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A method for sizing noise protective unit design features

Pavel A. Popov[a]*, Roman V. Zimnyakov[b], Alexander A. Igolkin[b]

[a]*Joint Stock Company Space Rocket Centre Progress, Zemetsa, 18, Samara, 443009, Russian Federation*
[b]*Samara National Research University, Moskovskoe shosse 34, Samara 443086, Russian Federation*

Abstract

The purpose of this paper is to develop a sizing method to decide the best design features of a noise protective unit (NPU). The method of "inverse matrix" was used to assess the local acoustic pressure drop when a wave goes through the multi-layer shell of the NPU. Solutions of the wave equations were used in each of the layers taking into account: 1) the incidence angle of the sound waves and the layer loss factor; 2) the input boundary conditions establishing the equality of the normal components of particle velocity and acoustic pressure at medium borders; 3) the system of algebraic complex equations and corresponding matrix equations. The telemetric information obtained during a real launch was processed by means of specially developed software. A novel method of sizing the best design features for a noise protective unit makes it possible to reduce vibroacoustic loads on spacecraft to acceptable levels. The comparison of the data calculated using this method and the experimental data showed their good agreement. The devised method appears to have considerable promise when developing new launch vehicles able to protect spacecraft from noise and vibration. At critical frequencies the levels of acoustic pressure decreased by half to two thirds.

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Keywords: launch vehicle, noise protective unit, acoustic pressure, noise and vibration, "inverse matrix" method, loss factor

1. Introduction

One of the most important tasks of product design in rocket and space technology is to perform vibrodynamic tests of its design. At this design stage, the frequency characteristics, strength properties and transfer functions of the

* Corresponding author. Tel.: +7-846-228-96-42; fax+7 -846- 992-65-18.
E-mail address: banduir@rambler.ru

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launch vehicle (LV) or spacecraft are tested [1, 2]. To develop the modes of vibration and acoustic stress on the structure elements, some conventional methods are used. However at increased stress levels it is necessary to find the ways of their reduction. The spacecraft acting as a payload [3, 4] should be protected against noise and vibration. Thus, when adapting a LV to particular spacecraft (SP), the designer sets forth rigid requirements as for the sound pressure level (SPL) depending on frequencies (especially 31.5 Hz, 63 Hz, 125 Hz).

The comparison of the design SPL for the spacecraft and the one measured SPL for NPU on the other payloads is shown in table 1.

Table 1 – Sound pressure levels

f, Hz	31.5	63	125	250	500	1000	2000
L, dB	Design SPL for adaptable spacecraft						
	126	128.8	131.8	132	130	125	122
	SPL of LV without damping material						
	132	130	135.1	128.6	120	117.6	114.2

One of the ways to improve noise protective properties of sound-proof structures is application of polyurethane foam (PUF), which characteristics are thoroughly considered in TsAGI (Central Aerohydrodynamic Institute) technical reports (not available in an open access). Installation of additional load (for example another spacecraft) imposes further mass restrictions on PUF. A well-known impedance method for determining sound-insulating characteristics of a multilayer structure was presented by Bogolepov, Kudisova et al [6, 7, 8]. However, previous research in this field disregarded the direction of acoustic waves propagation and their incidence angle. Damping properties of thin-walled shells were presented in [5, 8, 9, 10]. These studies do not take into account the case of a partial covering of the NPU with PUF. In this paper a novel method of sizing the best design features for a noise protective unit is introduced. The proposed method makes it possible to reduce vibroacoustic loads on spacecraft to acceptable levels. The "inverse matrix" method was used to assess the acoustic pressure drop when a wave goes through the multi-layer shell of the NPU, taking into account the properties of the shell in each of the layers, the shell radius, the angle of incidence of the acoustic waves and the loss factor.

Consequently, to identify the sufficient surface area of NPU by PUF with minimal weight loss and following the design requirements, it was necessary to develop several mathematical models.

2. Nomenclature

NPU – noise protective unit,
LV – launch vehicle,
SPL – sound pressure level,
PUF – polyurethane foam,
IC –initial condition,
SAC –sound absorption coefficient,
S_1, S_2 – joint areas for different NPUs,
J, *I* – SPL intensity,
φ –angle of incidence
S_i, S_k, – areas of local irregularities on surfaces 1 and 2;
R_i, r_k – sound absorption coefficient (SAC) of local irregularities;
R_0,– SAC of surface without damping material,
R_{SI} – SAC for area S_{SI}, which should be select.
S– NPU 98KS surface area;
S_{20}, S_{120},– areas with 20mm and 120mm damping material coating thickness;
R_{20}, R_{120} – 98KS SAC with 20mm and 120mm damping material coating thickness;
s_{20}, s_{120}, r_{20} – the same for NPU 17S13;
r_{140} – 17S13 SAC with 140mm damping material coating thickness.
IC – initial condition