Keynote Speech

Vibro-Engineering in Armaments

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Extended Abstract

High Energy Materials (HEMs), including propellants, explosives and pyrotechnics are the energy behind defence systems, particularly armaments (Ammunition, Rockets, Bombs, Missiles, etc.). Performance of almost all the armament systems, is significantly dictated by the type of HEMs being used. In almost every step during the life-cycle of HEMs (*processing, testing, transportation, deployment, etc.*), vibration engineering is associated and assumes a vital role in performance of overall systems. For instance, vibration casting for propellants and explosives, resonant acoustic mixing of propellants and pyrotechnics, oscillations of test bed in static evaluation of rockets, acoustic and non-acoustic combustion of propellants inside rocket motors, recoiling of gun during the firing of guns, generation of pressure waves in gun chamber during combustion / projectile motion etc., vibration remains an omni-present factor, influencing the product quality, performance, life and reliability. Hence, a thorough understanding of vibro-engineering is therefore essential in order to tame, generate, augment, support, modify, obstruct, optimize, various steps in the complete development Life-cycle of the HEMs, from cradle (*production of HEMs*) to saddle (*launch pad*) to grave (*disposal*).

Solid rocket propulsion is commonly used in defence systems owing to various advantages such as simplicity, low cost, etc. On the other hand High Explosives are also processed through similar routes but additionally include the melt-casting method. Processing of these HEMs includes essential steps of slurry mixing, casting, curing, performance testing, life assessment, environmental testing etc.

Composite solid propellants and Polymer Bonded Explosives (PBXs) are realized by high shear mixing in the form of thick slurry with viscosity in the range of 10 kilopoise. Currently, these HEMs are mixed in vertical planetary mixers (VPM), in which high shear is generated by co-rotating planetary moving blades. Recent advancements leading to design of a Resonant Acoustic Mixing (RAM) has the potential to change the entire dynamics of propellant mixing. It generates the required mixing patterns and flow, using acoustic waves. This mixer is essentially an engineering artifact resulting from the considerable developments in the field of vibro-engineering.

During propellant / high explosive slurry casting, induced vibration (excitation) of the rocket motors (or moulds) is widely used in order to obtain a high-quality (*void-free*) propellant grain / casting (*under various other rigid engineering constraints such as casting time*). Excitation points and parameters are properly controlled in order to obtain the desired modes leading to supported flow of slurry in tight corners, crevices and low cross section spaces inside a rocket motor / warhead / bomb.

However, once performance evaluation is attempted, the vibration as Good Samaritan changes role and becomes a demon to be controlled, mitigated and obviated. For the evaluation of processed qualified rocket motors, static testing is generally conducted and oscillations of thrust block may lead to significant changes in the obtained thrust time profile. Similarly, piezo-electric sensors in blast gauges used in static testing of High Explosives (bombs/warheads) also produce erroneous results due to ground excitation of sensors caused by the explosive blast. Means to mitigate such vibrations by applications of proper vibration isolators and application of filters during signal processing has been implemented. This effect is detrimental to the test set-up, as well as for the rocket motors / systems.

One of the major problems, being tackled at all fronts by the rocket scientists is Combustion Instability (CI). It is basically, oscillatory combustion wave superimposed over steady-state combustion pressure, which alters burning rates and may result in catastrophic consequences. Various factors e.g., rocket motor configuration, propellant characteristics, etc. can cause combustion stability during the operation of rocket motor. Combustion Instability studies are a specialized branch of vibro-engineering which deals with the investigation of various aspects related to the cause and methods to suppress the same while being limited within a variety of system / design constraints in a rocket motor. Attempts of suppressing combustion instability by adding aluminium of different particle size, changing cavity dimensions of solid propellants, changing throat area, altering propellant burning surface area, etc are reported. However, various analytical (mathematical) and experimental methods of investigations such as FFT, modal analysis, etc. form a part of such studies.

These rocket motors / systems are transported to the theatre / storage mostly by road. Nevertheless, any mode of transport, subjects the system to various levels of vibration which can even lead to system excitation resulting in structural failure or initiation of cracks, de-bonding if resonating conditions are attained. Use of suitable vibro-mounts and vibration-isolators is essential in order to control such un-intended excitations which fall in the gamut of vibro-engineering.

Under deployment, vibration acts as the biggest challenge for the system designer as it leads to excitation of systems due to various reasons. These include either induced or generated vibrations. Vibration from the platform (Induced: aircraft, tanks, etc.) or due to its own vibrations (Generated: wing/fin flutter etc.) or due to its operation (Generated: Recoil in guns generated due to firing of ammunition). These engineering considerations are made during the design and testing of the systems in order to ensure optimum performance and safety.

Controlled Vibrations can be used to produce a desired action and Un-controlled vibrations can lead to catastrophic failures. With particular emphasis on HEMs, a detailed vibro-engineering study of HEM based systems, considering various aspects and constraints (*e.g., non-rigid body dynamics in case of propellant / high explosive grains*) is of prime concern and often a major challenge.