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CONSIDERATIONS ON CLASSIFICATION OF THE MAIN COMPONENTS OF THE VEHICLES BY THEIR VIBROACOUSTIC FINGERPRINT

BY

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Abstract. The modern car industry is evolving under new premises, such as new propulsion technology, which imply offering to the customer the completed new solutions (charging station, service contract and remote diagnosis). Proven diagnostic technology is reaching its limits because is generally based on detecting the electrical faults and the mechanical, hydraulic and pneumatic failures have a slight degree of detection by this method. An alternative method of diagnosis could be the study of actual noise and vibration parameters of the main components of the vehicle subject to major faults and compare them to that specific to good status of operation. This paper deals with the classification of the main components of the vehicles by their vibroacoustic fingerprint. Those components of the vehicle grouped by vehicle category and their common patterns of vibroacoustic fingerprints must be permanently overseen and compare with those assigned to the status of good health for diagnosis.

Keywords: automotive, vibroacoustic diagnosis, classification, noise, vibration.

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1. Introduction

The Automotive Industry was invented by humans for fulfil their need of mobility and that is a clear idea that this industry took some characteristics from the inventors. One aspect is the vehicle life cycle which could be compare to that of a human been, and here we are speaking of the three main periods which presume the start of life cycle (childhood for humans), useful life (maturity for humans) and aging (the same like humans). Those 3 main periods of the vehicle life cycle are clearly delimited by the number of faults per time unit as represented in Fig. 1.

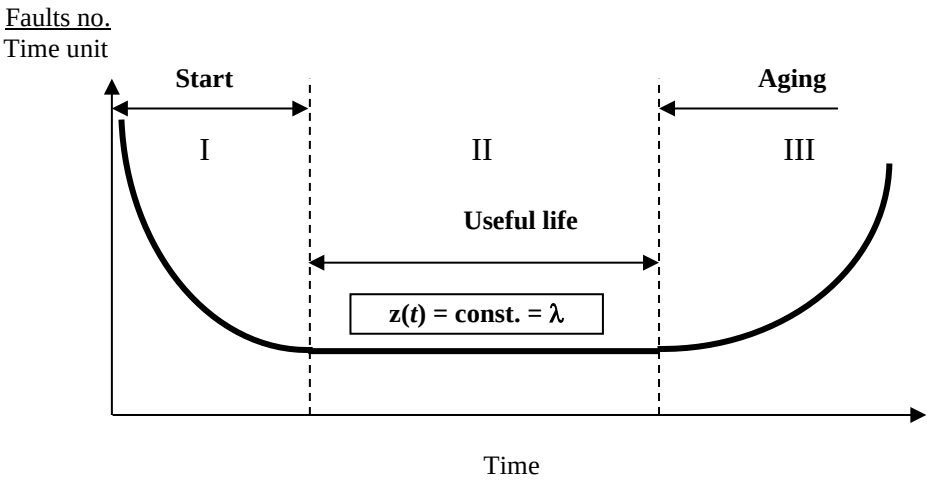


Fig. 1 – Faults evolution in a life cycle of an automotive (Andreescu, 2007).

Another common aspect with human is the diagnosis method of the human and vehicles based on study of the noise and vibration behaviour of the human / automotive internal organs. The term used in medicine for diagnosis based on sound analysis it called "auscultation" and refers to direct listening with the ear or stethoscope to the sounds of the heart and lungs, to establish the diagnosis (Chizner, 2008).

Medicine is having for human subjects a clear separation by age classes which are representative for general symptoms and behaviour in case of specific disease. The same is happening with the automotive vehicles which are grouped into specific classes and those could be used on vibroacoustic diagnosis for establish reference frequency and amplitude for normal state of operation and for fault state of operation.

2. Goal of study

The method of auscultation was used from early ages for the automotive industry. Initially auscultation was done by special trained persons with the help of adapted stethoscope as a tool for the auscultation of the internal combustion engine operation, usually on the final assembly line on the factory as part of the final control. Corresponding with technology evolution there was an evolution of this automotive specialized stethoscope like that presented in the Figs. 2 and 3.

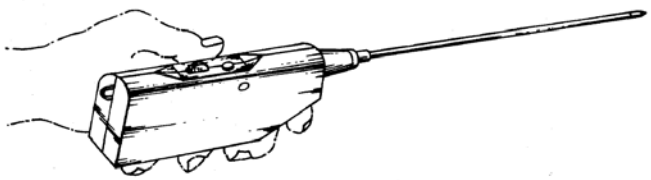


Fig. 2 – Electronic stethoscope for automotive (Epstein, 1993).

This device presented in Fig. 2 is an electronic stethoscope, with United States of America patent. The device was designed for general use and it was relying on the level of technical background of the user and the accurate of the test was influenced by an external factor like physical status of the person and surrounding noise from the area where was done the operation.

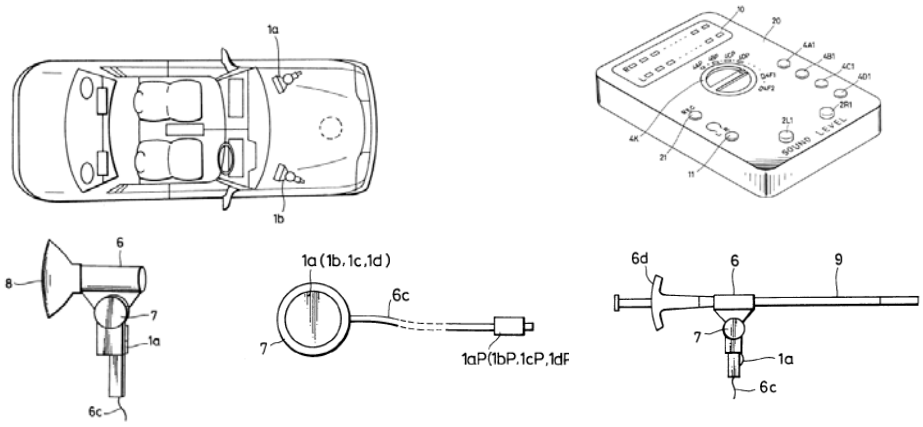


Fig. 3 – Device for abnormal noise detection of the automotive (Ishimoto, 1993).

Device from Fig. 3 is one patent for abnormal noise detection of the automotive with conversion of the acoustic pressure into an electrical signal made by the conversion element and amplified primarily and secondarily with corresponding amplifying unit.

Studying the actual status of diagnostic method used for automotive, could be observe that is based on electrical faults type detection and the other three remaining type as mechanical, hydraulic and pneumatic have slight degree of detection just by interpolation of electrical parameters measured directly (like clutch travel detection by measuring the variation of electrical resistance of the corresponding sensor). From those we see the opportunity for developing of the diagnosis method based on sound analysis extended with the vibration level monitoring made with an electronic system based on artificial intelligence.

For developing this vibroacoustic method of automotive diagnosis is necessary to create a database as library for vibroacoustic of vehicle as whole and for its major component like engine, gearbox, suspension, etc. This database should contain vibroacoustic fingerprint for good status of operation and for commonly appeared type of fault like damaged bearing.

3. Classification of the vehicle main components by their vibroacoustic fingerprint

As is mentioned above, diagnosis need was appeared first for humans in medicine and with its development there was created age groups representative for body behaviour in case of specific disease. Those groups, presented in the figure 4, are created by years as follows: 0-2, 3-5, 6-13, 14-18, 19-33, 34-48, 49-64, 65-78 and 79-98.

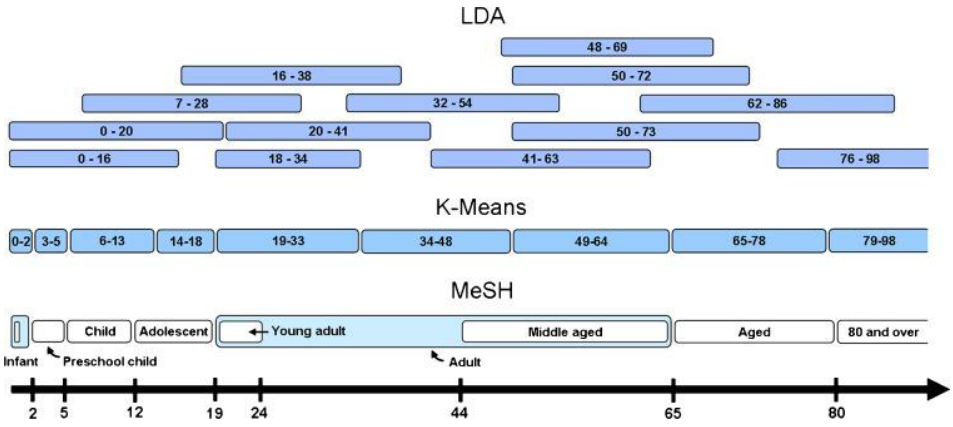


Fig. 4 – Human age groups according to medical criteria latent Dirichlet allocation (Geifman, 2013).

By their specific operation characteristics, the vehicles are generating noise and vibration, and in the eyes of the legislator are source of pollution. In accordance to this, the major regional laws are establishing certain limit levels as for example the European Union legislation dedicated to vehicle classes groups

which there are representative for vibroacoustic behaviour similar to human age groups as mentioned above (Regulamentul UE 2018/858).

This topic is useful for creating database for vibroacoustic method because we could observe that according to the class which belongs the vehicle have some certain vibroacoustic fingerprint identified by legislators, as is presented in Table 1 (Farmer, 2012).

Table 1

Sound level limits evolution for vehicles (Farmer, 2012)

Directives	92/97/EEC	84/424/EEC	77/212/EEC	70/157/EEC
Passenger car	74 dB(A)	77 dB(A)	80 dB(A)	82 dB(A)
Buses over 3.5 tones, less than 200 HP	78 dB(A)	80 dB(A)	82 dB(A)	89 dB(A)
Buses over 3.5 tones, over 200 HP	80 dB(A)	83 dB(A)	85 dB(A)	91 dB(A)
Buses and good vehicles less than 2 tones	76 dB(A)	78 dB(A)	81 dB(A)	84 dB(A)
Buses and good vehicles over 2 tones and under 3.5 tones	77 dB(A)	79 dB(A)		
Buses and good vehicles over 3.5 tones, less than 100 HP	77 dB(A)	81 dB(A)		
Buses and good vehicles over 3.5 tones, over100 HP and under 200 HP	78 dB(A)	83 dB(A)	86 dB(A)	89 dB(A)
Buses and good vehicles over 3.5 tones, over 200 HP	80 dB(A)	84 dB(A)	88 dB(A)	91 dB(A)

At a closer look on the vehicle as a generator of noise and vibration, we summarize the major sources explained in the Fig. 5.

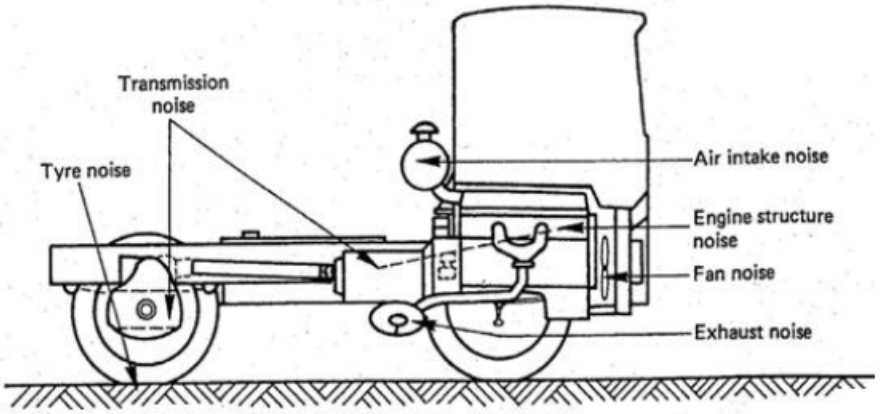


Fig. 5 – Major noise and vibration sources of the vehicle (Deulgaonkar *et al*., 2020).

If we take a closer look at the target faults for vibroacoustic detection (mechanical, hydraulic and pneumatic types) we could distinguish the most relevant main sources of noise and vibration of the vehicle are the following:

- internal combustion engine,
- auxiliary systems of the engine (exhaust, intake, fuel supply and cooling system),
- drive train,
- tyres.

The contribution rate of those major sources of noise and vibration of the vehicle are basically similar to the different classes of the vehicles (passenger cars, trucks and buses) and there are detailed in the Table 2 (Deulgaonkar *et al*., 2020).

Table 2

Percentage contribution of main noise and vibration sources of the vehicles (Deulgaonkar et al., 2020)

Sr.No.	Source	% Contribution
1.	Engine	22 - 30
2.	Exhaust system	25 - 35
3.	Intake system	05 - 15
4.	Fan and cooling system	07 - 15
5.	Transmission	12 - 15
6.	Tyres	09 - 15

In technical literature could be founded studies on particular components, referring to their vibroacoustic fingerprint and corresponding behaviour. This behaviour, described in Table 3 (Cinkraut, 2015), is basically similar for the same component from different suppliers which provide those products as a normal equipment to the vehicle manufacturers for specific vehicle class offer.

Table 3
Tyre acoustic Cavity Resonance frequency peaks related to sound pressure level (Cinkraut, 2015)

Wheels	TCR frequency [Hz]	Sound pressure level [dB (A)]			
		Front left	Front right	Rear left	Rear right
16” Fe	215	49.5	48	51	51.5
	238	52	50	50	52
16” Al	215	48	44	51	48
	236	47	47	49	50
18” Al	215	47	44.5	50	45
	228	51	52	57	58

4. Conclusions

Modern tendencies in automotive are based on offering the customers the advantage of time in utilization of the vehicle. Those solutions start with mobile phone application for finding the charging station on the route (in case of electrical vehicles) and end with remote diagnosis of the vehicles. Remote diagnosis is designed for avoid the unnecessary downtime for repairs, which could result in additional costs mostly for commercial vehicles in the case of unworked periods. This method of diagnosis, based on vibroacoustic, have the chance to close the gap of faults pool (mechanical, hydraulic and pneumatic type) which could not be detected by classical one based on the electrical parameters monitoring and offer the advantage of less used time for deeper diagnosis which could involve removing some parts from the vehicle.

Developing of the vibroacoustic diagnosis method presume to create the corresponding database by registration the vibroacoustic behaviour of the major components of vehicle, representative for targeted faults, in the good state of operation and the faulty relevant. From here could be done the determination of the relevant pattern of symptomatic for specific faults which could be identified by artificial intelligence of an electronic system. Those patterns are representative for the major components allocated to the main classes of the vehicles as passenger car, trucks and buses with relevant mass categories and some other specific criteria. That mean in the vehicle class, major components have a common vibroacoustic pattern for symptomatic generated by the similar components used for the same vehicle manufacturers.

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CONSIDERAȚII PRIVIND CLASIFICAREA PRINCIPALELOR COMPONENTE ALE AUTOVEHICULELOR DUPĂ AMPRENTA VIBROACUSTICĂ

(Rezumat)

Industria auto modernă evoluează sub noi premise, precum noua tehnologie de propulsie, care implică a-i oferi clientului noi soluții complete (de exemplu stație de încărcare, contract de service și diagnoză la distanță). Tehnologia de diagnosticare actuală își atinge limitele deoarece se bazează în general pe detectarea defecțiunilor electrice, iar defecțiunile mecanice, hidraulice și pneumatice au un grad redus de detectare prin această metodă. O metodă alternativă de diagnosticare ar putea fi studiul parametrilor reali de zgomot și vibrații ai principalelor componente ale vehiculului supuse unor defecțiuni majore și compararea acestora cu cea specifică unei bune stări de funcționare. Această lucrare tratează clasificarea principalelor componente ale vehiculelor după amprenta lor vibroacustică. Pentru diagnosticare, starea actuală de funcționare a componentelor, grupate pe categorii de vehicule, și modelele lor comune de amprente vibroacustice trebuie să fie permanent supravegheată și comparată cu cea atribuită stării de bună funcționare și respectiv de defect.