

   Report No. IGC/D PEND/ TJK-97/ 2001

3. Fatigue Design

   By Carl C Osgood, Cransbury, New Jersy, USA

4. Understanding How Components Fail

   By Donald J Wulpi, American Society of Metals

5. Residual Stress in Design, Process and Material selection

   Proceedings of ASM's Conference on Residual Stress in Design, Process and Material selection.

6. Experience on life extension of Russian aircraft

   By M.S.Nadgir

7. Metals Hand Book, Volume V.