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Weight Optimization of Gear Casing for 4R810 Diesel Engine

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Abstract

Weight optimization of engine components is an important process for maximizing the performance and efficiency of the any engine. Weight optimization of the casting can reflect in the cost reduction at foundry as well as the machine shop. The reverse engineering methodology can be successfully employed to carry out the weight optimization of the casting of gear casing. The 3 D scanning process is used to obtain the excess, redundant allowances present on the casting and further steps of design and development are done as per the modified casting allowances. The gear optimized casing manufactured is checked for safety by industrial software packages and final checking is done on the actual running engine. The weight reduction procedure reduces the weight by 540 grams of gear casing casting which reduces the natural cost as well as machining cycle time.

Keywords: Weight optimization, Reverse engineering, 3D scanning, casting allowances

1. INTRODUCTION

Gear casing is the enclosing part of an oil engine. It encloses the gear train, camshaft and supports crankshaft of the engine. As oil is circulated through the gear trains and other engine components, gear casing acts as a housing which protects the engine from outer dust and assures uninterrupted and efficient performance. Weight optimization of the casting of the gear casing lowers the final cost of the component which adds to the bottomline of the company.

For the weight optimization V. b. Venkayya carried out extensive comparison of the numerical methods that are used for the weight optimization [1]. C. Fleury compared Mathematical programming method (MP) and Optimality criteria method (OC) for efficiency and recommended Hybrid optimality criteria for better results. [2]. R. J. McGrattan obtained the weight and Cost Optimization of Hydrostatically Loaded Stiffened Flat Plates by 6 different scenarios of supports [3]. M. J. Milroy et al. studied the reverse engineering methodology which can further be used for creating CAD models for analysis and comparison. [4]. Simultaneous cost and weight minimization is carried out by C. Kassapoglou for composite-stiffened panels under compression and shear by considering different configurations for the panels [5]. B. Repgen carried out Optimization of Connecting Rods to Enable Higher Engine Performance and Cost Reduction by testing two materials for the required properties of the connecting rod [6]. P.S. Shenoy et al. cost and weight optimization of a steel forged connecting rod is carried out. A cyclic load of dynamic tensile load and static compressive load is considered for the test [7]. Size and topology optimization of vehicle body is carried out by A. Deb et al. The optimization is carried out by using industrial software packages [8]. A. R. Rao et al. presented Cost and Weight Optimization of Turbine Disks. Non Dominated Sorting Genetic Algorithm (NSGA) is employed in this paper to get the results [9]. R. Radiša et al. carried out the weight optimization of casting. The use of sophisticated software packages gave the quick and efficient results [10]. Y. S. Narayan et al. studied the modelling of core cavity preparation. The modelling of the side engine cover of gear box casing for a mini truck and preparation of core cavity for the same is done [11]. M. Kaufmann et al. studied integrated cost/weight optimization of aircraft structures. The major objective function considered is optimization of direct operating cost i.e. weighted sum of component weight and manufacturing cost [12]. D. Xu et al. carried out Topology optimization of die weight reduction for high-strength sheet metal stamping. Solid Isotropic Microstructure with Penalty (SIMP) is employed for forming analysis [13]. S. K. Prabhala et al. carried out Design and weight optimization of IC engine by studying two materials for the properties for employing them for the crankshaft and piston [14]. V. Ahuja et al. carried out the Application of Optimization Techniques in Reducing the Weight of Engine Mounting Bracket. Analysis of the engine bracket gives the input for the weight reduction [15]. S. M. Patil et al. carried out Modal and Stress Analysis of Differential Gearbox Casing with Optimization. In the process the natural frequency of the model is first obtained and changes are done in the shape without hampering that natural frequency [16]. V. B. Maner et al. carried out design analysis and optimization for the foot casing. Analysis is done for the detection of the redundant material and that excess material is removed [17]. S. Chaudhary et al. carried out the analysis of the foundry defects that can occur in casting process. Elaborate study with the preventive action for the defects is given for casting [18]. S. A. Haba et al. carried out digital manufacturing processes for cylinder block. GENgine system developed by using Open DCL and Visual LISP programming environments is used to carry out the manufacturing process. [19]. A.K.Nachimuthu et al. carried out static analysis of the connecting rod. The static analysis gives the areas where the reduction in the material is possible. This material reduction gives optimization of weight [20]. B. M. Padhiyar et al. carried out Optimization of Truck Chassis Frame for Weight Reduction. Use of Taguchi experiments is done for obtaining the weight optimization [21]. N. Liyong et al. carried out the numerical simulation and production trial of aluminium alloy gear box housing. The results from the simulation are checked with the actual results [22]. A. P. Wadekar et al. carried out defect analysis and validation of compressor housing. The software packages are used for carrying out the simulation for molten metal and areas of potential defects are obtained. Preventive measures are carried out to eliminate those defects [23]. M. j. Marques carried out the weight optimization of casting. In focus is placed on reducing the weight of the casing by reducing the area and number of feeding system components [24]. A. M.H. Elhewy et al. carried out the Weight optimization of offshore supply vessel based on structural analysis using finite element method. Design variables are selected as thickness, shape and cross sectional area. The blind search method is employed for obtaining weight optimization [25]. I. Subotic et al. carried out Weight Optimization of an Axial-Flux PM Machine for Airborne Wind Turbines. A combination of thermal, electrical and structural models is used for analysing the wind turbine. Direct grid search method is employed to obtain the required results [26]. C. Mia et al. carried out Frame weight and anti-fatigue co-optimization of a mining dump truck based on Kriging approximation model. Non Dominated Sorting Genetic Algorithm (NSGA) is used to reduce the thickness of dump truck plates [27]. J. Sedlak et al. carried out study on reverse engineering methodology. The paper analyzes the prototype component of the agitator gearbox in the form of a rough and chip-machined casting [28]. Y. Hu et al. carried out Research on weight-reduced optimization design of large nuclear power low pressure cylinder. In the process size optimization and topology optimization is done sequentially. Latin Hypercube sampling (LHS) and Solid isotropic material with penalization (SIMP) method is used in this study [29]. P. S. K. Reddy et al. carried out Weight optimization and Finite Element Analysis of Composite automotive drive shaft for Maximum Stiffness. Finite element model of optimum drive shaft is prepared in industrial analysis packages. The materials selected for comparison are E-Glass/Epoxy, Carbon/Epoxy and Boron/Epoxy [30]. O. GÜNGÖR et al. carried out optimization of the wall thickness (weight) of a thick-walled cylinder under axially non-uniform internal service pressure distribution. Residual stresses are calculated and are used for the analysis purpose. Autofrettage optimization is carried out and the results are compared with numerical topology optimization method [31]. A P Khode et al. carried out Shape Optimization and Weight Reduction of Seat Structure for Wheeled Armoured Amphibious Combat Vehicle. 8 different combinations of the seat structures are experimented and tests are carried out on them [32]. M. Winklberger et al. carried out Fatigue strength and weight optimization of threaded connections in tie rods for air craft structures. 3 combinations are experimented for the study and most efficient combination is selected [33]. S. M. Silaskar et al. carried out weight optimization of valve for cost effectiveness using value analysis. In this paper concept of value engineering is used for systematically put the different potentials for the weight reduction [34]. M. Bugday et al. carried out design optimization of industrial robot arm to obtain minimum redundant weight. In this paper the 3D modelling of the robotic arm is made and analysis of the same is carried out [35].

In this Paper, a fully fledged methodology is undertaken for the design and development of the gear casing. Reverse engineering is accompanied by 3 D scanners and sophisticated industrial software packages.

2. METHODOLOGY

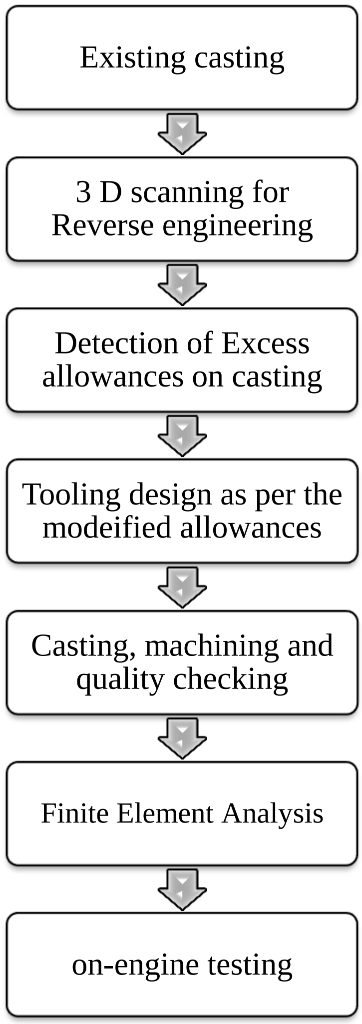

Fig.1 Flowchart of the methodology for weight optimization of gear casing

The existing casting contains excess allowances and these excess allowances reflect as redundant weight of the casting of the casing. The redundant weight also affects cost of the casting. A currently used casting of the gear casing is taken as the input to the process.

3. 3D SCANNING OF THE GEAR CASING FOR THE REVERSE ENGINEERING PURPOSE

For obtaining the amount of the allowances given on the casting of the gear casing, reverse engineering method can be used efficiently. By using the reverse engineering methodology, it becomes very easy to find out the variations present on the component in quick time. For the reverse engineering **ROMER ABSOLUTE 3D scanner** is used. This scanner can scan 1000 points per line and it has 30μm accuracy. The scanned point cloud data from the scanner is feed to **PolyWorks** software which generates 3D surfaces by employing curve fitting.

3.1 Detection of Excess allowances on the casting

For the detection of the excess allowances, **Geometric Qualify suite** is used. In this software, the 3D model from the PolyWorks software is loaded. A machining drawing of the gear casing is provided by the company. Comparison of the 3D model which is prepared and machine drawing is done which radially gives the allowances on the gear casing. A limiting criterion of 3 mm is employed and the allowances above 3 mm are considered as excess which are to be reduced.

Fig.2 Scanned model

Fig.3 Machining 3D model from company

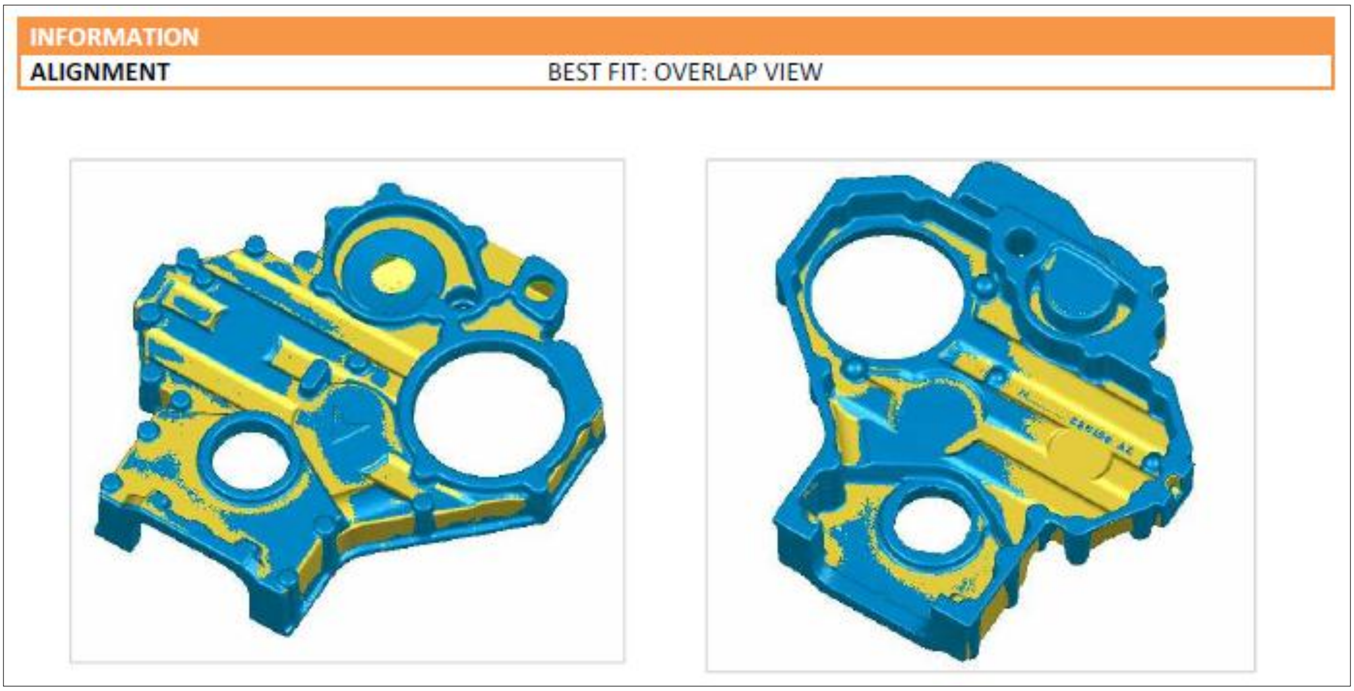

Fig.4 Overlapping of the scanned model and machining model

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The excess Allowances that can be reduced are as shown in the following tables.

1. Front side of Gear casing

a) View A

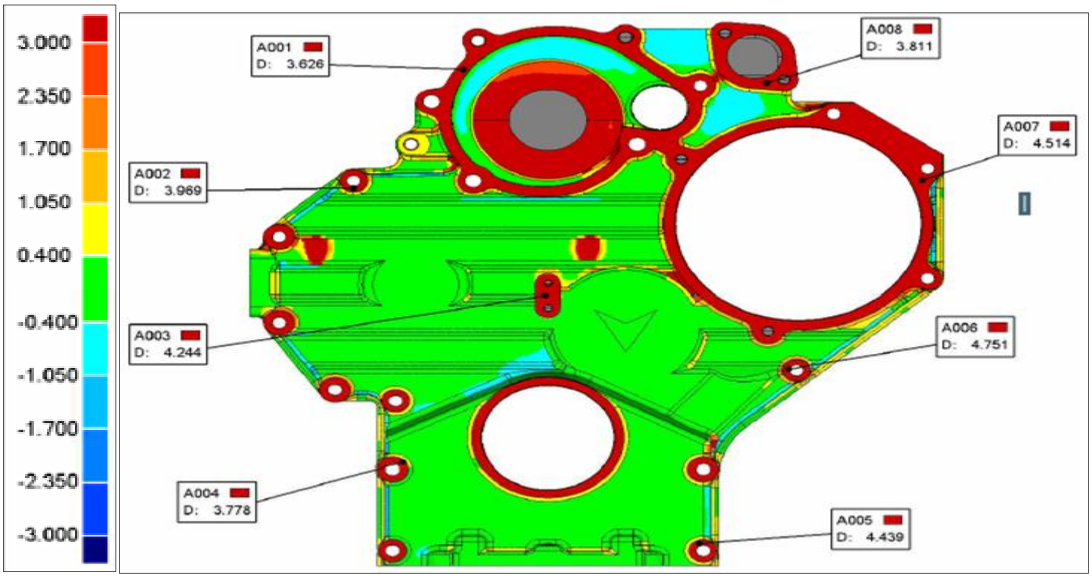

Fig.5 Gear casing view A

Table 1. Allowances given and reduction possible in view A

Name	Allowances Given(mm)	Allowances Defined(mm)	Reduction in Allowances (mm)
A001	3.626	3	0.626
A002	3.969	3	0.969
A003	4.244	3	1.244
A004	3.778	3	0.778
A005	4.439	3	1.439
A006	4.751	3	1.751
A007	4.514	3	1.514
A008	3.811	3	0.811

b) View B

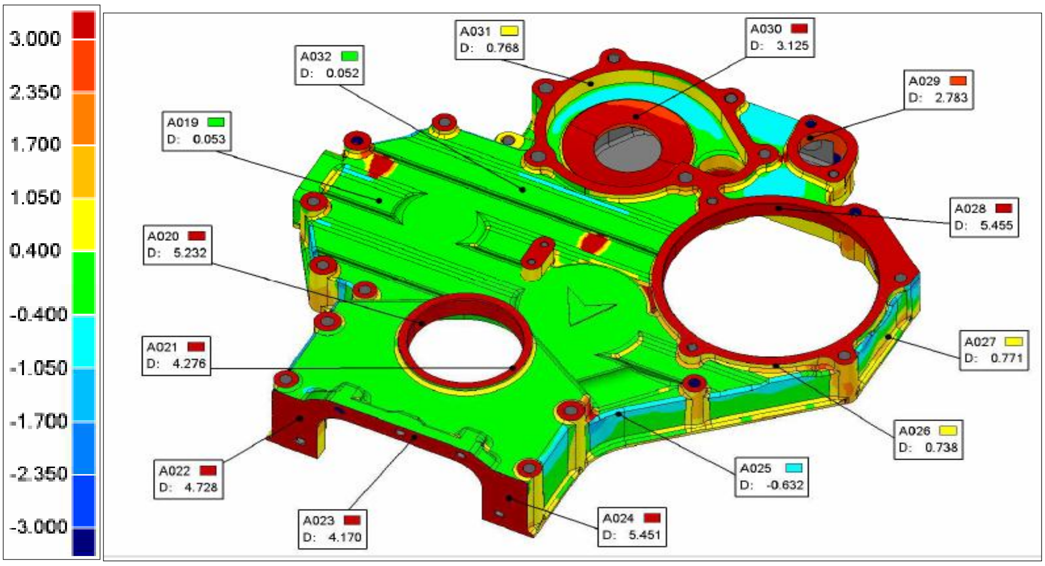

Fig.6 Gear casing view B

Table 2. Allowances given and reduction possible in view B

Name	Allowances Given (mm)	Allowances Defined (mm)	Reduction in Allowances (mm)
A020	5.232	3	2.232
A021	4.276	3	1.276
A022	4.728	3	1.728
A023	4.17	3	1.17
A024	5.451	3	2.451
A028	5.455	3	2.455

Similarly the other excess allowances on the gear casing are tabulated as follows.

Table 3. Allowances given and reduction possible

Name	Allowances Given (mm)	Allowances Defined (mm)	Reduction in Allowances (mm)
A034	6.488	3	3.488
A035	3.26	3	0.26
A039	5.111	3	2.111
A042	5.579	3	2.579
A048	3.7	3	0.7
A053	5.1	3	2.1
A055	5.912	3	2.912
A056	4.105	3	1.105
A009	3.889	3	0.889
A010	3.678	3	0.678
A011	3.919	3	0.919
A012	3.847	3	0.847
A013	3.751	3	0.751
A014	3.559	3	0.559
A015	3.641	3	0.641
A016	3.673	3	0.673
A017	3.921	3	0.921
A018	4.381	3	1.381
A061	5.422	3	2.422
A063	3.916	3	0.916

4. DESIGN AND MANUFACTURING PROCESSES –

- Pattern and core box (Tooling)

  After determining the excess allowances on the gear casing, pattern and Corebox are designed for the new development process. In general 2 mm allowance is given on the castings but as gear casing is very thin part, there is a possibility of the bending of the part. Hence 3 mm allowances limit is defined. Pattern design and manufacturing is done by ensuring that there will be very less or no flash formation around the gear casing.

- Foundry and Machining processes

  After the manufacturing of the pattern and core box, casting of the gear casing is taken. While casting process, proper support is given to core by using the chaplet so that there will not be any unwanted movement of the core within the mould. The green sand moulding is carried out for the economical and precise casting. When the casting cools down, it is taken out from the mould and is then shot blasted for removal of the sand particles on the casting. The casting is checked for the defects and checked castings are sent for the machining.

  The casting process is followed by the machining process. Specialised fixtures are designed and manufactured for ease and accuracy of the machining. Machining is done as per the tolerance limits provided for the different points on the casting. For the quality checking of the gear casing, inspection gauges are manufactured. Inspection gauges give less fatigue to the worker due to the ease of the checking process. It provides quick checking and accuracy of the casing can be easily maintained.

5. FINITE ELEMENT ANALYSIS

After the machining, the gear casing is again scanned and 3D model of it is produced by using PolyWorks software. The 3D model prepared is then analysed in the industrial software packages such as ANSYS 16 for the safety of the parts.

1. Force Analysis

The force analysis checks the effect of forces and moments acting on the part. By using this analysis we predict the amount of stresses acting at different points and the deformation caused due to those force or moments. The analysis is carried out by using ANSYS 16 software package.

The forces acting on the gear casing are as follows -

Moment of 12g = 120 N/mm^2 on the mounting face

Fixed support – the gear casing bolted to the crank case hence, fixed support is taken at holes drilled for bolting purpose.

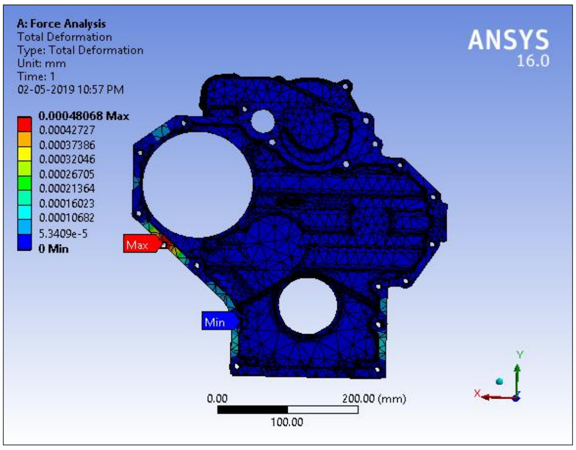

Fig.11 Total deformation in force analysis

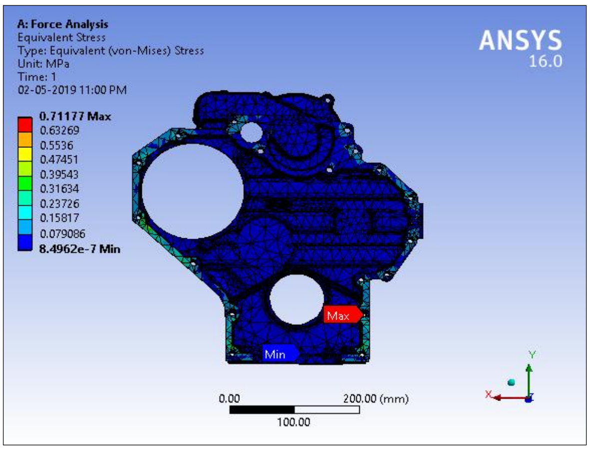

Fig.12 Equivalent stress in force analysis

From the analysis it is observed that the maximum stress acting on the gear casing is 0.71177 MPa. The tensile strength of the gear casing is 200 MPa. Also the maximum deformation in the gear casing is 0.00048068 mm which is negligible. Hence the gear casing is safe for working and is acceptable for use on oil engine.

2. Sealing analysis of the gear casing

Gear casing acts as a cover for the engine gears and other parts. It is also connected to the oil pan of the engine. The oil is circulated through the gears of engine for smooth working. Hence, the gear casing also comes in contact with oil. This oil should not leak through the gear casing. For ensuring that there is no leak of oil the sealing analysis is carried out. The major possibility of oil leak is through holes drilled for bolting when the engine is running hence sealing analysis of the bolting holes is carried out. The gear casing is fixed at the inner mounting face. Hence for analysis fixed support is given at mounting face. Every bolt is applied by 25 Nm torques while bolting process. For analysis purpose the torque is converted to the preload.

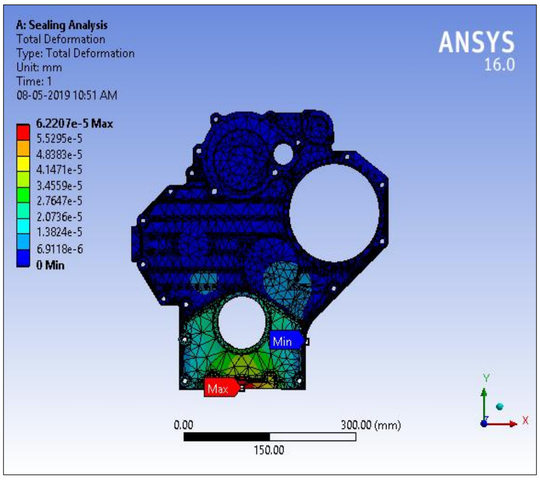

Fig.13 Total deformation for sealing analysis

From the analysis it is evident that the total deformation of the gear casing at the bolting holes is 6.2207e^{-5}, which is very negligible. Hence, the gear casing will resist any form of leakage through bolting holes after fixing on the engine and hence it is met with acceptability criteria and safe for use.

6. ON-ENGINE TESTING

After the finite element analysis of the gear casing the actual testing is done. For that the gear casing is mounted on the oil engine on assembly line. The engine is tested for a full cycle of testing and the behaviour of the gear casing is observed and the on-engine testing is carried out. The gear casing is found safe and fully functional in the On Engine testing.

7. CONCLUSION

The design and development process of the gear casing gives about 540 grams of the weight reduction in the process. The weight optimization of the gear casing reflects in the cost reduction of Rs. 2, 17,080 per year. The reduction in the allowances on the casting of the gear casing also causes decrease in the machining cycle time.

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