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Explosion Proofness Testing of Fuel System of an Aero Engine

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***Abstract* - Explosion proofness test is one of the very important tests to qualify the fuel system as airworthy system. Test facility was not available in India to carry out this test, Foreign vendors were demanding huge amount of money to conduct this test. Considering the necessity, criticality and economic aspect, efforts were made to create this facility in India. Finally, the rig was set up in India and the test has been completed satisfactorily. This has saved huge amount of Foreign Exchange (F.E.) and also provided the technical expertise and exposure to representatives of different agencies involved/participated in this test.**

This paper describes the purpose of test, test conditions; pass/fail criteria, salient features of rig set up and its working principle, calculation of n-hexane quantity for all test conditions, experimental determination of ignition energy for various altitudes, comparison of experimental and theoretical curves for ignition energy and details of units subjected to explosion proofness test.

Keywords: Explosion Proofness, ignition energy, n-hexane, main chamber, sample chamber, Line Replaceable Unit (LRU) and Fuel System.

1. INTRODUCTION

Fuel System of an aero engine is being designed and developed by Hindustan Aeronautics Limited, Lucknow in collaboration with Goodrich Engine Control System, United Kingdom. Regional Centre for Military Airworthiness, Lucknow is the airworthiness certification agency for the same. It consists of Hydro-mechanical and electrical sub-assemblies which are operated by DC/AC power. Fuel system is located on engine and surrounded by fuel vapour laden atmosphere.

There is a possibility that when electrical subassembly of units operate it may generate a spark of such intensity which can ignite the surrounding air-fuel mixture.

Explosion Test consists of two sub tests i.e. Explosion Strength Test and Spark Ignition Test. In this paper details about spark ignition test have been discussed.

2. PURPOSE

Explosion Proofness Test is performed on fuel system (HMS) to "demonstrate its ability to operate in flammable atmospheres without causing an explosion. This test also intended to identify any 'hot spots' available in electrical sub-assemblies which can ignite the surrounding air-fuel fixture.

3. TEST CONDITIONS

Fuel System LRUs of an Aero Engine were tested to cover full flight envelope [1] of a light weight combat aircraft i.e. ground level, 20,000ft, 40,000ft and 60,000ft at 150 degree ºC temperature in stoicheometric mixture of N-hexane in a chamber. N-hexane is used as test fuel because it has similar inflammable properties as ATF.

4. PASS/FAIL CRITERIA

When unit operate in air-fuel vapor atmosphere in main chamber for 5 numbers of times at different altitude conditions, there should not be any explosion in the main chamber. However, when same spark energy is given to sample chamber containing same mixture as in main chamber, mixture should explode.

5. FUEL SYSTEM OF AN AERO ENGINE

Fuel System is driven by the high speed spool of the engine through gearbox. system provides dual stage pumping, control & meter the fuel delivery for both the Main System and Reheat System of the engine for all altitude conditions. Fuel system comprises of following six LRUs.

- First Stage Pump
- Low Pressure Filter
- Main Engine Control Unit
- Reheat Fuel control Unit
- Reheat Distribution & Purge Valve
- Dump Valve

Last two units do not have electrical sub-assemblies; hence these units were not subjected to this test.

6. DETAIL OF TEST SET UP

Test rig of explosion Proofness test consists of following main sub-assemblies as shown in Fig.1.

6.1 MAIN TEST CHAMBER

The main test chamber consists of a static cylinder with hemispherical movable lid mounted on MS frame. The volume of the test chamber depends on the size of the unit to be tested. The main chamber outer periphery is insulated with rock / glass wool (or equivalent) to prevent heat loss. Ports / vents have been provided for pneumatic electrical connections. Viewing ports are also provided for observation of flame inside the chamber during testing. Test Units are kept in this chamber during testing.

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6. 2 SAMPLE CHAMBER

A sample chamber of appropriate capacity is provided in the circulation line. The chamber is also provided with viewing port for observation of flame inside the chamber. A spark plug is fitted inside this chamber for igniting the air / fuel mixture to ensure that mixture is flammable.

6. 3 HEATING SYSTEM

The main chamber has 16 heaters of 2KW each rating powered by 3-phase power supply. These heaters & temperature controllers are embedded in the main chamber to maintain the uniform temperature of 150° C.

6. 7 VALVES

Two Relief Valves, one on main chamber and second on sample chamber are provided. Pressure setting of these valves is 4 bars (safetypurpose). Four isolating valves (S1-S4) are provided for isolating the main chamber from rest of the system while testing the LRU's. These valves also utilized while determining the minimum spark energy in sample chambers. These are pneumatic valves and can also be operated manually in emergency.

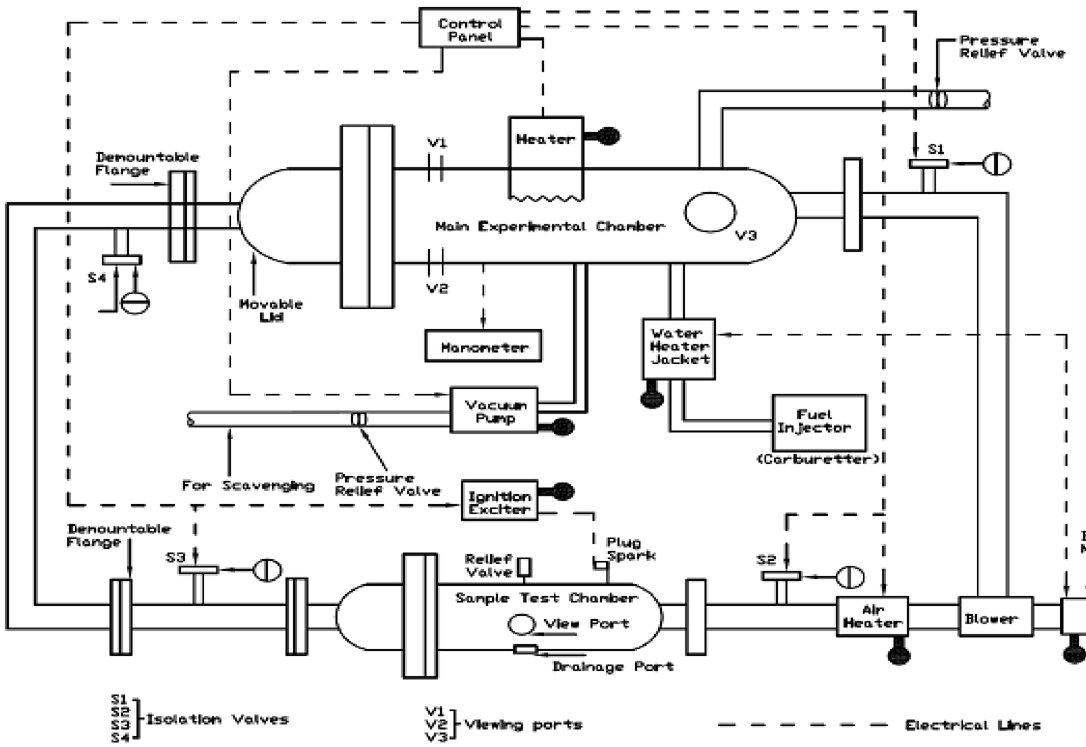

Fig. 1 Schematic of Explosion Proofness Test Set Up

6. 4 AIR CIRCULATION SYSTEM

Air circulation is provided by rotary drum blower coupled with a 500W motor. Circulation rate is 50 l/sec.

6. 5 VACUUM PUMP

A rotary vacuum pump [2] of 900l/min capacity is provided for reducing the pressure in the main chamber & rest of the system. Pump is capable of reducing the system pressure up to 70 mm of mercury. It is capable of reducing the chamber pressure to the required level**.**

6.6 FUEL INJECTION

Fuel is injected through carburetor system. Needle valves [3] regulate the quantity of air and fuel. Outlet of the valve is connected to the main chamber by a short length of pipe, which is surrounded by water jacket provided with a heater. The measured quantity of fuel is fed into the needle valve through funnel mounted on the system.

6. 8 PRESSURE GAUGES

Two Bourdon tube type pressure gauges are mounted on the main chamber. One gauge enables chamber pressure measurement during the depression in the range from 0-760 mm. Second gauge from 0-5 bar is provided to indicate the pressure built inside the chamber during the explosion.

6.9 CONTROL PANEL

The power supply for test facility is fed from a 400V AC, 3 phase system. The control panel controls the power for, Main chamber, sample chamber heaters, Air heater, heater for water jacket, blower and vacuum pump.

6.10 TRIP PULSE UNIT (TRIGGER)

A Trigger [4] unit capable of generating variable voltage from 0-10,000 DC Volts to create the spark energy and provision for variable add on capacitance with

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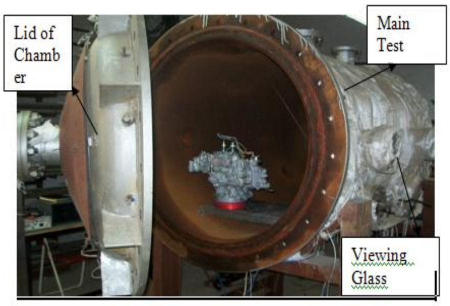
voltmeter indication is a part of the test facility. This unit is capable of generating spark energy of the order of 100 Joules. Schematic of full test set up is shown is Fig. 1.

7. WORKING PRINCIPLE

After making electrical connections the unit is kept in main chamber and door of chamber is closed. Vacuum is created in the chamber with the help of vacuum pump. After achieving required pressure, heaters are switched on to achieve 150 degree C temperature in the chamber. Once required temperature and pressure achieved, the rig is ready for filling the n-hexane in the chamber. After closing all relief valves, calculated quantity of n-hexane is admitted in the test chamber with the help of funnel and needle valves. When full quantity of n-hexane is admitted in the chamber, the needle valve is closed and relief valve is opened. Mixture of air and n-hexane is circulated in main chamber and sample chamber with the help of blower to make the mixture homogenous. After circulating the mixture for 3-4 minutes the blower is switched off and relief valves are closed. In this way mixture of air & n-hexane is confined in sample chamber and main chamber.

Now electrical supply is given from outside to unit kept in main chamber for operating the electrical sub-assemblies in air- fuel mixture atmosphere. Each sub-assembly is operated for five times to assess that there is no spark generated in the unit. After checking the operation of the unit, the spark of known energy is given from trigger unit to sample chamber for ensuring that the mixture of air & n-hexane is



UNIT IN TEST CHAMBER

Fig. 2

inflammable. Description of Test facility with Unit in test chamber is shown in fig. 2.

After familiarization with test set up, next step is to calculate the fuel quantity with respect to each altitude for making the stoicheometric air-fuel mixture in the test chamber.

8. CALCULATION OF N-HEXANE QUANTITY

Following formula is used for calculating the fuel quantity of n-hexane [1] required for different altitude conditions.

Where

Q: Volume of n-hexane in ml

V: Volume of Main Chamber in litre

P: Pressure (pascal) in main chamber with respect to altitude.

T: Temperature of main chamber in degree Kelvin i.e. 150+273= 423K

γ : Specific gravity of n-hexane [5] = 0.66

$$Q = 396 \times 10^{-6} \times \frac{V \times P}{T \times \gamma} \quad (1)$$

By application of (1) fuel quantity is calculated by substituting the pressure values with respect to each altitude, result of the same are summarized in table 1 below.

TABLE 1

SN	Test Conditions	Qty of n-Hexane
1.	3,000ft	285ml
2.	20,000ft	146ml
3.	40,000ft	59ml
4	60,000ft	22.7ml

After determining the quantity of fuel to be admitted in test chamber with respect to each altitude condition, next step is to calculate the ignition energy required to ignite the mixture with respect to each altitude condition.

9. DETERMINATION OF IGNITION ENERGY

To determine ignition energy required to ignite the air fuel mixture (for different altitude conditions) is one of the herculean task of this test. Because ignition energy required for igniting the air and n-hexane mixture can not be calculated theoretically. Hence, a numbers of experiment have been carried out to find the ignition energy of air fuel mixture with respect to each altitude.

Ignition Energy[6] generated by Trigger Unit to ignite the mixture of sample chamber is expressed by:-

$$E = 1/2 \times CXV^2 \quad (2)$$

Where C: Capacitance, V: Voltage

By combination of C and V values the different energy levels were generated and supplied to ignite the mixture. The value of ignition energy at which air fuel mixture ignited was found for each altitude. Four experimental values were obtained for each altitude. The same is tabulated below.

TABLE 2

Sl. No.	Test Condition	Energy level			
		Exp1	Exp2	Exp3	Exp4
1.	3,000ft	0.30J	0.32J	0.52J	0.39J
2.	20,000ft	0.4J	0.56J	0.6J	0.58J
3.	40,000ft	0.70J	0.75J	0.80J	0.78J
4.	60,000ft	2.2J	2.1J	2.0J	1.8J

Trend of ignition energy Vs altitude is shown in Below.

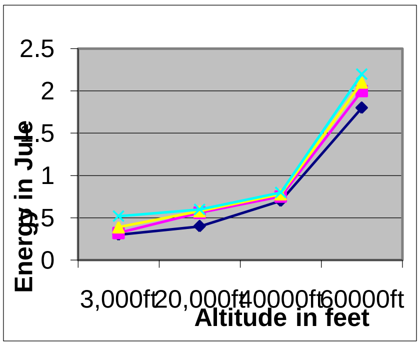


Fig. 3 Exp. Ignition Energy Vs Altitude

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As per above curves ignition energy is increasing with increase of altitude, this shows the resemblance with standard curves for ignition energy Vs altitude curves.

10. TESTING OF FUEL SYSTEM LRUs

After making the electrical connections in the unit, the unit is kept in the main chamber and lid of the main chamber is closed. N-hexane is admitted in the main chamber and homogeneous mixture and altitude condition is produced as discussed in working principle of test set up. Unit is electrically operated 05 times at all altitude conditions from outside side and explosion is viewed in main chamber through glass. No explosion is observed.

Ignition energy is supplied to sample chamber for igniting the air-fuel mixture. It is to be noted here that experimentally determined ignition energy is utilized to ignite the mixture in the sample chamber. For safer side the highest ignition energy found by experiment for each altitude is used during testing. When this energy supplied to sample chamber the mixture ignited, this proved that mixture in the main chamber is inflammable. Same process is repeated for all four altitude conditions.

Ignition energy used during testing for various altitude is shown in graph below.

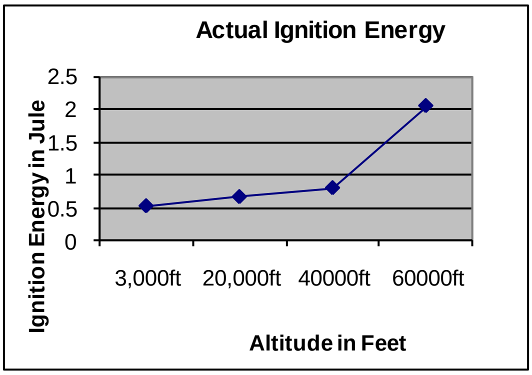

Fig.4 Ignition Energy Vs Altitude

11. CONCLUSION

During testing of fuel System LRUs no explosion took place in main chamber. However same mixture in sample chamber was exploded when ignition energy is supplied to it. This proves that mixture used in testing is inflammable and unit is not generating spark of such energy which can ignite the mixture in the main chamber. This satisfied the acceptance criteria of test requirement. Fuel System of an aero engine demonstrated the ability to operate in flammable atmosphere without causing an explosion.

This test has been done on Fuel System for the first time in India. Successful completion of test has saved huge amount of FE. Experience gained by various agencies will be very useful for conducting such type of critical test in future.

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