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THE POSSIBILITIES OF ELECTRONIC TOLL'S UTILIZATION IN RELATION TO ENVIRONMENT CONSERVATION AND ROAD SAFETY

Current electronic toll should start to play the important role not only in charging for the road use but it is chance to use it as the promoting element in environment conservation and road safety activities. The paper describes the toll system proposal that instead of to a usual way of vehicles' per kilometre charging takes into account harmful environmental impacts and road safety as well. The purpose of proposal is charging according to every specific vehicle's harmful environmental impacts and road safety per particular road section. The proposal is recently researched and results of a theoretical analysis are presented in the paper that includes the basic experimental engine's evaluation and telematic part.

Keywords: *electronic toll, environment conservation, road safety, engine vehicles, telematics*

1. Introduction

The nowadays systems of electronic toll can significantly increase efficiency of solving problems of the sustainable development of motorway, road and urban traffic. Up to now usually applied electronic toll is designed in different modifications but with the same basic aim to charge vehicle's drive per concrete road section. The purpose of the charge is to obtain financial means for a road maintenance and construction. Above mentioned the only contemporary electronic toll systems' aim was used by authors in their more complex proposal as one part so called economy toll part. Beside this part another two parts are proposed i.e. ecological and safety ones. The principle of presented electronic toll proposal is based on individual and technically validated payment for the harmful vehicle's environmental and safety impacts instead of a basic payment for vehicle's drive only. The proposal's purpose is to promote driver's behaviour to maintain his vehicle's correct technical conditions (minimizing harmful emissions) and to keep regardful and safe drive. The paper contains only a part of the mentioned task i.e. engine's problems linked with the ecological part of electronic toll. It is technical reasons of individually aimed charge of harmful emission mass production in different sections of a transport infrastructure. To achieve this aim it is necessary to monitor an every vehicle involved into the system from the point of the instantaneous production of single harmful emission fractions. It requires some specific smaller changes as in a way of the homologation measurement as in

some more principle changes in the content of regular emission inspections. The relatively simple indirect measurement within the whole vehicle's operation is linked with these changes.

2. Problems of the driven vehicle's emission measurement

2.1. Principle of proposed way of indirect emission measurement of driven vehicle

The production quantification of single emission fraction of an every single vehicle during the whole operational period on specified road sections is possible to solve technically. But it would be extremely expensive to equip a vehicle by small physical and chemical laboratory installed e.g. in the engine's exhaust design section. This equipment is usual in US's or Japan's market but their initial price can exceed the luxury car's price and it is the reason of their wider operational non-acceptance. In case these equipments' price would not be decreased in future by way of some radical invention it is possible to say that their utilisation remain in a applicable research area or in vehicles' homologation measuring system.

In virtue of above mentioned statements authors concentrated on the indirect operational measurement of engine vehicles in their proposal i.e.:

- The "standard" emission characteristics will be determined by precise methods during homologation measurement of every specific type of vehicle's engine. These characteristics describes the instantaneous value of mass production of single

harmful emission fractions and it is in dependence on the set of specific engine's operational modes that is possible to take into account.

- The operational modes of vehicles' combustion engines use to be defined by two independent quantities i.e. revolutions n [1.min.$^{-1}$] and the useful torque of crankshaft M [Nm]. The emission characteristics are described by 3D – dependences under usual conditions where every instantaneous mass production Q_i of every i-th emission fraction is quantity depending on n_i and M_i. Authors accepted conclusions that at modern engines, mainly at compressor and electronically operated combustion ones, is necessary to define their operational modes by more independent quantities for this purpose.

- With the regard to the gradual operational engines' wear-out the above mentioned "standard" characteristics are updated during vehicles' periodical emission inspections. These updated characteristics are derived from "inherited" basic shapes of "standard" characteristics where the modification is carried out on important areas by updating measurement only. By authors' proposed quasi-static measuring method likes to be suitable for the periodical measurement. The method requires low investment and operational costs and it provides the adequate preciseness.

- During the whole vehicle's drive and under any changing operational conditions the sequence of operational engine's modes is only monitored and saved into a memory in time dependence. Consequently the sequence of mass production of instantaneous emission values is assigned to operational modes by updated emission characteristics. The integration in time determines total production values of single harmful emission fractions at any chosen road section.

- According to authors' proposal the methods of telematics are possible to utilize and to monitor every single vehicle involved into the system at all over the Czech Republic or even Europe. This way of electronic toll is rightful and significantly promoting the ecological behaviour. The appreciation of vehicle measured harmful impact per unit stays as the only problem here. In financially hierarchal localities the *economy's* toll per kilometre is possible to determine and its ecological toll's fraction (done by the vehicle's unfavourable impact on the environment) as well.

2.2. Form choice of dynamic and emission characteristics

The instantaneous and total production of single emission fractions is possible to determine in virtue of measured engine modes' sequence with the support of power and emission stated engine's characteristics. The engine's torque becomes derived (calculated) quantity i.e. indirectly measured output quantity of engine's power characteristics and this torque is dependent directly on measured input quantities under the proposed system of operational measurement. Directly measured input quantities of the computation are in principle chosen the same as for the torque as for the instantaneous production values of every single emission fraction.

In proceeded proposal the unified form of power and emission characteristics was chosen. The "4D" dependence of every single output quantity on three input quantities i.e. revolutions n, indicator of the fuel supply uPa and indicator of the air supply uV. Fig. 1 shows useful torque as the chosen output quantity but it is the only one possibility from the other quantities' set (chosen mainly in a form of single emission fractions). Experiments were carried out with a four-stroke diesel compressor engine ŠKODA LIAZ ML 635.

Directly measured input quantities of computation i.e. n, uPa and uV is generally possible to measure in relatively easy way. This measurement is possible carried out continually during the whole vehicle's drive. For example the attitude of injection pump's ratchet within the bounds 0 – 100% was chosen as the fuel supply indicator uPa and input air pressure into the engine (behind a turbo-blower) within the bounds 1.3 – 1.7 bar was chosen as the air supply indicator uV.

Fig. 1 shows the example of general relation in a shape of the skew surface $M(n, uPa, uV)$, presented for the only one chosen value of input quantity $uV = 1.7$ bar.

Similarly **z** – axis can be used for another quantities in different characteristics e.g. engine's operation characterized by fuel supply dPa[mg/s], emissions CO[mg/s], CO_2[mg/s], NOx[mg/s], HC[mg/s], solid particles PM[mg/s] etc.

The advantage of further analysis is done by mathematical expression and its charting. The researched particular dependencies are charted by the same way and it is possible to carry out computable or graphical comparisons e.g. by the overlapping of two researched quantities on **z**-axis when axis **x** and **y** are constant.
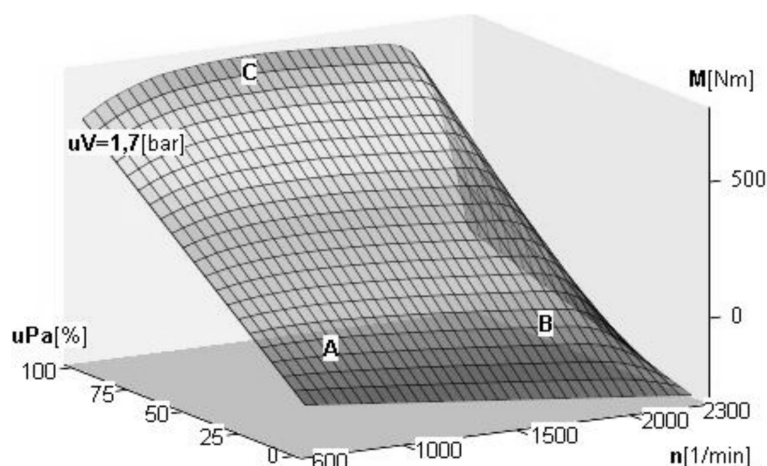
Fig.1. Example: 4D characteristics of diesel compressor engine. The indirectly measured useful torque M is charted in dependence on revolutions n and the fuel supply indicator uPa and the air supply indicator uV. The only one surface is shown uV=1,7 bar (from the measure range 1,3 - 1,7 bar)

2.3. Ways of characteristics' periodical actualization

It is proposed that the shown characteristics' form (see Fig. 1) will be determined in its "standard view" on the needed graduate levels uV at homologation measurements. These characteristics could be valid for the first three years of new vehicle's operation. After it, during the first and next regular technical and emission inspections the applied characteristics' update could be carried out. In principle The measurement could be carried at three points (see Fig. 1) marked as **A**, **B** and **C**.

The principle of expectation is that characteristics' updated quantity surfaces of gradually wear-out engine keep the basic features of "standard" characteristics. Every single standard characteristics obtained at the homologation is possible only to "shift and rotate" onto the position done by points **A**, **B** and **C**. This method is evaluated by authors and obtained preliminary results are favourable. In case of need it would be possible to enlarge number of measured points and the single characteristics preciseness' update would radically improve. The characteristics' surface could change into anomaly skew one that could express the results of engine's gradual wear-out precisely. The update could be carried out by simpler and cheaper way e.g. quasi-static method that is described in another paper. The schema of proceed is following:

- The vehicle's driven wheels are placed on freely rotating cylinders. The suitable gear is shifted (usually low) and the engine is operated with adjusted revolutions on value adequate to measured points e.g. point **A**. The later repeated measurement should do the same but with points **B** and **C**.
- The engine is loaded by unmeasured brake' torque for short time e.g. by vehicle's brake or by electric or hydraulic retarder. The value of load torque must be app. adequate to pre-chosen point e.g. **A**.
- During app. two minutes of constant and in this moment not measured load all required output parameters are measured in form of single emission fraction production
- Then it is necessary to clutch down smartly and at this moment the engine gets into full free acceleration and during several initial milliseconds [ms] the useful torque is measured by angle acceleration. In this way measured value is highly precise and it is adequate to stabile torque (by what the engine was loaded during former two minutes).
- At pre-chosen measured points **A**, **B** and **C** is possible to keep the pre-adjusted revolutions nevertheless the load torque is not possible to adjust precisely. It influences the real points **A**, **B** and **C** attitude form the general required slightly differ. It is quite principally unimportant from the point of computational possibilities.

2.4. Example of the measurement and vehicle engine power characteristics' computation

The updated 4D – characteristics are possible to obtain in the form of continuous functions immediately usable to computation. Clearly it possible to imagine this function as the set of quantities' surfaces that is shown in Fig. 2. The example shown in Fig.1 was developed hereby: shown surfaces gradually stepped by one tenth of 1 bar uV and they are gradually shifted on the vertical axis but it was only done for clear presentation. The scales of presented shifts are not drawn in Fig. 2 for a greater clarity. If the specific vehicle engine's characteristics exist in practice, where
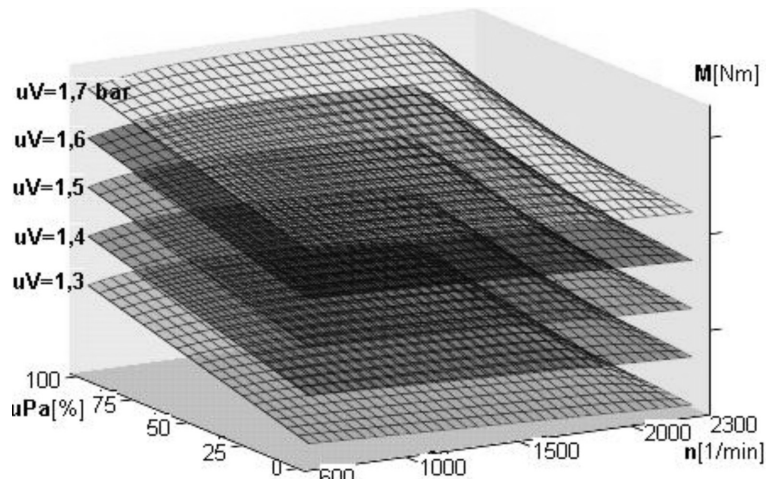
Fig. 2. Example of power characteristics of diesel engine. M is engine's useful torque in dependence on regulations n, fuel supply indicator uPa and air supply indicator uV within the bounds uV=1,3 - 1,7 bar

on the vertical axis **z** is torque and on the others are single emission fractions, then is possible to observe vehicle's power and emission operation without nay problems during the whole drive.

2.5. Example of the measurement and vehicle engine's emission characteristic computation

As an example of the quantitative expression of diesel engines' exhaust gas solid particles the quantity called "quantified opacity" (working name) is applied here; using a symbol Q[m³/s] and representing air volume disqualified by the engine (in m³ per second) on the proposed hygienic limit e.g. 5% opacity.

The presented hygienic limit was selected as the preliminary one to clearly show the way of computation and it will be necessary to detachedly determine

it in collaboration with a health research. If the engine intake is e.g. 0.2 m³ .s⁻¹ of air under the detachedly defined operational mode and the measured opacity is 30% at exhaust pipe i.e. disqualified air volume on to hygienic limit 5% will be app. higher then 1 m³.s⁻¹ that is possible to express by Beer-Lambert's law and state equation of gases.

2.6. The possibility of characteristics' utilisation to optimise engine's working modes and vehicle

Signals of directly measured quantities i.e. n_i [1/min], uPa_i [%], uV_i [bar] and the instantaneous vehicle's speed v_i [km/h] are saved into the board computer at every i-th moment of its drive (at time intervals e.g. $\Delta t = 0{,}01$ [s]). In virtue of this saved data and the above mentioned actualised characteristics the value of use-
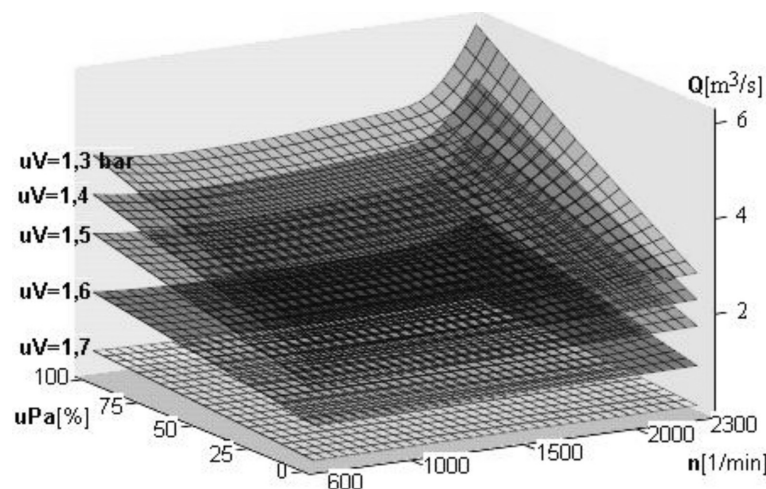

Fig. 3. Example of diesel engine's emission characteristics. Q[m³/s] is quantified opacity (air volume in m³.s⁻¹, disqualified on hygienic limit 5% of opacity), in dependence on revolutions n, fel supply indicator uPa and air supply indicator uV within the bounds 1.3 -1,7 bar

ful torque M_i [Nm] is computed in real time at every i–th moment (as the basic data to analyse vehicle's instantaneous dynamic properties):

$$M_i\left(n_i, uPa_i, uV_i\right) \qquad (1)$$

and other data of every inspected emission fraction e.g. the above defined quantified opacity Q_i [m³/s]:

$$Q_i\left(n_i, uPa_i, uV_i\right) \qquad (2)$$

Then it is easy to compute different emission quantities in real time with chosen sample frequency that are possibly usable to optimise vehicle's drive economy and ecology. For example it can be instantaneous specific opacity Qm_i [m³/kWh] that determines disqualified air volume [m³] above the hygienic opacity limit as a result of engine's useful work 1 kWh:

$$Qm_i = \frac{1,08 \cdot 10^8}{\pi} \cdot \frac{Q_i}{M_i \cdot n_i} \qquad (3)$$

Likewise every other instantaneous value of the inspected emission quantity production is possible to continually determine. The possibility of continual evaluation from the point of view of economy and ecology is evident. The aim of the continual evaluation is to instantaneously operate the engine's modes and the way of vehicle's drive. The optimization criterion of this operating is the complex technical and economy point of view that includes as the fuel financial costs (determined in virtue of emission gases' carbon molecules) as the financial appreciation of single emission fractions' harmfulness.

2.7. The possibility of characteristics' utilisation in the fair ecological taxation

The vehicle, included into the proposed electronic toll system, is driven in time sequence Δt [s] on geodetically defined road sections ΔS_i [m]. Indirectly measured values of single harmful emission fractions of instantaneous production are linked with these sections e.g. by quantified opacity Q_i [m³/s]. Example: the vehicle was driven at the moment $i=a$ into the especially observed urban area and at moment $i=b$ left the area.

At every single i-th road section the optimisation criterion of vehicle's driving mode is defined by a support of measured data. This can be stated e.g. as the instantaneous production Qv_i [m³/m]of the inspected emission fraction related to 1 meter of road:

$$Qv_i = \Delta t \cdot \frac{Q_i}{\Delta S_i} \qquad (4)$$

Then the criterion of ecological tax is obtained by the data summarisation within the bounds of $i=a$ and $i=b$. This can be described by e.g. total production Qs of the specified emission fraction during the vehicle's operation on the inspected road section:

$$Qs = \sum_{i=a}^{b} Qv_i \cdot \Delta t_i \qquad (5)$$

Presented quantities Qvi and Qs, multiplied by charging rate that expresses a measure of environmental degradation, compose the proposal of ecology and economy criterion for continual technical operating optimal vehicles' drive mode with regard to its load, time and geodetically defined crossed locality.

3. The proposal principles of telematics' part

From the telematics' point of view the original conception of on-board unit (OBU) is proposed to solve the above specified problems. The OBU's functionality includes not only known telematics' applications e.g. electronic toll, digital speed recorder, vehicles' position and costs monitoring etc. but it is enlarged by vehicle's information module. Information are processed and verified there and the computation of driving properties and emission parameters is carried out to use the obtained information mainly for electronic toll determination. Except of the presented elementary application the utilisation of obtained information in further telematic applications will be derived e.g.: monitoring of dangerous load transport where the condition of safe realisation is good knowledge about vehicle's technical situation, driving characteristics and safety.

The result of on-board unit analysis is the definition of elementary functions which should be fulfilled in the electronic toll system. The analysis determined single information relations and their interconnection and mainly information relations linked with outside subsystems as vehicle's electronics and vehicle's driving property sensors. The final analysis stems from European project MISTER (Minimum Interoperability Specification for Tolling on European Roads) and from prepared standard CEN 17 575 that solved a OBU's technical specification in future electronic toll systems.

The further used source was national project's results (MD ČR 802/210/108 ITS) characterising national ITS's architecture (includes system of electronic toll) under conditions of a transport and a telecommunication in the Czech Republic.

4. Conclusion

The presented proposal of modern electronic toll conception stems from the principle of road transport sustainable development. The form of aimed influence at vehicle's user was proposed to promote user's

activities in way of the vehicle's correct technical maintenance (minimizing harmful emissions) and the keeping of regardful and safe drive.

From the point of telematics' view the proposal is linked with principals of current electronic toll systems that fulfil economy part only up to now. Two other parts of toll are proposed in the paper i.e. ecological and safety toll.

From the point of engines the system that continually quantifies harmful impacts of every individual vehicle during the whole operation and on the specified "tolled" roads (sections) was proposed. The instantaneous production of single emission fractions are related to "length meter" of road and it enables to determine taxes promoting the vehicle user's proper behaviour.

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