EXPERIMENTAL AND THEORETICAL STUDIES ON FUEL SLOSHING IN AUTOMOTIVE FUEL TANKS

Abstract of the Thesis

Submitted by

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ABSTRACT

Sloshing is the free surface motion of liquid in a partially filled container. During liquid sloshing, free surface waves interact with container walls and develop hydrodynamic pressure and moment. These parameters affect the dynamic stability of liquid containers. Understanding the behaviour of free surface of liquid at various excitation conditions of tank is very important in the design of liquid container and fuel tank for automotive, marine and space vehicles.

In automobiles, fuel sloshing inside a fuel tank creates noise, structural vibrations and increases the fuel vapour formation which affects the performance of automotive fuel systems. The fuel inside the tank is subjected to violent motion during acceleration, braking of the vehicle and while travelling on rough terrain. Baffles, floating mats and lids are used inside the fuel tank by many investigators in order to suppress the free surface motion of liquid.

An extensive literature review shows that free surface motion of liquid was analyzed for regular geometric shapes of tank such as rectangular, cylindrical and spherical. Since very few studies only available to understand the fuel sloshing in automotive fuel tanks, a systematic study is taken up in this work to analyze the behaviour of free surface of liquid in the fuel tank under uniformly accelerated motion and sinusoidal motion of the tank.

This study is divided into two phases. In Phase I, a mathematical equation is developed to predict the position of free surface of liquid in a uniformly accelerated rectangular tank. The dimensional analysis is performed to identify the conditions that need to be met for complete similitude between the model and the actual fuel tank. Based on the similitude relations, length and acceleration scales are arrived to study the liquid sloshing in the fuel tank by applying uniformly accelerated motion. The numerical simulations of free surface motion are carried out using ANSYS FLUENT solver and Volume of Fluid (VOF) technique is used to track the liquid-air interface. Influence of fill level and position of baffles on elevation of liquid free surface are analyzed numerically. Experimental setup is developed to study the effect of uniform

acceleration on liquid sloshing in fuel tank. The results of mathematical equationand numerical simulations are validated with experimental results.

In Phase II, the behaviour of free surface of liquid is analyzed by applying sinusoidal motion to the tank. Influence of fill levels, position of baffles and excitation frequencies on elevation of free surface of liquid are analyzed numerically. Experimental setup is developed to study the effect of sinusoidal motions on liquid sloshing in fuel tank. The results obtained from numerical simulations and experimental studies are compared with the solution of analytical equation available in the literature. The regression equations are developed to represent the influence of excitation frequency and liquid level on elevation of free surface of liquid in the fuel tank. From this study the following points are highlighted as conclusions.

The free surface motion of liquid in a uniformly accelerated tank is numerically predicted using VOF technique. The profiles of free surface obtained from numerical simulation are comparable with that of the experimental studies. The slope of free surface of liquid obtained by numerical simulation is in good agreement with that of the solution obtained using analytical equation. Further, it is noticed that, the slope of free surface of liquid inside the tank remains the same at stable position for the various liquid levels.

When the vertical baffles are introduced inside the fuel tank, it reduces the effective length of the tank and restricts the horizontal motion of free surface waves which subsequently reduces the amplitude of elevation of free surface in a uniformly accelerated tank. However, slope of the free surface remains the same irrespective of number of baffles inside the tank.

When a 50% filled tank is subjected to sinusoidal motion with excitation frequency of 0.5 Hz and 0.6 Hz, a standing wave is initially formed which is then converted into travelling wave. At an excitation frequency of 0.7 Hz, the standing wave is converted into two travelling waves and these waves collide with each other. The results also show that, magnitude of free surface elevation increases when the excitation frequency is increased. The elevation of free surface of liquid obtained from numerical simulations and experimental studies are compared with the solution obtained using analytical model available in the literature.

The free surface motion of liquid in tank with one baffle is analyzed for 25%, 33%, 50% and 60% fill levels. It is observed that for all the fill levels only standing wave is formed which oscillates back and forth and there is no travelling wave formed. Further, the magnitude of elevation of free surface decreases with increase in fill levels. This is due to the increase in mass of liquid, which absorbs the disruption applied to the tank.

On the basis of dimensional analysis, regression equations are developed to find the elevation of free surface of liquid for the given fill level and excitation frequency applied to the tank. Introduction of vertical baffles inside the tank helps in restricting the horizontal component of wave motion and in absorbing the kinetic energy of the liquid waves. Thus, elevation of liquid free surface is significantly reduced.

This study provides useful information to understand the liquid sloshing phenomenon in a fuel tank at different liquid levels and operating conditions of vehicle. As mentioned earlier most of the studies in this area were carried out for standard shapes of liquid containers whereas this work has been carried out in a fuel tank which is used by leading automotive manufacturer. Hence the results are realistic which will be more useful for efficient design of automotive fuel tanks.