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EIGEN MODES IDENTIFICATION FOR HYBRID WIRE ROPE ISOLATORS

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Abstract: *Finding the of eigen modes of vibration and dynamic behavior of a system is of high importance in analyzing vibration isolation solutions. This paper presents how to evaluate eigen modes or eigen frequency of hybrid wire rope isolators and to determine their influence on the dynamic behavior of the analyzed system. The hybrid wire rope isolators are combinations between wire rope and rubber.*
The measurements performed in dynamic conditions, but also with electrodynamic shaker, highlight the eigen modes and describe the behavior of these hybrid wire rope isolators compared to the basic wire rope isolators – the starting point of the hybrid components.
Keywords: *hybrid wire rope, eigen frequency, vibration measurement*

1. INTRODUCTION

In the last years the automotive industry and research department have paid more attention to wire rope isolators, compared with rubber elastic elements, for shocks and vibration attenuation.
The construction of wire rope isolators (figure 1) is ingenious, but still based on relatively simple design [6]. 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, cables twist, 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

In comparison with rubber elements, the 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].

On the other side the rubber elastic elements, which are also very widely used until now, present very good qualities in noise and vibration attenuation.
The solid structure of wire rope isolators might be a disadvantage in terms of vibration attenuation and transmissibility. The wire rope isolator's and rubbers advantages have brought into discussion the development and analysis of a new elastic element called hybrid wire rope. The hybrid wire rope isolators represent different combinations between rubber and wire rope isolators in order to obtain a new product with better properties.
The goal of this paper is to evaluate the eigen mode, to evaluate the vibration behavior of each new product called hybrid wire rope isolator compared with basic wire rope isolators. This evaluation has been made in dynamic conditions and modal testing with impact hammer and electrodynamic shaker.

2. EXPERIMENTAL SETUP

Measurements were made in engine test bench where wire rope isolators are used for vibration attenuation of the exhaust line. The scope of these isolators is to attenuate vibrations induced by the engine and exhaust line in the fixation bracket, respective on any car body. Thus we evaluated the vibrations that come into support, the vibration level coming out of elastic elements and impact of the eigen modes in vibration behavior.
The hybrid wire rope isolators represent a combination between a basic wire rope isolator and rubber. The basic isolator is a KR type product with 3.5 mm wire rope diameter. Starting from this basic wire rope isolator we develop several types of hybrid wire rope.

KR basic product KR wire coated KR rubber core

Figure 2: Hybrid wire rope isolators

The characteristics of hybrid wire rope isolators analyzed (figure 2) are:

- Hybrid wire rope isolator with wire coated: these elastic elements have a coat of cable that ends with a thin layer of rubber. Rubber coated cable ends are fixed between the two plates of the elastic element. The purpose of these cable end coating was to isolate the vibration transmitted through metallic ways;
- Hybrid wire rope isolator with rubber core: these elements have in the middle a conical rubber mounting. The scope for this conical rubber mounting is to modify the stiffness and to absorb the vibrations transmitted through metallic ways.

The measurements are performed in two stages. In the first stage are determined the eigen modes of each elastic element using electrodynamics shaker and afterwards an impact hammer. In the second part the vibratory characterization of these elastic elements is done in dynamic conditions according and observing the eigen modes previously established.
Installing the wire rope isolators and hybrid isolators on the electrodynamics shaker and introducing a low frequency signal shows the modes in free load conditions (figure 4). Relationship between the input signal, evaluated with a force sensor, and output signal, measured with a triaxial sensor, allow transfer function representation of each elastic element.
Determination of eigen modes or eigen frequency using impact hammer is performed using as load conditions of the exhaust line weight (Figure 3). Triaxial accelerometers were installed in order to evaluate the input signal which is entering the wire rope isolators but also the output signal that is filtered by it. This is made by evaluating the elastic elements response at the point of impact but also the transfer function of the item at the point of measurement. Measurements are made under a bandwidth of 1000 Hz and a resolution of 1 Hz. This measurement procedure provides information about eigen frequency of each element analyzed in real load conditions.

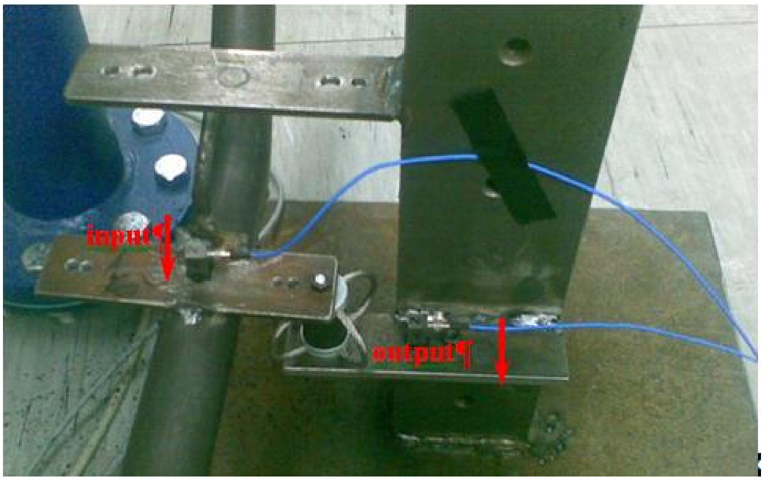

Figure 3: Measurement points

Figure 4: Shaker testing

Dynamic test are intended to identify which of the previously determined eigen modes have an influence in the vibrations transmission. Measurements are performed with the engine running at full load; the whole engine speed range from 950-4500 rpm. With these measurements we can estimate the impact of each elastic element in vibration attenuation but also identify the eigen modes of hybrid wire rope isolators. Sensors were placed on both exhaust line to evaluate the vibrations that come into elastic element, and on the bracket to evaluate the signal that is transmitted through elastic element.

3. RESULTS

Signal acquisition was performed with an LMS testing equipment where we have connected triaxial accelerometer PCB, with sensitivity 1 mV/(m/s^2). The post processing was performed using the LMS TestLab software. The graphs presented in this paper show the frequency response of the system as the ratio of the input signal (shaker, impact hammer, dynamic input signal) and the output signal measured with a triaxial sensor. Each graphic shows three curves corresponding to each direction X/Y/Z, directions corresponding to the vehicle coordinate system.
After performing measurements to determine the eigen modes with electrodynamic shaker and signal analysis, in all three cases a presence of 25Hz eigen frequency is found. The wire rope isolator has a dominant frequency of 168 Hz but a there are present other frequencies present, that may be of importance in the dynamic operation.
Although the case of the wire rope isolator with coated wire ends, is very close to basic constructive element, there is a slight change in the natural frequency and the dominant frequency is at 175 Hz. For the case of hybrid element with rubber core, where construction is different and stiffness is modified, a completely different behavior is observed. The dominant frequency is at 271 Hz, but there are present frequency peaks around it.

Table 1: Shaker-eigen frequency

Test type: shaker			
Wire rope isolator	KR basic product	KR wire coated	KR rubber core
Frequency [Hz]	25	24	25
	116	55	88
	168	120	135
	203	157	220
		175	271

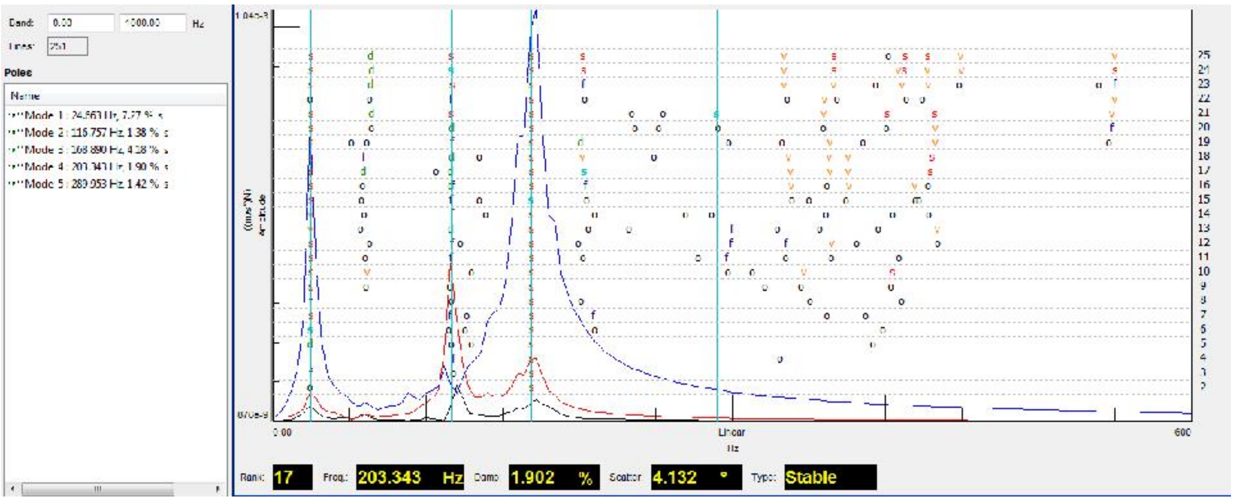

Figure 5: KR 3,5-7 basic product-shaker test

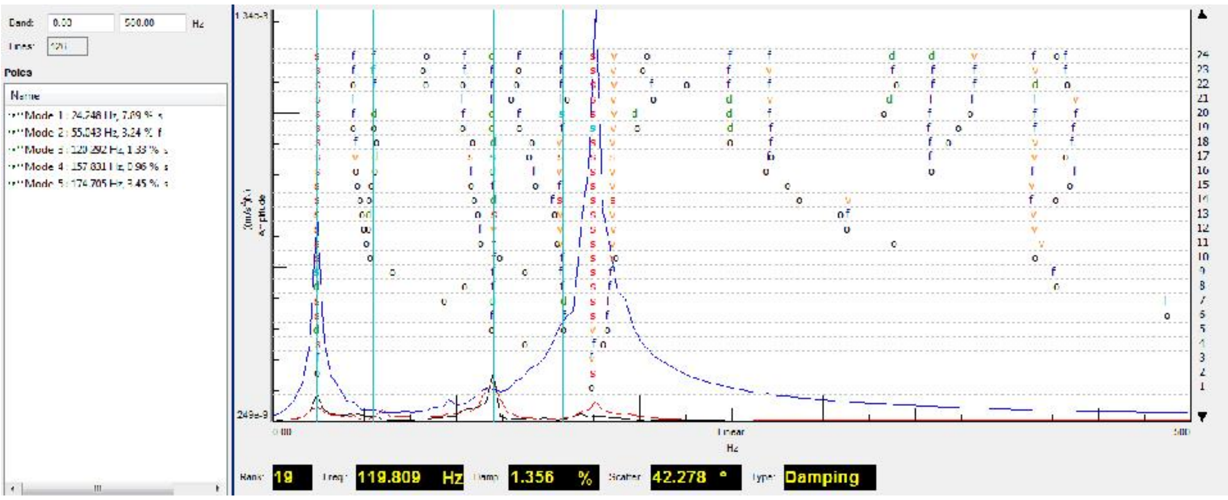

Figure 6: KR 3,5-7 wire coated-shaker test

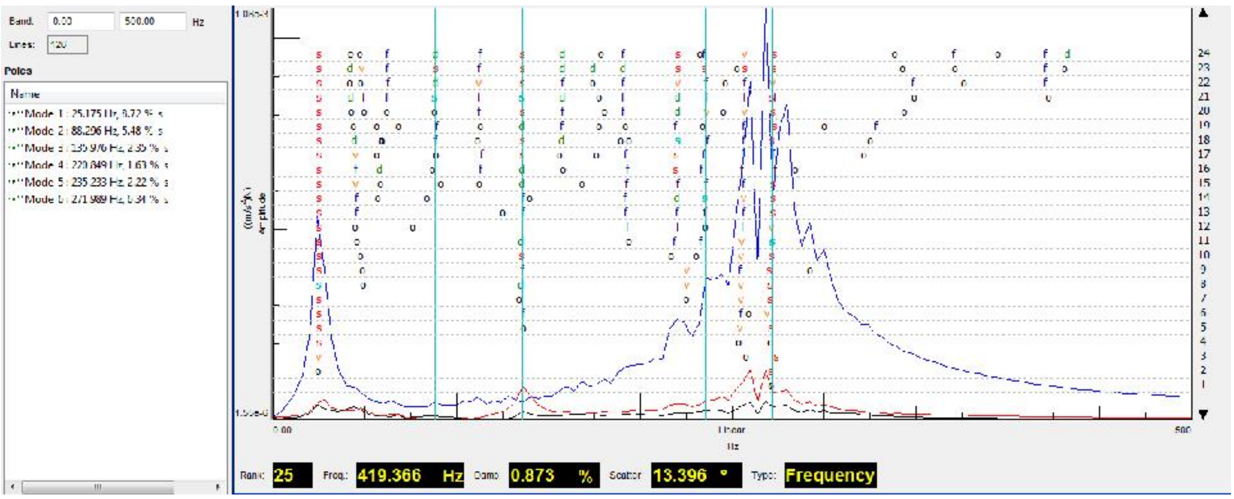

Figure 7: KR 3,5-7 rubber core-shaker test

Measurements have highlighted the eigen frequencies of isolators measured with shaker in free testing conditions. Determined frequencies will be observed in order to attenuate the vibration of exhaust line, using the dominant frequencies that appear in dynamic conditions.

Impact hammer measurements were performed in bench tests where elastic elements have been mounted on exhaust line under its weight load. The results are presented in table 2 and are obtained by applying stability and coherence criteria between input and output signal. Can be noticed that isolators have a large number of eigen frequencies corresponding to each element but there are some common to all three elements at 600 Hz. Another aspect seen is that the dominant frequency of the elastic elements under load does not correspond to those determined with the exciter.

Table 2: Impact testing-eigen frequency

Test type: impact testing			
Wire rope isolator	KR basic product	KR wire coated	KR rubber core
Frequency [Hz]	98	97	78
	210	203	306
	264	308	363
	305	434	435
	435	550	519
	450	568	631
	569	600	660
	594	658	772
	618	776	862
	660	870	920
	775	923	
	920		

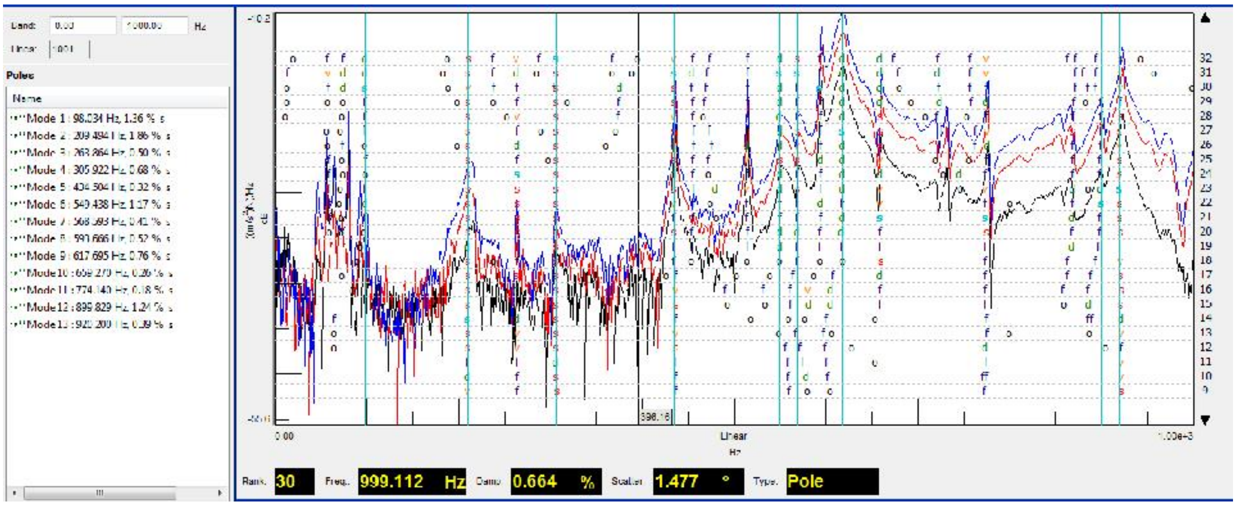

Figure 8: KR 3,5-7 basic product-impact test

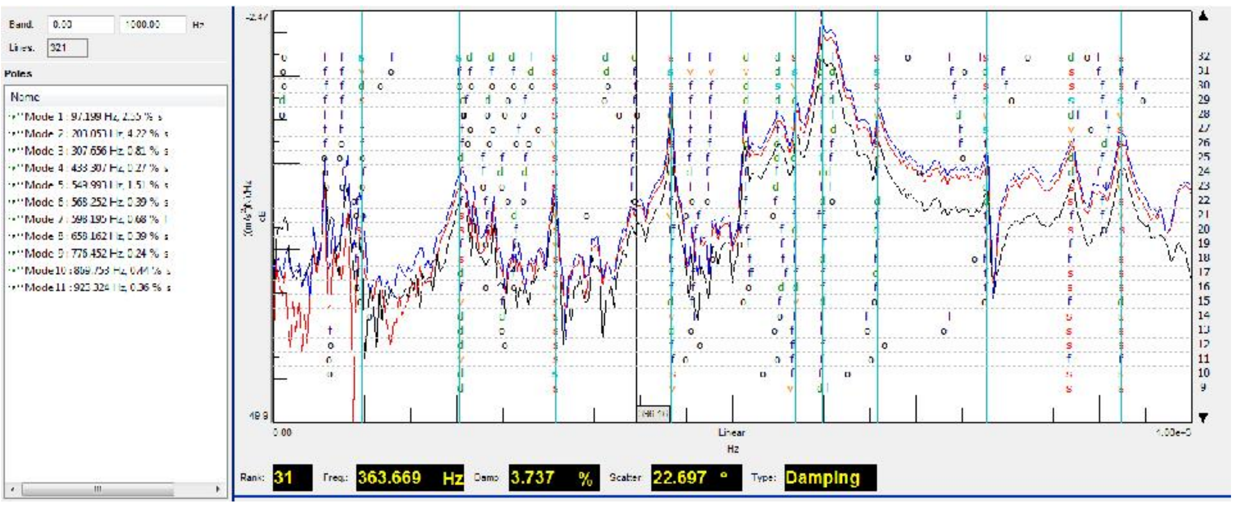

Figure 9: KR 3,5-7 wire coated-impact test

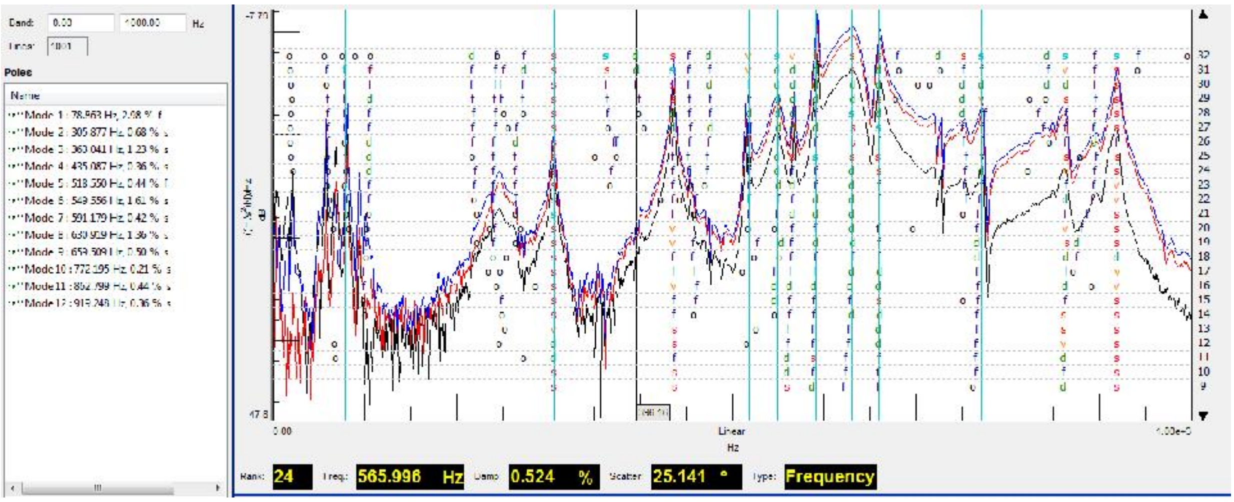

Figure 10: KR 3,5-7 rubber core-impact test

The third type of test identifies frequencies that have a major impact on vibration behavior. Highlighting eigen modes was achieved by determining the transfer function as a report between input signal and output signal. The results are summarized in table 3 form where it can be noticed that all three types of elastic elements have common eigen frequency at 80 Hz, 600 Hz and 1120 Hz. The wire rope isolator with coated wire ends have the same frequency, aspect which shows that a thin layer of rubber on the wire ends does not influence their behavior modes in dynamic conditions. Hybrid wire rope isolators with rubber core show more intermediary frequency, issue that can have a negative impact in vibrations isolations.

Table 3: Dynamic tests-eigen frequency

Test type: run up			
Wire rope isolator	KR basic product	KR wire coated	KR rubber core
Frequency [Hz]	80	80	80
	600	600	240
	1120	1120	300
	1160		520
			820
			1120

The three types of tests on each element highlight the frequencies that have a major impact in vibrations attenuation and their transmission. Frequency of significant impact in the low and medium frequency range are 80 Hz and 600 Hz for all three types of elastic elements.

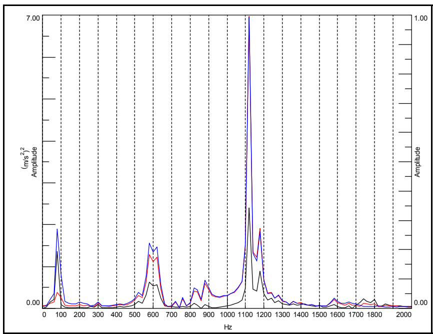

Figure 11: FRF - KR basic product

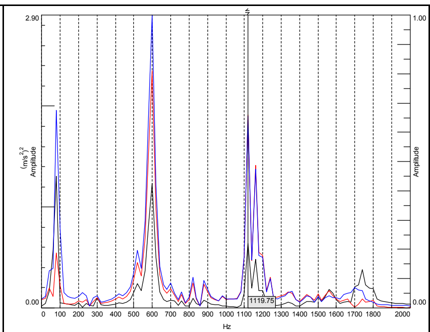

Figure 12: FRF - KR wire coated

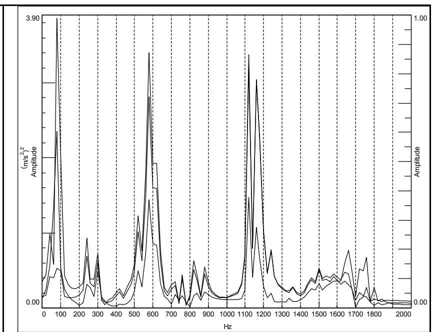

Figure 13: FRF - KR rubber core

Our expectations before performing tests of hybrid wire rope isolators with wire ends coated was to find eigen frequency very close to the pure wire rope isolator but with an higher efficiency in the overall level of vibration attenuation. Measurements and analysis of acquired signals confirmed expectations regarding this type of isolator. The wire rope isolators with hybrid rubber core kept the eigen frequencies of the basic wire rope isolator and added a few more due to the rubber.

Dominant frequencies identified using shaker were not reflected in measurements made with elastic elements under the exhaust line weight load. However, some lower frequency amplitude, of around 80 Hz, identified by these types of measures proved to be of great importance in vibration analyses. Unlike this type of test, measurements made with impact hammer have revealed a large number of frequencies which can contribute in determining the vibration behavior. Among the identified frequencies were found also those that have a major impact in dynamic environment.

4. CONCLUSIONS

This work presents the evaluation of eigen frequency of hybrid wire rope isolators, compared with basic wire rope isolators. For this several models of hybrid wire rope isolators were defined and developed, two of them presented in this paper. The objective is to check if the new created elements change their behavior and consequently their frequencies compared with wire rope isolators basic product - starting point of the modeled hybrid elements.

In order to achieve a correct identification of the eigen frequency of the elastic elements considered three types of tests were performed: with shaker, with impact hammer and run up running. Elastic elements were used in application for vibration attenuation of the exhaust line and vibration transmitted through exhaust line to the mounting brackets.

The results of the analysis acquisitions made were summarized in tables, where it can be observed the evolution of frequencies dependency on each specific test. It is noticed that the hybrid wire rope isolators with wire ends coated has the same frequency as basic wire rope product. The thin layer that covers the ends of the wires does not have a major influence in eigen frequency but it - improves attenuation qualities of vibrations transmitted through these types of isolators. The hybrid wire rope isolators with rubber core had an entirely different behavior. Even if it kept some frequency from the basic element, it introduced several additional frequencies which might become a disadvantage in dynamic operation.

This paper has achieved its objective by identifying eigen frequencies of wire rope isolators and the way these frequency change with the construction of hybrid elements. Further work will focus on analyzing these elements in terms of the efficiency in attenuation of the overall level of vibration but also improve the studied elements.

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