Applied and theoretical mechanics.

DISTRIBUTED DYNAMIC ABSORBER FOR CONTROLLING STRUCTURE BORN NOISE IN INFRARED IMAGER

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INTRODUCTION

New tactics of carrying military and antiterrorist operations calls for a development of a new generation of sophisticated portable infrared (IR) imagers for spotting an opponent force independent of night or day, even with heavy camouflage. The superior performance of such imagers is achieved by using novel optronics along with cooling the IR sensors down to the cryogenic temperatures (77K typically) using closed cycle integral rotary driven Stirling cryogenic engines [1]. Since such devices may sometimes be used in a close proximity to the opponent force (e.g. thermal weapon sights, hand-held and ground-based IR cameras), their overall performance is defined not only by their low weight, bulk and power consumption but also, and primarily, by their aural stealth.

Achieving the desired level of aural stealth within tough bulk and money budget is a challenging task. As a matter of fact, even the best examples of “should-be silent” IR imagers appear to be quite acoustically detectable from as far as 50m away.

Typical cryogenically cooled IR imager comprises an optical train (telescope), evacuated envelope (Dewar) containing focal plane array (FPA) thermally connected to the cold finger tip of a cryogenic engine, and accompanying electronics mounted upon an optical bench or, sometimes, for the sake of bulk and weight saving, directly upon a package enclosure.

Stirling cryogenic coolers which find wide use in such imagers typically comprise two major components, these are: compressor and expander [1,2]. The reciprocating motion of a compressor piston provides the required pressure pulses and the volumetric reciprocal change of a working agent (helium, typically) in the expansion space of an expander. A displacer, which is located inside a cold finger, shuttles the working agent back and forth from the cold side to the warm side of the cooler. During the expansion stage of the thermodynamic cycle, heat is absorbed from the cold finger tip (cold side of a cycle), and during the compression stage, heat is rejected to the ambient from the cold finger base (hot side of a cycle).

In fact, such cryogenic engines comprise numerous movable components, the mechanical motion of which produces essentially wideband vibration export. Since the cooler is normally rigidly mounted upon the optical bench or even imager enclosure, having finite stiffness and showing numerous undamped resonances over the wide frequency range, the above vibration export is further easily translated into the resonant structural vibration and then into the acoustic noise, the spectrum of which comprises specific resonant peaks correlating closely with the frequencies of the above structural resonances. From experience, even silent cryogenic engine may produce quite a lot of aural structure-born noise when mounted upon wrongly designed and resonating optical bench or enclosure.

Suppressing the above structural resonances is possible (however, to a particular extent only) by using free or constrained layer damping treatments, where damping occurs as a result of the cyclic tensile or shear deformation of the damping layer [3,4]. The performance of those approaches, though, is not sufficient since the above deformations are relatively small and not all types of structural vibration necessarily cause the desired sort of deformation in the damping layer.

The authors propose novel approach to solving the problem of structure-born vibration and noise by combining the spreadable free damping layer and the principle of wideband dynamic absorption. In this approach, the so-called distributed wideband absorber is formed by a visco-elastic layer (e.g. soft silicon rubber) which is spread over the primary system and in which the plurality of lumped bodies (e.g. small metal balls) is embedded. The favorable damping effect in such a system occurs due to the energy dissipation taking place as a result of a vibration-induced motion of the above lumped bodies and their dynamic interaction with their “neighbors” and the primary system through the visco-elastic layer.

As a practical application, the authors consider suppression of the vibration and noise levels produced by the Integrated Dewar Cooler Assembly (IDCA) mounted upon the vibration isolated optical bench of the IR device. The performance of vibration and noise control is discussed based on the experimental results.

EXPERIMENTAL RIG

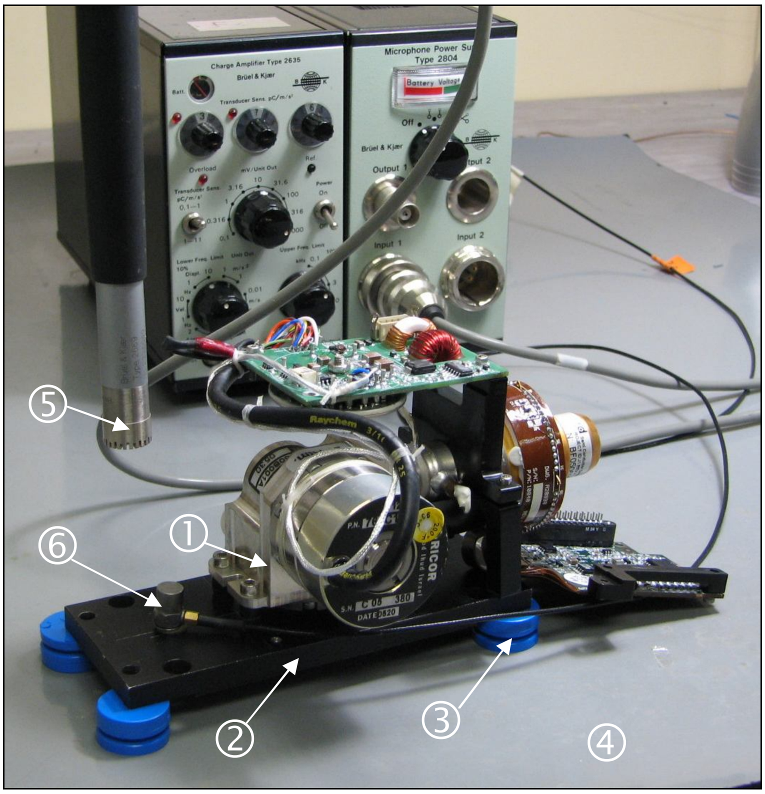

Figure 1

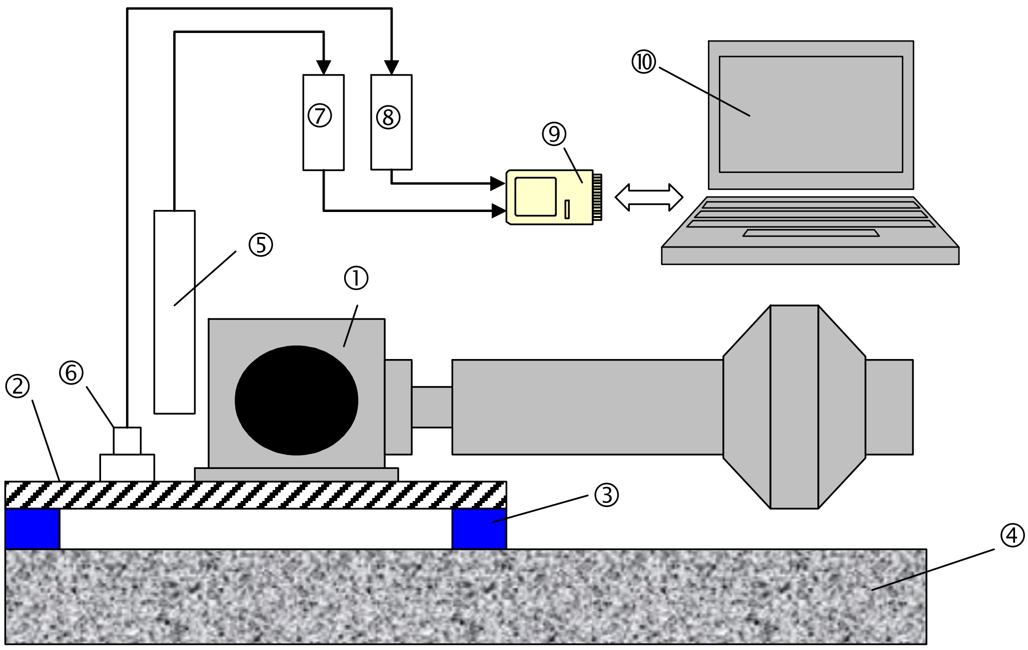

Figure 2

In the present study, the IDCA comprising the Ricor's K560 integral rotary driven cryogenic engine was used. Figure 1 and 2 show the experimental rig and its schematics, where the above IDCA ① is mounted upon the optical bench dummy ②, supported from the stabilized table ③ by four vibration isolating mounts ④.

Noise and vibration levels are monitored using microphone Type 2669 ⑤, miniature accelerometer Type 4393 ⑥, charge amplifier Type 2635 ⑦ and microphone amplifier Type 2804 ⑧ (Bruel & Kjaer). The ACE Signal Analyzer (Data Physics) and the notebook ⑩ are used for A/D conversion and signal analysis.

RESULTS OF EXPERIMENT

EXPERIMENTATION WITH ORIGINAL OPTICAL BENCH

Figures 3 and 4 show the spectra of vibration and sound pressure levels (SPL) produced by the IDCA driven in a close loop mode. Both spectra in Figures 3 and 4 show specific peaks corresponding to the resonant frequencies in the frequency range up to 10 kHz.

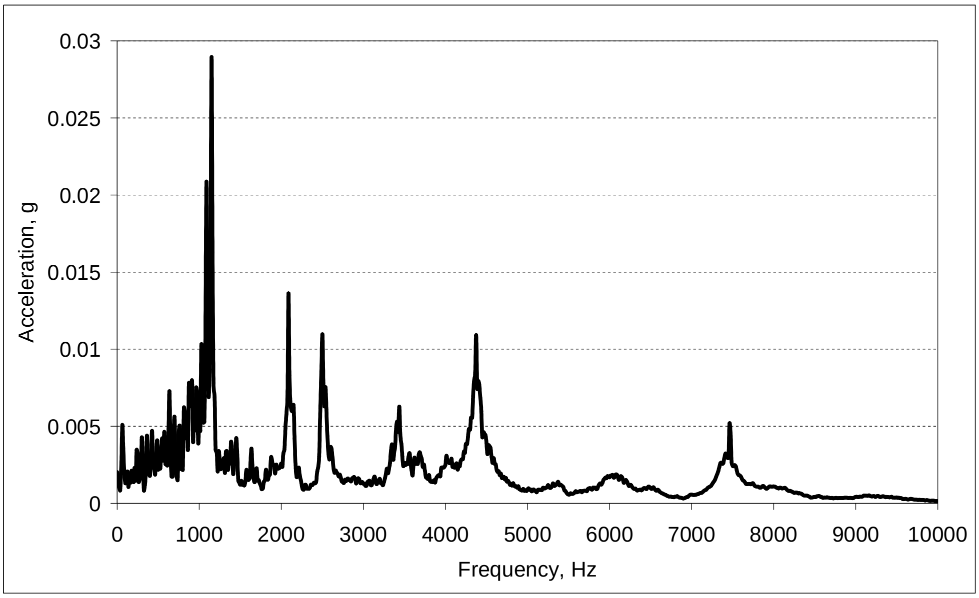

Figure 3

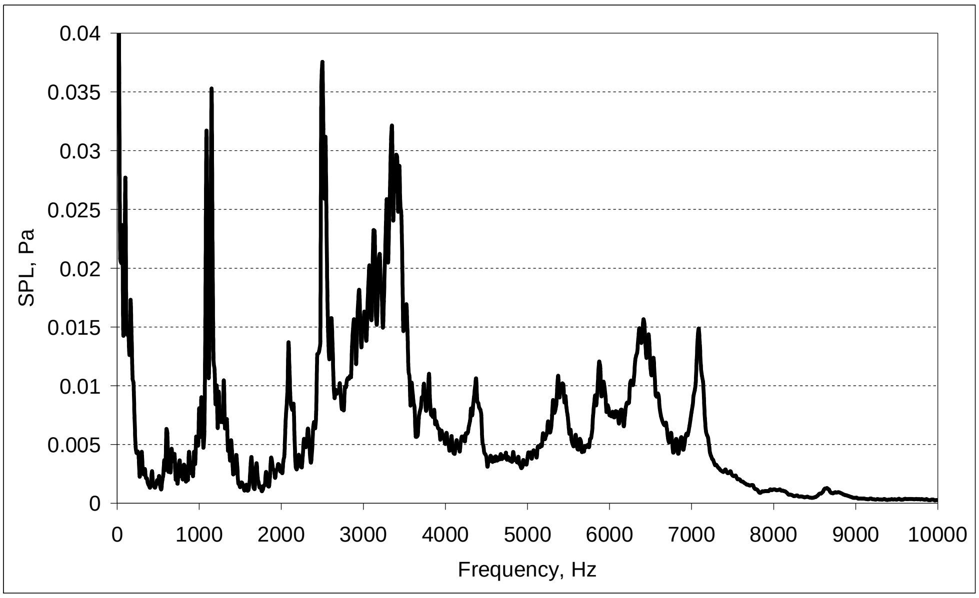

Figure 4

EXPERIMENTATION WITH DAMPED OPTICAL BENCH

Since the space allowed for vibration protective arrangement inside the IR imager is quite limited, the authors applied the idea of so-called distributed dynamic absorber. In this particular case, the bottom side of the optical bench was covered by a silicon layer with steel balls imbedded, as detailed in Figure 5.

Figures 6 and 7 show the performance of vibration and noise suppression attained by the distributed dynamic absorber. In particular, Figure 6 compares the spectra of vibration measured in the optical bench taken before (Ref) and after applying the absorber (Distributed absorber).

Figure 5

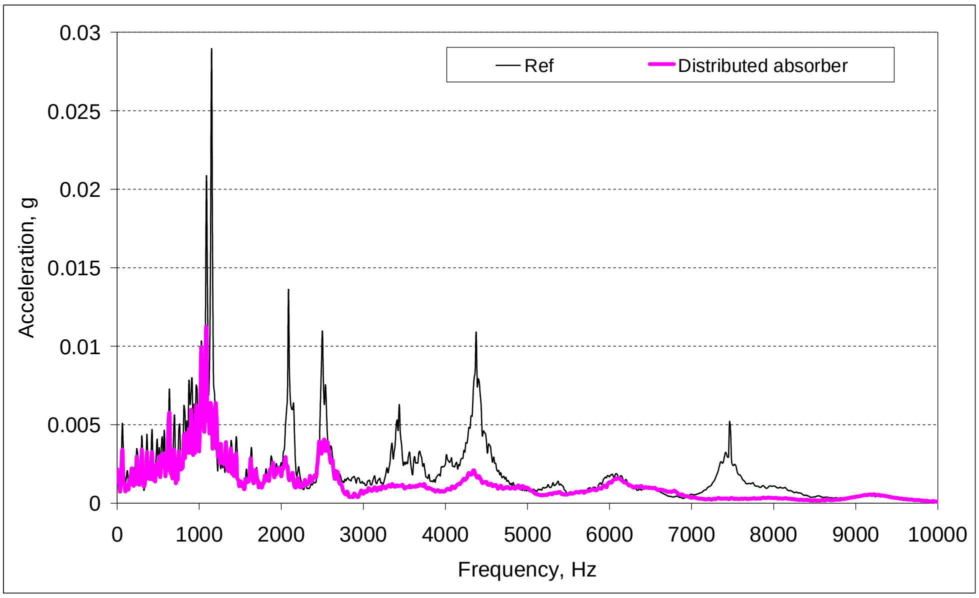

Figure 6

As seen in Figure 6, practically all the structural resonances are essentially suppressed. Similarly, Figure 7 compares the SPL spectra. From Figure 7, most of the resonant peaks are suppressed. The exemption is the frequency band 2.5 – 4.5 kHz, where, most probably, the noise is airborne radiated from the cooling engine.

It is worth noting that applying the silicon layer (with no balls) produces no visible outcome in terms of suppressing vibration and noise. Further, from experiment, the performance of the above distributed dynamic absorber depends strongly on the proper combination of balls size and silicon stiffness. This supports our assumption about the essential energy dissipation in such system is achieved through the effect of wideband dynamic absorption.

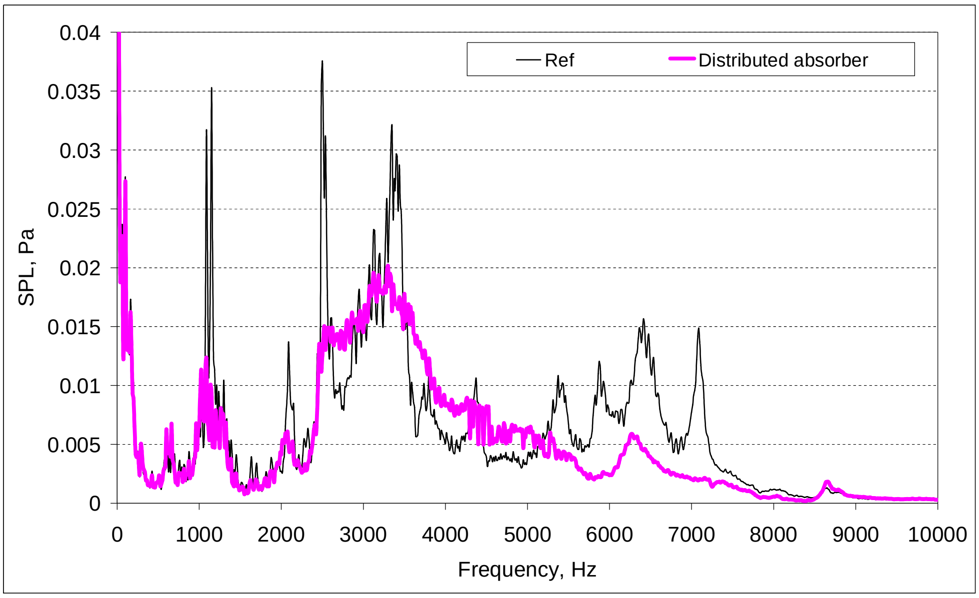

Figure 7

CONCLUSION

The novel approach to a control of structure-born vibration and noise radiation by suppressing structural resonances in the optical bench of the IR imager by using the distributed dynamic absorber is proposed and attainable performance is experimentally evaluated.

From experiment, there exists such an optimal combination of balls size and silicon layer stiffness that the structure-borne vibration and acoustic noise may be essentially suppressed over the entire frequency range.

Further efforts will be focused at developing analytical methods of analysis and optimal design of distributed dynamic absorbers.

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