COMMENTS CONCERNING DETERMINATION OF FLEXIBILITY OF SPARK IGNITION COMBUSTION ENGINES

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Abstract. The following paper presents topics related to determination of dynamic properties of multi-point injection petrol engine, which obviously influence dynamics of vehicle propelled with such engine. These properties, determined on analytical way using engine’s flexibility factor, where compared with simulations based on Leidemann’s equations. It has been stated, that using proper factors in mentioned equations can result in reliable results with no need to carry out the inconvenience of engine benchmarks. Some cases where however found in tested group of engines, in which traditional method of flexibility estimation where not effective enough. Such case is presented further in this paper together with suggestion of new approach to this problem.

1. Introduction

Getting good dynamical properties of combustion engine should not be a goal itself but should rather serve to improve dynamical properties of vehicle propelled with this engine. It particularly concerns heavy automotive vehicles, which can negatively influence fluency of traffic due to their poor engine dynamics. Right now different measures are used to determine dynamical properties of engine. Mostly it is a time of acceleration of car propelled with tested engine [3]. Acceleration through the gears or on direct gear is used as a measure of this property and as a measure of tank engines as well [2]. Such approach consists of a great number of simplifications because its results are influenced by external factors (weather, road conditions), which are normally not mentioned together with results although their influence on acceleration is considerable. The results depend also on gear ratios in power transmission system and dynamic radius of wheel, efficiency of all elements of power transmission system. It is the reason, why comparisons normally assume that engine drives vehicle with fixed gear ratio in power transmission system. This assumption is necessary to eliminate a great deal of variable factors occurring during acceleration. The direct gear is assumed to be most useful, because dynamic properties resulting from simulations can then be compared with those given by flexibility factor, not influenced by acceleration time factor. Direct gear is also used to determine flexibility of tank engines. Examinations that have been done so far state, that the most objective way of determining those properties is to determine the flexibility factor on base of external engine characteristics. It can be done during engine benchmarks or it can given by engine’s producer.
Engine flexibility is given by flexibility factor. It can be estimated on base of external engine characteristics\textsuperscript{[1]} using following equation:

\[ E = e_M e_n = \frac{M_{\text{omax}}}{M_N} \frac{n_N}{n_{\text{omax}}} \]  

(1)

Where:
- \( e_M \) - span (flexibility) of torque,
- \( e_n \) - span of turning speed,
- \( M_{\text{omax}} \) – maximum engine’s torque,
- \( M_N \) – torque related to nominal power,
- \( n_{\text{omax}} \) – turning speed of maximum torque,
- \( n_N \) – nominal turning speed

First part of this multiplication states the span (flexibility) of torque and depends on curve of engine’s torque. Route of this curve depends on factors such as: characteristic of inlet system, characteristic of timing gear, characteristic of power-supply system. By changing these parameters the route of torque curve can be influenced in way that the user wants, to properly adjust engine to its working conditions. The way torque flexibility is improved depends on possibilities and analysis of profitability of certain method in certain case (certain engine). If it comes to changing the second part of multiplication, it is strictly connected with changes in first part consisting in movement of torque curve maximum point. Span of turning speed depends on this maximum point and by manipulating it, efficient engine flexibility manipulation can be done.

2. Flexibility of multi-point injection engines

Multi-point injection gains broader and broader application if it comes to petrol engines. It is related to strict ecological and economical restrictions forcing development of inlet and supply systems of modern automotive engines. Because with multi-point injection method of getting combustion mixture is quite close to that in self ignition engines, it is now broadly used, but in the future the direct petrol injection seems to be bigger hope. Engines using this way of getting combustion mixture are up to ecological restriction but it would be interesting to test their dynamic properties. 64 engines of well known brands such as: Audi, BMW, Citroen, Deawoo, FIAT, Ford, Lancia, Mazda, Nissan, Opel, Peugeot, Renault, Rover, Toyota and Volovo were tested, gaining the average overall flexibility of \( E=1.724 \), which is quite a low value comparing to previously tested 206 engines using different methods of getting combustion mixture\textsuperscript{[4]} which got value of 2.073.

Also the simulations of flexibility factor using Leidemann’s equation with appropriate factors\textsuperscript{[4]} gave identical outcome. Statistical verification of reliability of gained results let us state, that minimum number of tests for this type of procedure is 36, assuming 5% error of flexibility deviation.
Standard deviation equals approximately 0.3, critical value is approximately 2 and maximum absolute error that can occur 0.1 (5% of average flexibility value \(E\)). That is the reason why in tests of 64 engines all mentioned conditions where fulfilled. It is confirmed by calculated values of variability factor measured with standard variation and equal to 16.67% of arithmetic mean value and average deviation amounting to 10.38%. Average deviation measures the flexibility dispersion of half of investigated engines (in narrowed variability range) in relation to mean value (median), but it has to be said that this parameter gets always lower values than variability factor. Because variability factor value is less than 20%, tested engines have very similar flexibility and thanks to that fact new Leidemann’s equation factors could be gained.

In recently tested sample of 206 engines, the great majority consisted of carburettor engines, which have bigger flexibility but are not up to economical and ecological norms. Using new values of factors in Leidemann’s equation increased probability level comparing to values obtained for mentioned sample of 206 petrol engines. For multi-point injection engines, average probability level of flexibility improvement increased form 0.0003 up to 0.0008.

3. **Flexibility of PSA-Renault ES9 engine**

Using the external characteristics of PSA-Renault ES9 engine, very modern in its designers assumptions, its flexibility was estimated with help of torque curve trace and producer’s technical data. Fig. no. 1 shows trace of torque curve for mentioned engine

\[ M_o \]
Nm

\[
\begin{array}{|c|c|c|c|c|c|c|}
\hline
\text{min}^{-1} & & & & & & \\
\hline
200 & 200 & 2000 & 3000 & 4000 & 5000 & 6000 \\
\hline
\end{array}
\]

\[ 300 \quad 240 \]

*Fig. 1 Trace of torque curve for PSA-Renault ES9 engine*

Characteristic data of PSA-Renault ES9 engine:
- rated power 140 kW with 5500 min\(^{-1}\),
- maximum torque 267 Nm with 4000 min\(^{-1}\),
- torque with rated power 243.4 Nm.

On basis of this data engine’s flexibility was estimated according to formula (1) and it resulted in: \(E=em \times en = 1.097 \times 1.375 = 1.508\), which is very low value for such a modern engine, especially when it is said by users to be very flexible engine [4].

The nature of the problem is given on fig. 1, which make it legible, that torque curve runs above 90% of maximum torque value on 90.1% of its total length, which is useful torque. It results in very flexible engine, because the engine works nearly always with the maximum torque. The supply field of the torque [1] is in this case close to
maximum, while in other engines, even the very flexible ones according to formula (1),
torque supply field is much smaller and only small part of torque curve lies above 90% of
its maximum value, as it is shown on fig. 2 for Opel ECOTEC V6 2.5 engine.

![Graph](image)

**Fig. 2 Trace of torque curve for Opel ECOTEC V6 2.5 engine**

In case of engine shown on fig. 2 only 66% of torque curve lies above 90% of its
maximum value (field marked with the arrows on the figure) although this engine has total
flexibility much higher than PSA-Renault ES9 estimated as $E=1.9$ – which makes it 26%
higher. Torque curve characteristics shown on fig. 2 has been estimated using computer
software fulfilling all before mentioned norms considering statistical reliability. There
could be of course found in world-wide literature (mainly Russian) more detailed methods
describing external engines characteristics than Leidemann’s equations, but these are
accurate enough to roughly characterize external characteristics of combustion engine in
relation to the method of gaining the combustion mixture and combustion itself.
4. Conclusion

Above mentioned examples together with considering about flexibility of combustion engines let us draw following conclusions:

1. Leidemann’s equations are a good tool for fast, rough characteristics of combustions engine, assuming that appropriate factors are used and method of gaining the combustion mixture and combustion itself for specific group of engines is properly assumed. The more engines were statistically tested to gain the Leidemann’s equation factors, the more reliable this factors are.

2. Not all engines can be accurately described although the statistical methods of gaining the correction factors is correct. That is the reason, why the additional criteria showing the part of torque curve being above 90% of its maximum value should be an important criteria taken into consideration when estimating flexibility of engine. It is especially important for engines with flat torque curve trace and relatively high values of torque.

3. Fulfillment of economical and ecological criteria forced on combustion engines by development in engines design and restrictive norms does not lead to any improvement if it comes to dynamics of spark ignition engines – on the contrary it leads to its deterioration parallel to design improvements. Flexibility of engines with spark ignition comes in following way, when ordered from highest to lowest values: carburettor engines, single-point injection engines, multi-point injection engines, direct injection engines.

4. Last point does not consider self-ignition engines within which the same strict norms led years ago to TDI engines, with flexibility factors much higher than it is before mentioned spark ignition engines.

Literature


UWAGI NA TEMAT WYZNACZANIA ELASTYCZNOŚCI SILNIKÓW SPALINOWYCH O ZAPŁONIE ISKROWYM

W artykule przedstawiono problematykę wyznaczania właściwości dynamicznych silnika benzynowego o wtrysku wielopunktowym, wpływających w oczywisty sposób na dynamikę pojazdu napędzanego przez ten silnik. Porównano te właściwości określone na drodze analitycznej poprzez współczynnik elastyczności silnika z symulacyjnymi badaniami przeprowadzonymi w oparciu o wzory Leidemanna. Stwierdzono, że przy odpowiednim doborze współczynników w tym wzorze można uzyskać wiarygodne wyniki bez uciekania się do kłopotliwych badań hamownianych silnika. Nie mniej jednak stwierdzono przypadki w ocenianej grupie silników dla których tradycyjna metoda oceny elastyczności jest mało skuteczna i taki przypadek omówiono w dalszej części artykułu oraz przedstawiono propozycję nowego podejścia do tego problemu.

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