TECHNICAL NOTE

QUALIFICATION OF COMPRESSOR IMPELLER FOR AERO-ENGINE APPLICATION

R. Ragupathy, Wg Cdr (Retd) Simon K John
Scientist
Regional Centre for Military Airworthiness, Engines
CEMILAC, HAL, Engine Division
CV Raman Nagar
Bangalore-560 093, India
Email : ragu.ur@gmail.com

M. Esakki Muthu
Manager, ETBR & DC
Hindustan Aeronautics Ltd
CV Raman Nagar
Bangalore-560 093, India

Abstract

This paper presents the approach for qualification of indigenously developed compressor impeller for aero engine application. Indigenisation is understood to be the most important tool for effective technical empowerment of a developing nation. Indigenisation philosophy is adopted by several countries in various fields such as power, infrastructure, aerospace, military equipments and etc. Indigenous development fills the technical, financial and time frame gap between imports and ab-initio design and development. Hence, for a healthy technical growth of any developing nation, Indigenous development activities should go along with ab-initio design activities. Indigenous development has become an integral process of activities of Defence sectors due to its potential benefits. Indian defence imports stands at staggering 65 % of the total defence acquisition. In order to make the best use of indigenization opportunities in the defence sector, conservative figures would suggest an amount more than 100,000 crores. This gives an indication of the potential and benefits of indigenous development in defence sectors.

In this paper a methodology for indigenous development of a military turboshaft engine compressor impeller is discussed. This activity has enabled uninterrupted supply of the component and a substantial Foreign Exchange savings.

This paper specifies the various tests conducted over the forging. It also brings out the results of cyclic spin test on the component for 22500 cycles as life substantiation, 15% and 22% over speed test as structural integrity substantiation and 150 hours type test on engine for quality and assembly substantiation.

This indigenous development procedure described in this paper can be readily extended to suitable critical aero engine component.

Introduction

Indigenous development in general terms is the transformation to suit new culture. In engineering terminology it is the localization of system design / manufacture for having economic benefits as well as self reliance. The benefit of indigenous development is well understood across the world. India has taken up strong moves of indigenous development in various fields such as power, infrastructure, aerospace, military equipments, refineries and etc. Indigenous development in these possible fields will lead to Foreign Exchange savings of several crores of rupees in addition to self reliance.

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In this paper a methodology adopted for indigenous development of a military turboshaft engine compressor impeller is discussed. This paper covers the procedure right from inspection requirements at various stages, forging, machining, life tests, structural integrity tests, type test and associated Finite Element analysis.

Indigenous Development

Indigenous development is the most important tool for effective technical empowerment of a developing nation. Indigenous development philosophy is adopted by several countries in various fields. In Defence sectors, uninterrupted supply, self sufficiency and independency are of paramount importance to ensure high degree of system readiness. If a system is a brought-out item, then multiple source of supply is required to be established which will be strategically decided. This will be a tedious and time consuming process. Developing in-house designs will really benefit in a long run but there will be an inhibition period for any new design activity. Indigenous development not only fills this inhibition gap but also provides valuable inputs for ab-initio design projects by virtue of the experiences accumulated. Hence for a healthy technical growth of any developing nation, Indigenous development and ab-initio design and development activities should go parallelly. Indigenous development has huge economical impacts; it is in the order of thousands of Crores of foreign exchange savings for a country like India. Moreover in case of brought-out items, procurement lead time will sometimes be as high as 1-2 years especially for aerospace applications. Such a procurement delay is not tolerable in defence sectors, this affects the system availability for service and can even hamper nations security. In total, indigenous development has the synergic benefits of FE savings, improved country economics, self reliance, independency, knowledge base for ab-initio design activities, improved system availability and improved national defence.

A flowchart describing indigenous development process of mechanical component is shown in Fig.1.

Component Description

The component selected for indigenous development is the centrifugal compressor impeller of a turboshaft engine powering a military helicopter. Centrifugal compressor is a critical component of engine. Earlier this part was manufactured in-house from imported forgings. These forgings have been taken up for the indigenous development. The component material is TA6VPQ. The forging prior to machining will be in solution treated and annealed condition. Stabilization treatment will be carried out in rough machined condition. The finished impeller is shown in Fig.2.

Development of Forgings and Inspection

The material is forged by a 300T press. The die block material is N.C.M steel with hardness about 350-400 BHN. The contraction allowance for die sinking is 1%. The weight of the forging is around 7 kg. The finished forging is supplied in solution treated and annealed condition. The various tests were conducted at different temperatures on the specimen cut from forging at various locations. The tests were carried out over the forging are as listed below:

- Chemical analysis
- Hydrogen content
- Fluorescent penetrant inspection (for surface defects)
- Ultrasonic inspection - contact method (for internal defects)
- Ultrasonic inspection - immersion method (for internal defects of partly machined parts)
- Grain flow test
- Micro and macro examination
- Hardness test
- Tensile test at room temperature*
- Tensile test at 300°C*
- Plain tensile on core test piece*
- Notched tensile test*
- Low cycle fatigue test at room temperature#
- High cycle fatigue test at 300°C#
- Creep test at 300°C#
- Fracture toughness

The results of all the tests specified are found satisfactory. In addition to these tests, creep tests was carried out on imported forging in order to have a comparison between imported and indigenized forgings. Indigenized forgings found to have better creep resistance compared

* Tests were carried out on 3 specimen each, for radial and tangential

Carried out on 3 specimen

to imported forgings. With these tests indigenized forgings were proved and were further taken up for machining.

Substantiation Testing of Impellers

Three impellers are machined to carry out cyclic spin test, overspeed test and 150 Hrs type test respectively. Cyclic spin test is for life substantiation, over speed test is for structural integrity substantiation and type test is for quality and assembly substantiation. A brief on these tests are as discussed below:

Cyclic Spin Test

In cyclic spin test the component is spun between max. speed and min. speed. The 100% speed of the component in engine is 33500 rpm. Since the component is allowed to over speed by 5% which is equivalent to 35175 rpm, it is considered as the maximum speed for the test. The impeller works at an elevated temperature, the exit temperature is 200°C. Facilities are not available at the test rig to simulate the elevated temperature. Hence the component is tested in room temperature at the calculated equivalent speed which takes the temperature effect on material strength into account (i.e.) the effect of temperature is compensated with speed.

Hence, equivalent speed is defined as the rpm at which the component in room temperature has to rotate in order to maintain the factor of safety equal to that of the component rotating at actual speed in elevated temperature. The equivalent speed is arrived at through 3-D FEM non-linear static stress analysis using ANSYS v11.0 software package.

Finite Element Analysis

The equivalent speed is estimated based on the equivalent stress approach. Initially, stress analysis was carried out for 105% speed of impeller with engine operating conditions (component's hot temperature conditions). Then Factor of Safety is calculated with respect to 0.2% PS. A second analysis is carried out with room temperature and the equivalent speed is obtained with the above Factor of Safety with respect to the earlier analysis.

Loads Considered

Initial Stress Analysis : This analysis is carried out as per engine operating conditions. The loads considered for the analysis are:

- Inertia load due to rotation of Impeller at 35175 rpm (105%).
- Clamping load due to bolt torque tightening of 15 daN-m.
- Temperature gradient of 50°C at entry and 200°C at exit.
- Pressure on vanes.

Second Analysis : This analysis is carried out as per equivalent spin test at RT (Room Temperature) conditions. The loads considered for the analysis are:

- Inertia load due to rotation of Impeller at the equivalent speed of 37100 rpm(110.7%) corresponding to the FS of first analysis.
- Clamping load due to bolt torque tightening of 15 daN-m.
- Pressure on vanes.

Material Properties

Density : 4.42 g/cc
Poisson's ratio : 0.3

Young's modulus and co-efficient of linear thermal expansion for different temperature levels are provided in Table 1.

Table-1 : Material Properties for FE Analysis

Temperature	20°C	100°C	200°C
E, MPa	106000	101538	96154
$\alpha \times 10^6/°C$	9.0	9.5	9.8

Results

FEM analysis is carried out for both cases and von Mises stress plots are shown in Fig.3 and Fig.4.

The max stress from the above Von-Misses Stress plots and Factor of Safety values for both the cases are highlighted in the following Table-2. This shows the match in factor of safety based on which equivalent speed is taken.

The equivalent speed is found to be 37100 rpm to cater for a component temperature variation of 150°C to 250°C

Table-2 : FE Analysis Results

Max Speed (rpm)	Max Stress (MPa)	Max Temp (°C)	0.2% PS at Correspon-ding Temp (MPa)	F.S w.r to 0.2% PS
35175	518.27	200	750	1.45
37100	572.19	RT	830	1.45

and maintaining a factor of safety of 1.45 with respect to 0.2% P.S.

With these input, the cylic spin test cycle is defined as follows :

Speed range : 15000 rpm (min) to 37100 rpm
Dwell : 2 seconds at min. and max. rpm
Temperture : Room temperature
No. of cycles : 22500 cycles with inspection at every 5000 cycles

The number of cycles arrived at for the test is the product of total technical life of the component and cyclic exchange rate of 2.5. The inspections had been carried out at 5000 cycles and it multiples. As part of the inspection, balancing of the component in rig assembled condition and component growth had been assessed along with microscopic crack if any. On completion of cyclic spin test of 22500 cycles the component was found to be satisfactory vide the inspections carried out.

Over-speed Test

As a part of the procedure for indigenous development, it is necessary to prove the structural integrity of the component by subjecting it to two over speed tests equivalent to 115% and 122% of the design speed. This 115% and 122% were derived for ensuring the factor of safety over 0.2% P.S and UTS respectively. Each test should be carried out for duration of 5 minutes. After 115% speed test, the permanent growth if any, in the component shall not impair its normal operation in the engine. After 122% speed test, permanent deformations are allowed but there shall be no bursting of the component and no evidence of imminent failure.

115% and 122% works out to 38525 and 40870 rpm respectively at engine operating conditions. With FEM analysis using ANSYS software mentioned above, the equivalent speeds at room temperature conditions are found as 44000 and 46600 for 115% and 122% respectively. After the test, inspection were carried out with respect to the same parameter checked during cyclic spin test. The result of the inspection were satisfactory.

150 Engine Hrs Type Test

Besides satisfactorily completing rig level tests on the impeller, the type test was conducted on the engine. The type test is primarily for quality and assembly substantiation of the impeller on the engine. The type test cycle is of 150 hours, it comprises of 25 cycles each of 6 hours duration. The type test cycle devised is shown in Fig.5.

In addition to this cycle, engine was run at 115% of engine speed for 5 minutes with temperature equal to that of maximum output at 33,500 rpm. After the completion of 25 cycles/150 hrs, the impeller was subjected to dimensional inspection and crack test and found satisfactory. With this exercise, the impeller was completely substantiated for type certification.

Conclusion

Through this paper, the definition and advantages of indigenization are discussed. Requirement of indigenous development for a developing nation has been emphasized. A generalized procedure for indigenous development of mechanical components is presented. The centrifugal compressor indigenous development activities including development, manufacturing and testing as per the test schedules are discussed. Based on the test results, the component was cleared for part life which will be reviewed for increment subsequently based on the component sampling data after the first overhaul. Moreover, this activity has resulted in a substantial Foreign Exchange savings.

This procedure described in this paper can be readily extended for indigenization of suitable critical aero engine component.

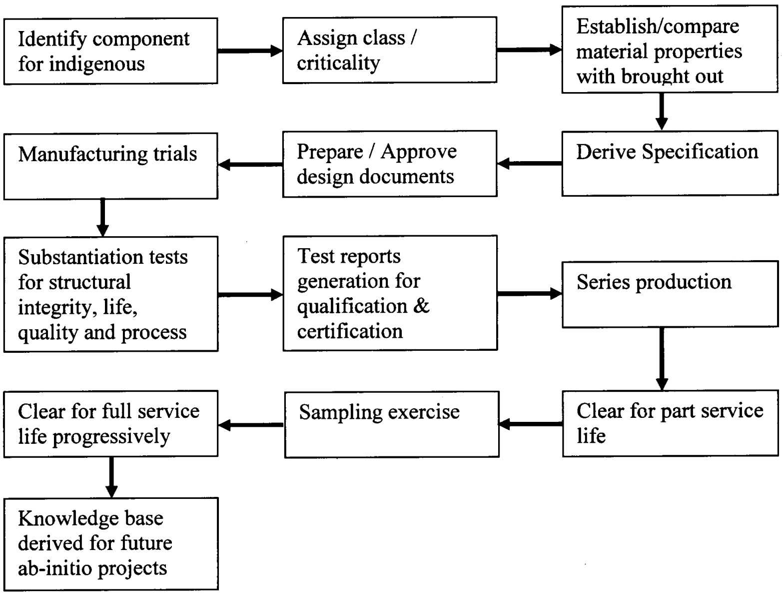

Fig.1 Path for Indigenisation for a Mechanical Component

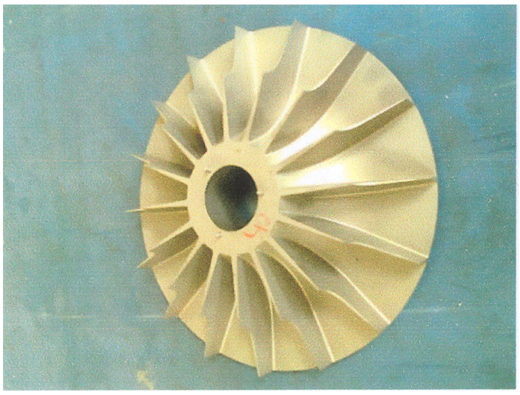

Fig.2 Centrifugal Compressor Impeller

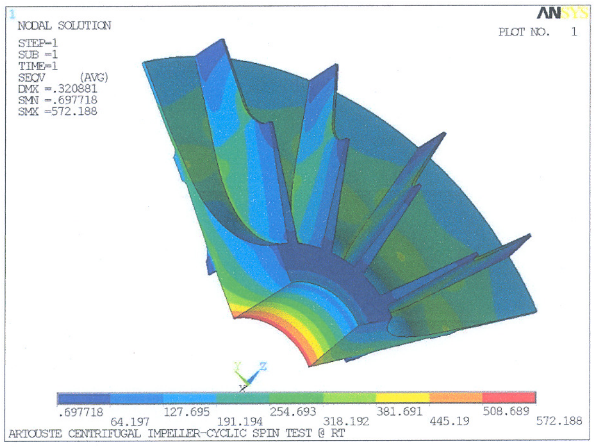

Fig.4 Von-Misses Stress Plot of Impeller at 110.7% RPM at Room Temperature (RT)

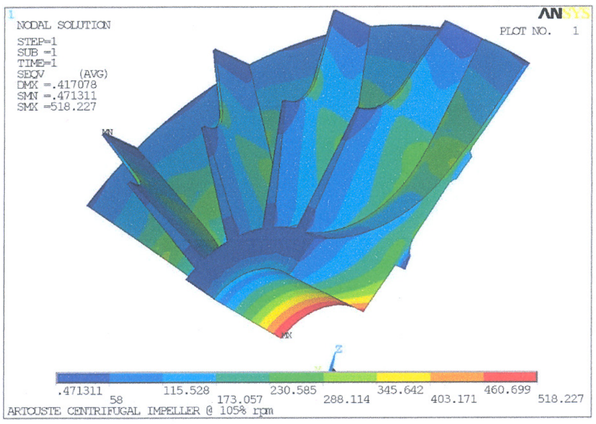

Fig.3 Von-Misses Stress Plot of Impeller at 105% RPM at Operating Temperature (Max. 200°C)

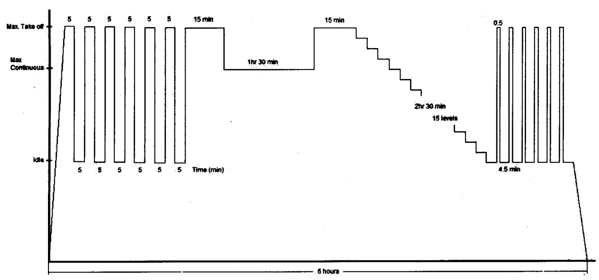

Fig.5 Type Test Schedule