ANNALS of the ORADEA UNIVERSITY.
Fascicle of Management and Technological Engineering, Volume XI (XXI), 2012, NR2

EVALUATION THE INFLUENCE OF THE NUMBER OF WINDINGS FOR A WIRE ROPE ISOLATOR IN FREQUENCY RESPONSE FUNCTION

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KEYWORDS: wire rope isolators, dynamic characteristics, vibration isolation,

ABSTRACT: Wire ropes isolators are used in many applications for vibration attenuation due to the friction phenomenon between wires. Wire ropes isolators have different response characteristics depending on the diameter and number of wires, the number of strands, number of wires, number of windings, twists. Our objective in this paper is to present de influence of the number of windings in frequency response function and in vibrations isolation. For achieving the goal has been performed measurement on the wire ropes isolators with different number of windings for determine the dynamic characteristics and behavior in operational conditions. These different wire rope isolators are mounted on exhaust line of the engine test bench for evaluating the vibration isolation characteristics in run-up conditions testing. The result will help us to define the behavior of the wire rope isolators with respect to the windings number.

1. INTRODUCTION

Wire rope isolators are used for vibration and shock isolation in aeronautic industry, automotive industry, buildings, shipboard, medical equipment, computer equipment, so on.

The construction of wire rope isolators [6] is ingenious, but still based on relatively simple design. Stainless steel wires are twisted into a cable, which is mounted between two bars. Wire rope isolators have different response characteristics depending on the diameter of wire rope, number of strands, cable length, cable twist, the number of cable per section and on direction of the applied force.

The isolators are designed to support [2] the static weight of the equipment and allow some additional amount of displacement which flexes and slides the strands of the cable against each other, dissipating friction as heat.

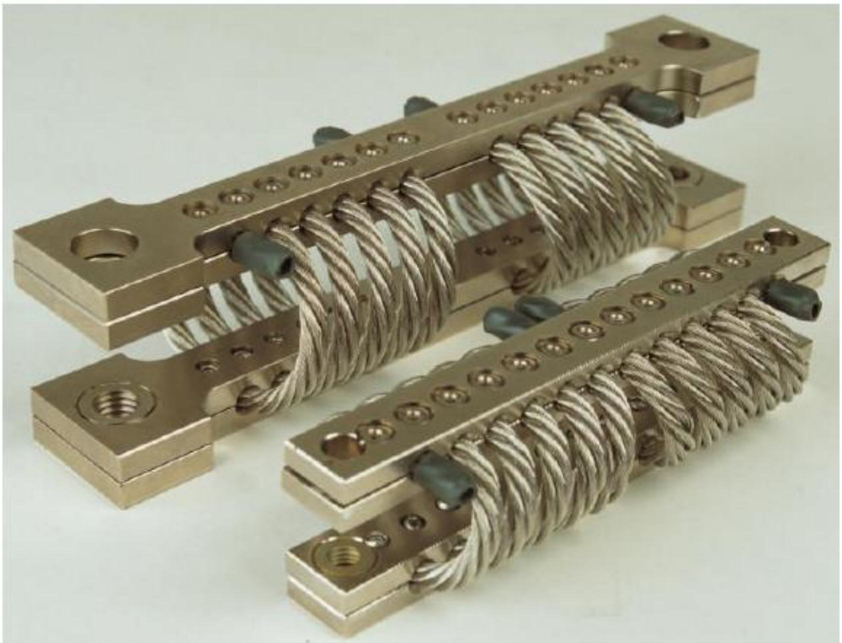


Figure 1

Wire rope isolators are full metal structure, maintenance-free and are not subject to aging due to external factors like oil, salt water, chemicals and variations in temperature. Most applications of wire rope isolators are found in situations where equipment needs to be mounted against shock or vibration, but where sound isolation is of minor importance. The other advantages of a wire rope isolator lie in the ability to combine a high level of both shock and vibration isolation, in combination with relatively small dimensions. Wire rope isolators are limited by their own construction and may for this reason be loaded in any direction without the risk of malfunctioning [7].

Wire rope isolators are a type of spring dampers that consist of stranded wire ropes held between rugged metal retainers. Due to dry friction between the different layers hysteresis occurs. This is actually the reason why the wire rope spring is such a good damping device since energy is dissipated.

The stiffness of helical spring isolators is difficult to characterize for predicting dynamic performance. The spring rate is not constant, but highly dependent on the changing geometry of the helix, the direction of loading, and the amount of preload

Wire rope isolators have between 5-20% damping [6]. The amount of damping is related to wire diameter and stroke. The larger the wire diameter, the more damped (and stiffer) the isolator. Damping can be less with small amplitude vibration

A linear system such as an SDOF or an MDOF, when subjected to sinusoidal excitation, will respond sinusoidal at the same frequency and at specific amplitude that is characteristic to the frequency of excitation. The phase of the response, in general case, will be different than that of the excitation. The phase difference between the response and the excitation will vary with frequency. The system does not need to be excited at one frequency at the time. The same applies if the system is subjected to a broadband excitation comprising a blend of many sinusoids at any given time. It is obvious that, in order to find how the system responds at various frequencies, the excitation and the response signals must be subjected to the Discrete Fourier transform. The characteristics of a system that describe its response to excitation as the function of frequency is the Frequency Response Function defined as the ratio of the complex spectrum of the response to the complex spectrum of the excitation.

The frequency response function is a tool for performing vibration analysis and testing. The objective of modal testing and vibration analysis is to identify the natural frequencies, damping ratios, and mode shapes of a structure. All mechanical and physical structures have natural frequencies. A natural frequency is the frequency at which the structure would oscillate if it were disturbed from its rest position and then allowed to vibrate freely. All structures have at least one natural frequency. Nearly every structure has multiple natural frequencies [5].

Resonance occurs when the applied force or base excitation frequency coincides with a structural natural frequency. During resonant vibration, the response displacement may increase until the structure experiences buckling, yielding, fatigue, or some other failure mechanism.

The natural frequencies can be calculated via analytical methods during the design stage. The frequencies may also be measured after the structure, or a prototype, is built. Each natural frequency has a corresponding damping ratio. Damping values are empirical values that must be obtained by measurement.

A frequency response function (FRF) is a transfer function, expressed in the frequency domain. Frequency response functions are complex functions, with real and imaginary components. They may also be represented in terms of magnitude and phase. A frequency response function can be formed from either measured data or analytical functions.

2. THEORETICAL MODEL

A frequency response function expresses the structural response to an applied force as a function of frequency. The response may be given in terms of displacement, velocity, or acceleration. Furthermore, the response parameter may appear in the numerator or denominator of the transfer function.

Consider a linear system as represented by the diagram in Figure 2 [1]:

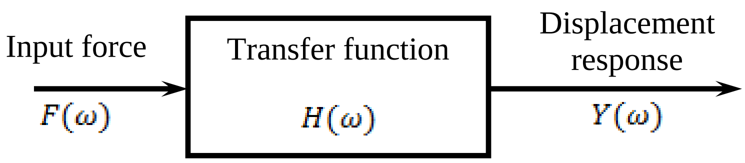


Figure 2

Where:

$F(\omega)$ is the input force as a function of the angular frequency ω□

$H(\omega)$ is the transfer function.

$X(\omega)$ is the displacement response function.

Each function is a complex function, which may also be represented in terms of magnitude and phase. Each function is thus a spectral function. There are numerous types of spectral functions. For simplicity, consider each to be a Fourier transform.

The relationship in Figure 2 can be represented by the following equations

$$Y(\omega) = H(\omega)F(\omega) \tag{2.1}$$

$$H(\omega) = \frac{Y(\omega)}{F(\omega)} \tag{2.2}$$

Similar transfer functions can be developed for the velocity and acceleration responses. Let`s consider a single-degree-of-freedom system subjected to a force excitation as shown in Figure 3. The equation of motion is given by [4]

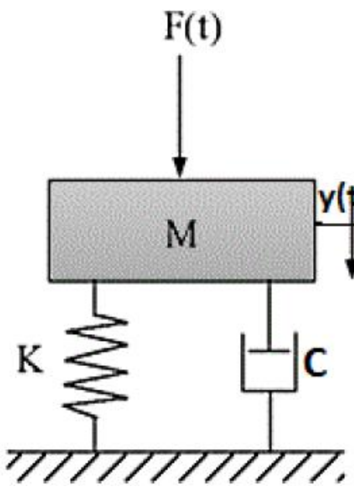


Figure 3

$$m\ddot{y} + c\dot{y} + ky = F(t) \tag{2.3}$$

Where the variable are:

m - mass of the system
c - viscous damping coefficient
k - stiffness
y - absolute displacement of the mass

$$F(t) = F\cos(\omega t) \tag{2.4}$$

Where

F– forcing excitation amplitude
ω – excitation frequency

$$\ddot{y} + \frac{c}{m}\dot{y} + \frac{k}{m}y = \frac{F}{m} \tag{2.5}$$

by convention

$$\frac{k}{m} = \omega_n^2 \tag{2.6}$$

$$\frac{c}{m} = 2\xi\omega_n \tag{2.7}$$

ω_n- natural frequency
ξ – damping ratio

$$\ddot{y} + 2\xi\omega_n\dot{y} + \omega_n^2 y = \omega_n^2\frac{F}{k} \tag{2.8}$$

The Fourier transform of each side of equation (2.8) may be taken to derive the steady-state transfer function for the absolute response displacement. After many steps, the resulting transfer function is:

$$\left|\frac{Y(\omega)}{F(\omega)}\right| = \frac{1}{k}\quad\frac{\omega_n^2}{\sqrt{(\omega_n^2 \quad \omega^2)^2 + (2\xi\omega\omega_n)^2}} \tag{2.9}$$

In many vibration problems, the primary excitation force typically has a repetitive periodic nature and in some cases this periodic forcing function may be even purely sinusoidal. Examples are excitations due to mass eccentricity and misalignments in rotational components, tooth meshing in gears, and electromagnetic devices excited by ac or periodic electrical signals. Frequency-domain considerations are applicable even when the signals are not periodic. In fact, a time signal can be transformed into its frequency spectrum through the Fourier transform. For the time being, it is adequate to realize that for a given time signal, an equivalent Fourier spectrum, which contains all the frequency (sinusoidal) components of the signal, can be determined either analytically or computationally. Hence, a time domain representation and analysis has an equivalent frequency-domain representation and analysis, at least for linear dynamic systems. For this reason, and also because of the periodic nature of typical vibration signals, frequency response analysis is extremely useful in the subject of mechanical vibrations.

3. TESTS DEFINITIONS

The measurements have been done in the engine test bench. On the exhaust line of diesel engine, with index K9K 732, was mounted three wire rope isolators types. The objective of the measurements was to analyze the impact of number of windings in frequency response functions and how changing the number of these have impact in eigen mode.

For this evaluation were choosing wire rope isolators with 3, 4 and 5 number of windings on one side which have mounted in the same position on the exhaust line replacing the original elastic element from rubber. The wire rope isolators type used for testing was:

- J4 13 – 06 G2 – 3 windings on one side
- J4 13 – 08 G2 – 4 windings on one side
- J4 13 – 10 G2 – 5 windings on one side

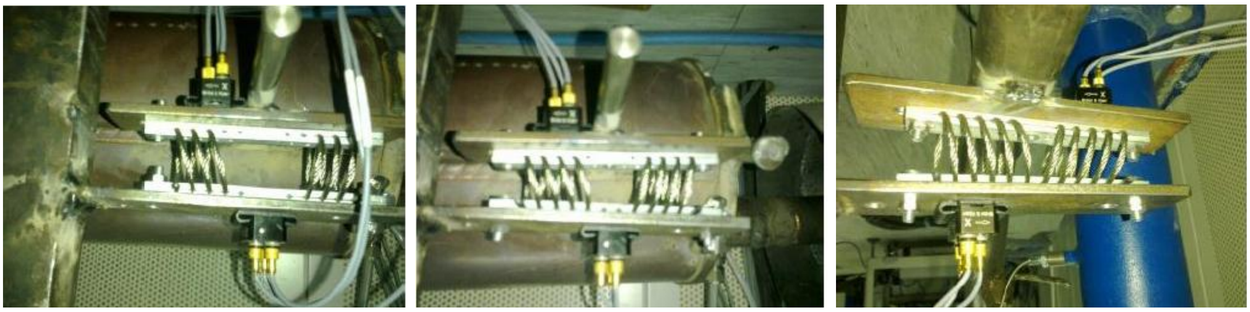


Figure 4

In measurement points was used an 3-axis accelerometer which have to evaluate the input signal into wire rope isolator in point defined ECH:01 X/Y/Z and other 3-axis accelerometer for output signal comparison in point defined RH:01 X/Y/Z. The directions corresponding to each axis are:

X – transversal axis of engine crankshaft

Y – longitudinal axis of engine crankshaft

Z – vertical axis

In additions with 3-axis accelerometers have been used an uniaxial accelerometer mounted on cylinder head on point defined CU:REF for engine for evaluating the engine functioning and excitation induced by engine in exhaust line.

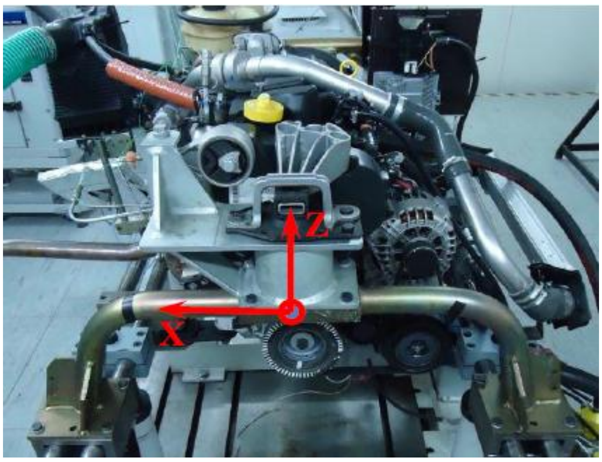


Figure 5

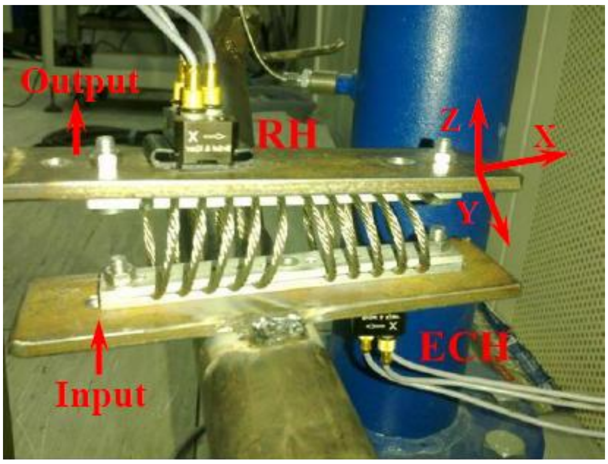


Figure 6

Vibrations measurements have been done using an LMS acquisitions systems, TestLab software and B&K accelerometers.

The acquisitions were meant to highlight the excitement of exhaust line through all speed range. This acquisition was performed under engine operational condition 950-4500 rpm, bandwidth set to 2560 Hz and 5 Hz resolution. After signal acquisitions, were made checking on temporal data for a signal corresponding to the functioning correctly and the engine. If the signal corresponds to a good measurement acquired and the signal is repeatable than is possible to prepare the post processing of acquisitions.

The wire rope isolators present good characteristics of vibration isolation and shock absorber due to the friction between wires. To emphasize these features the wire rope isolators must be install for working in the compression and the system which should be isolated system to be isolated to large amplitude of vibrations.

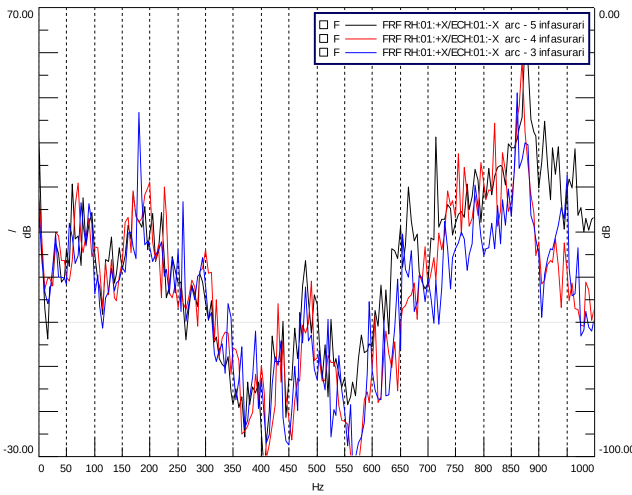
In our case, the exhaust line is suspended by elastic elements and the wire rope isolators are constrained to traction.

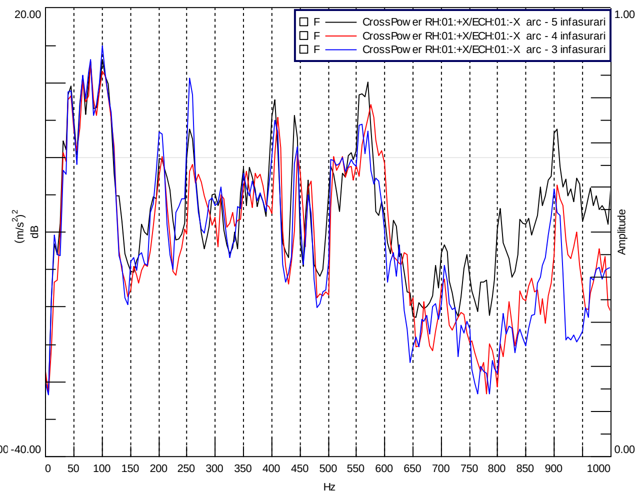
4. RESULTS

The objectives of this work were to identify the influence of a number of windings of wire rope isolators in frequency response for a specific application. The analysis followed the description of the behavior of some types of wire rope isolators with 3, 4 and 5 windings on one side in the low and medium frequencies.

The expectation of the result was to have significant modification in frequency response function according with changing the number of wining. By adding or subtracting the wire rope windings the stiffness of elastic element is changing. If the stiffness is changing the frequency response functions is modifying by default.

In the post processing of the signal acquired have obtained the frequency response function (FRF) of the system and the system response (point RH:01) reported to the input signal (ECH:01) is presented below. Because the dynamic system response measured was different from our expectations have been done a supplementary analysis (cross power analysis) between the two signals, input and output.

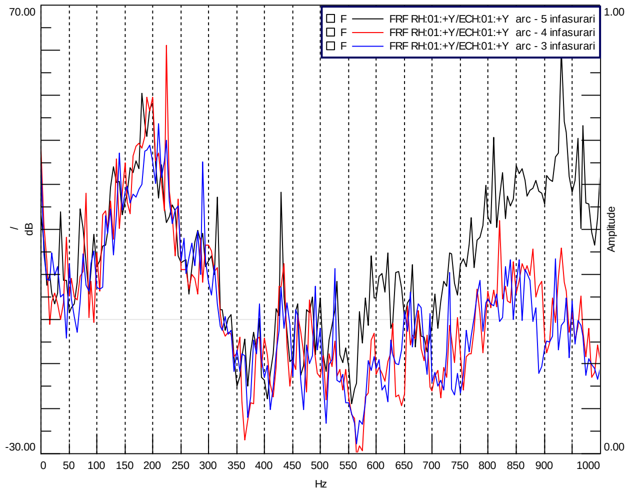


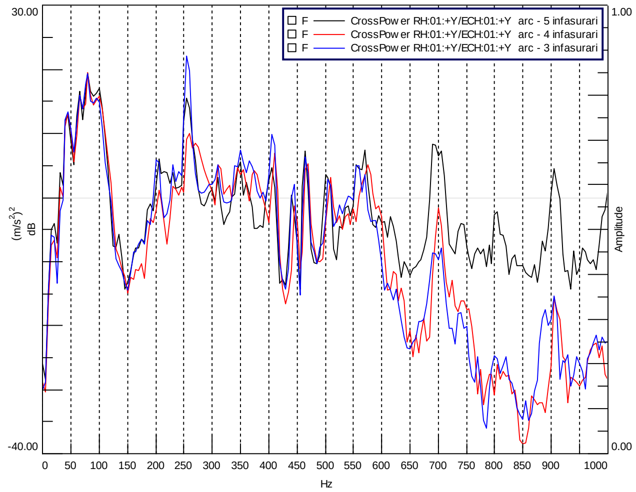


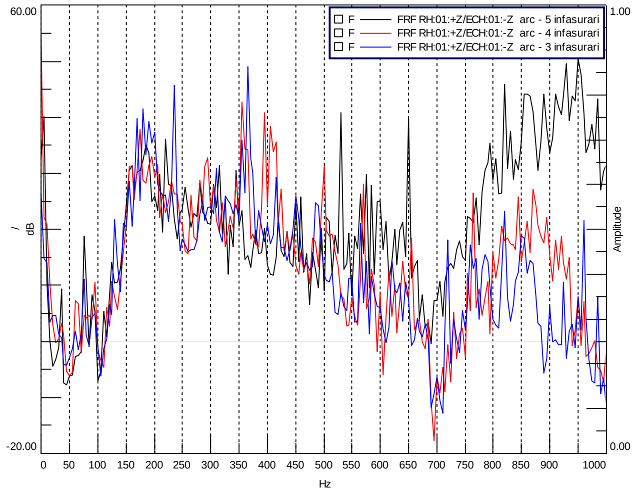
The cross power spectrum is a measure of the mutual power between two signals at each frequency in the analysis band and contains information about both the magnitude and phase of the signal. Its phase at any frequency is the relative phase between the two signals and as such it is useful in analyzing phase relationship, identifications or isolations of common signals components, operational modal analysis.

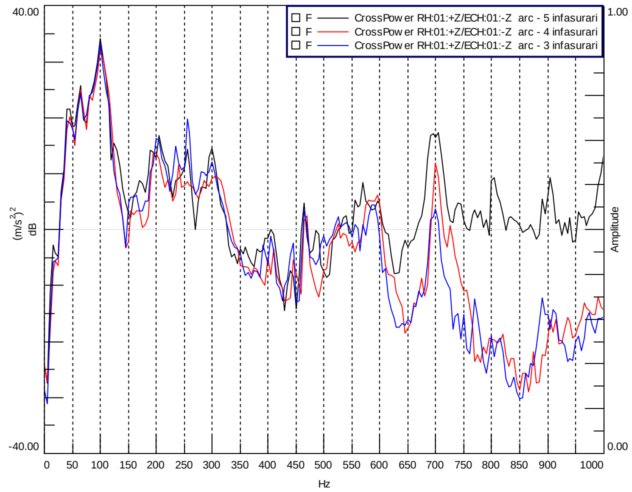
Since it is a product, it will have value when the both signal level are high, and a low value when both signals levels are low. It is therefore an indicator of major signal levels on both the input and output.

In comparison have represented on the same graphic the frequency response curves (FRF and CrossPower) corresponding to each direction in order to evaluate how the number of windings of wire rope isolators influence the response system and how it changing the eigen modes by adding and removing the windings. Graphical representation was made to the frequency of 1000 Hz and a representation of the amplitude response in dB









Frequency analysis performed on the three types of wire rope isolators indicated, contrary to our expectations, a similar behavior for low frequencies up to 300 Hz. In contrast for the medium frequencies 300-1000 Hz the frequency response curve present normal behavior according the number of windings

5. CONCLUSIONS

Wire rope isolator represents optimal solutions for shocks and vibrations attenuation. Their characteristics can be put forward if we choose ones suited for the application where they are used and fitted in order to reduce the structure displacement. Wire rope isolators present very good damping characteristics due to the friction phenomenon between the wires.

In this paper we have tried to highlight the influence of the number of windings on the frequency response. Elastic elements of wire rope have been mounted on the exhaust line of a diesel engine installed on the test bench. We have to mention that the mountings were under traction stress caused by the way the exhaust line was fitted and the displacements induced by the engine were very small compared to the ones generally absorbed by WRI.

Measurements were realized on the entire engine speed range and the accelerometers installed in the mounting points of the exhaust line assessed excitation values that enter the exhaust line and the ones transmitted through elastic elements to mountings and to the vehicle body. The acquired signal analysis have pointed out frequency response of wire rope isolators with 3, 4 and 5 windings for the low and medium frequency range

By changing the number of windings and thus change the elastic element stiffness, our expectations regarding the three types isolators was to find their eigen modes and different behaviors for all low and medium frequency range. Reality set of measurements showed an almost identical frequency response of these elastic elements. These results are done due to the particular aspect of installation and application that have been used. On the one hand the wire rope isolator was set to work in traction, so the exhaust line under its own weight pulled the elastic element. On the other hand induced displacements engine exhaust line were small compared with movements for these types of springs are effective. Using this type of WRI we didn't overwork the capabilities of these elastic elements in this application

For future applications, these types of elastic elements are used in applications with proper vibrating systems which will highlight the influence of the number of windings in their frequency response and for attenuation the vibration of exhaust line will use other types of wire rope isolators.

ACKNOWLEDGEMENT

This paper is supported by the Sectoral Operational Programme Human Resources Development (SOP HRD), financed from the European Social Fund and by the Romanian Government under the contract number POSDRU /89/1.5/S/59323, POSDRU/88/1.5/S/59321.

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