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Reliability and Quality Assurance Experience in Launcher Hold and Release System used in GSLV

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ABSTRACT

The launcher hold and release system (LHRS) was successfully used, for the first time, for GSLV-D1 mission after thorough test and evaluation, in line with reliability and quality assurance (R&QA) requirements. Various R&QA techniques are applied to make LHRS failure-free. Failure mode effect and criticality analysis (FMECA) was used as a tool for identifying critical failure modes. Single-point failure modes (SPFMs) identified from FMECA are strengthened by design modifications and the same are verified by testing. Testing philosophy is tailored to have more number of tests at the system level. Capability demonstration tests and failure mode simulation tests were carried out during system qualification phase. Acceptance tests are done on the flight hardware at launch pad to demonstrate better confidence on the system. This paper illustrates how R&QA techniques complimented and added value at different stages in the development cycle of LHRS, by means of few case studies. Testing methodologies adopted and problems encountered during the development and qualification phases are described in brief. Various problems surfaced during preparation for flight are also discussed.

Keywords: Launcher hold and release system, system reliability, quality assurance, GSLV, single-point failure modes, strap-on motors, failure mode effects and criticality analysis, FMECA, reliability and quality assurance, R&QA, geosynchronous satellite launch vehicle

1. INTRODUCTION

The geo-synchronous satellite launch vehicle (GSLV) has four liquid motors strapped to the solid core motor. As per the lift-off sequence, the strap-on motors are first ignited and their performances verified before the core motor is ignited. Disturbances like surface wind and failure of any one or more strap-on motors to build-up thrust will destabilise the vehicle on the launch pad. The launcher hold and release system (LHRS) is used to hold the vehicle in stable condition against all kinds of disturbing forces. The launch computer releases the hold by LHRS after confirming satisfactory perf ormance of the strap-on motors. The core motor is ignited only after confirming LHRS release.

The LHRS is designed and qualified by the Aerospace Mechanism Group of VSSC with the support of various agencies. The LHRS was successfully used, for the first time, for GSLV-D1 flight. The LHRS is made up of four hydraulically actuated release mechanisms with its associated instrumentation system. The release mechanism works on the collet-grip principle. It is actuated by a multiple redundant hydraulic system, which is based on accumulator circuit. The instrumentation system is used for system health monitoring, issue of release command, and to obtain confirmation of release. Failure or malfunction of any one or more of the components/subsystems can cause the launch to be aborted or can be catastrophic to the mission. It can also cause damage to the launch pad.

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2. SYSTEM DESCRIPTION

The LHRS is basically made up of four release mechanisms, a multiple redundant hydraulic system and an instrumentation system. The mechanisms are symmetrically oriented on the launch pedestal. They are interfaced with the longerons of vehicle core base shroud. The mechanism has a collet with a number of concentric fingers. The fingers are deflected radially inwards by drawing it through a sleeve (designed to work as a piston also) to grip over the tapered surface of a shaft. The collet is connected to the base of the unit and the shaft is connected to the vehicle core base shroud. A pretensioning nut on the shaft preloads the mechanism. The pre-loaded mechanism is released by moving the sleeve/piston by hydraulic power. The piston movement allows the collet fingers to move radially outwards and assume their natural position so as to release the grip over shaft. A disc spring stack pulls up the shaft. A pictorial view of the mechanism in assembled condition is shown in Fig. 1.

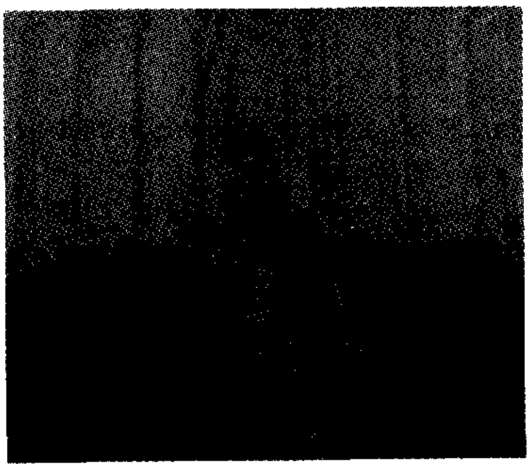

Figure 1. Mechanism assembly

The hydraulic system has two independent chains, each having a bank of accumulators as stored power source. A hydraulic powerpack with an air-operated pump, relief valve, filters and associated components charges both banks of accumulators and also fills the pipelines connecting the mechanisms. The accumulator pressure is isolated from the mechanism by cartridge valve-soleniod valve logic. Energising the solenoid valve allows the cartridge valve to open. The high pressure oil from accumulators flows to the mechanism and moves its piston. The hydraulic system works on blowdown mode. Figure 2 presents the hydraulic system schematic. The hydraulic system is so designed that actuation of any one solenoid valve, out of the four solenoid valves provided, will ensure release of all mechanisms. This provides four levels of redundancy in actuating elements and two levels of redundancy in pipelines.

The instrumentation system is used for measuring/monitoring parameters representing (i) system health (ii) mechanism-release process (iii) confirmation of release, and (iv) interfacing with launch computer system. During launch operations, all LHRS-related commands are issued directly from the automatic launch sequence program running in the launch computer system.

3. RELIABILITY TOOLS

Failure mode effects and criticality analysis[1] (FMECA) was used during different phases of LHRS realisation. The FMECA made at each phase focused on the single-point failure modes (SPFMs). The SPFMs identified were either eliminated through design modification or through extensive testing to confirm adequacy of design margin and also to eliminate doubts on the system functioning. The FMECA for LHRS was accomplished in two ways, namely, the hardware approach and the functional approach. The hardware approach of FMECA basically analyses the potential failure possibilities of individual hardware items. This is a bottom-up approach. This study helps to identify the weak links that have to be strengthened with alternate routes or change in the component type. The hardware approach was followed in LHRS in the initial phase of system design and component selection.

The functional approach recognises that every item is designed to perform a number of functions

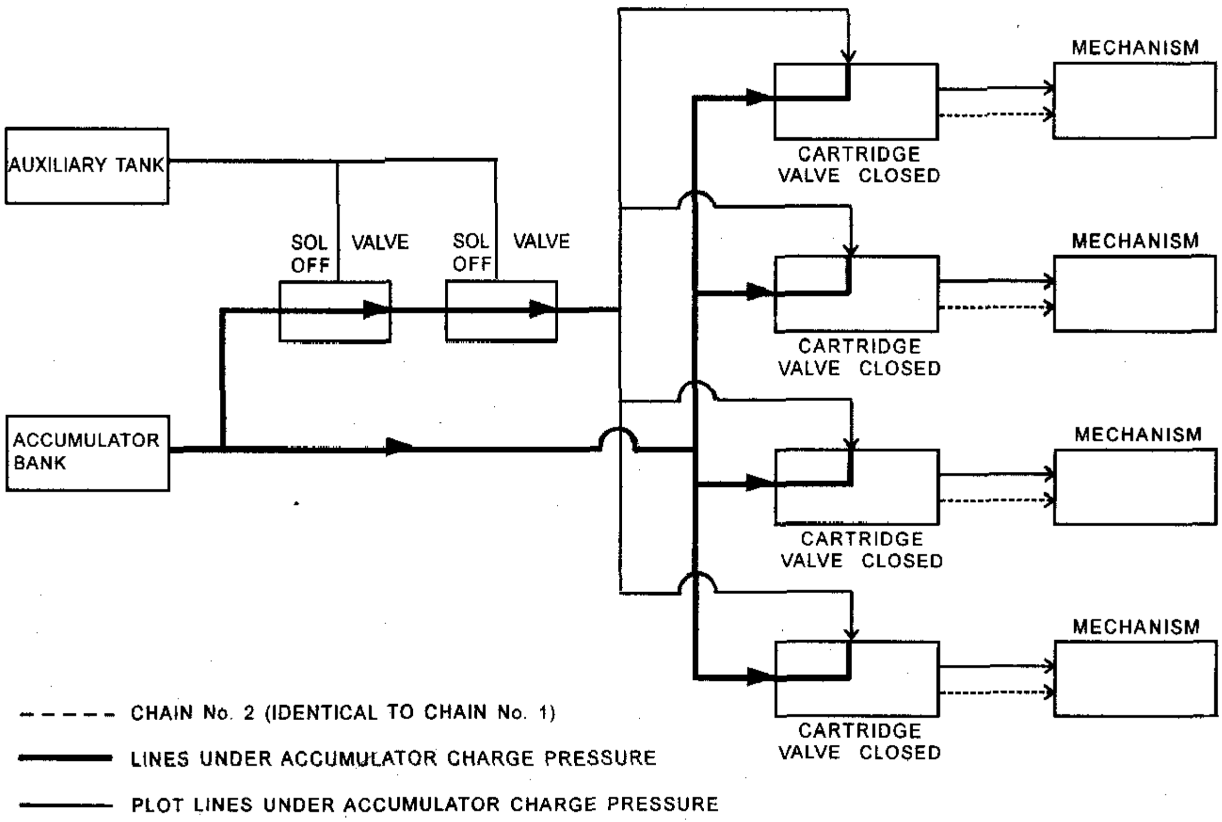

Figure 2. Schematic of hydraulic system

that can be classified as output. This approach was adapted in the testing phase to build confidence in the system. In this regard, testing was done at sub-assembly or system level. Special attention was given to the area that may cause SPFM, leading to system/mission failure.

4. TESTING PHILOSOPHY

The tests were planned to demonstrate the reliability requirements specified for LHRS, based on the GSLV mission reliability specifications. The reliability requirement of LHRS was 0.98658, which calls for 68 cycles of tests to meet the system-level reliability.

Mechanism was designed, fabricated and tested in-house, whereas hydraulic components were procured from reputed industries. Hence, it was decided to carry out limited-screening tests on the hydraulic components/modules and full-fledged system-level tests to meet the reliability requirements.

4.1 Testing Methodology

Tests for system development and qualification were planned as

(a) Screening tests on components/modules

(b) System-level tests to demonstrate the reliability requirements. These tests include failure mode tests, capability demonstration tests, and off-nominal condition tests

(c) Environmental tests, namely, acoustic and vibration tests on functionally critical components

(d) Functional test simulating one chain alone, along with strap-on engine test, to verify functioning of LHRS in the actual service environment

4.1.1 *System-level Tests*

A simulated test rig was setup at the laboratory to carry out all system-level development and qualification tests. This was followed by a series of tests at launch pad with actual vehicle interface.

Following are the types of tests done at system level.

- Normal configuration with two chains and four release valves, load and pressure nominal
- Off-nominal conditions with one/two chains and one/four release valves, load and pressure varied
- Failure mode simulation with one chain, one release valve
- Capability demonstration with a reduced number of accumulators, drain valve kept open

5. SYSTEM-LEVEL TESTING–PROBLEMS ENCOUNTERED

A number of problems were encountered during system-level testing. Two such problems have been described as case studies 1 and 2.

Case Study 1

The FMECA study has pointed out that the environment generated by firing of strap-on engines can cause failure/malfunction of LHRS. A functional test of LHRS in the strap-on engine firing environment was hence recommended. To meet this, a functional test of LHRS, simulating one chain alone was carried out along with one of the strap-on engine hot test. This test was successful. It proved the robustness of design, particularly the release mechanism. In addition to the above test, the mechanism and solenoid valve were qualified for the predicted acoustic and vibration levels of strap-on engine firing for an extended period of 60 s. These tests were very useful to avoid a last minute vibration test which otherwise would have to be done to qualify for the higher peak vibration levels recorded during the first launch attempt.

Case Study 2

The LHRS system was configured with two chains having independent power sources. Check valves isolated the chains. A leak in the check valves makes the independent chains connected causing loss in chain-level redundancy. The FMECA pointed out that a combination of: (i) external leak in any of the field joint or components and (ii) leak in check valve can lead to a system failure. This was suggested to be verified by testing.

During failure mode simulation testing, i.e. simulation of total external leak in one chain, it was observed that the pressure in the alternate chain also was being reduced. Chain isolation was hence modified by putting zero leak cone seated solenoid valves, two numbers in series for redundancy, in between the chains.

6. FLIGHT EXPERIENCE

During the flight phase, two problems were cropped up. These were:

- During system preparation for launch, one accumulator showed oil trace causing an increased drop of accumulator pressure. After detailed analysis, it was decided to go ahead for the flight. This decision was based on the acceptance test data obtained from the functional acceptance testing of the LHRS at lower bound accumulator pressure conducted at the start of launch campaign. The LHRS system worked satisfactorily, holding the vehicle during the first launch attempt.
- Vibration levels recorded at the LHRS mechanism and solenoid valve locations during the first launch attempt were higher than the levels qualified earlier. This higher g-level was for a short duration. After detailed analysis, the system was cleared for second launch attempt on the basis of the environmental qualification test carried out for an extended period of 60s on the suggestions based on FMECA findings. During the second launch attempt, the system worked successfully in releasing the hold.

7. CONCLUSIONS

The following concluions have been drawn:

- Detailed FMECA analysis and updating the same at each phase of design focusing on SPFM aids to refine the design and the testing methodology. By this, troublesome features are either eliminated or their impact on system functioning verified by extensive testing.

- The carefully planned system-level tests with various simulated failure modes and capability demonstration testing, give additional confidence on the reliable functioning of the system.
- Thorough investigation of failures and anomalieshelp to improve the reliability and quality of the system.

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