TRACTIVE EFFORT CURVES IN GEARBOX ANALYSE

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ABSTRACT
A common feature of all engines with internal combustion is the need for a gearbox. This constructive requirement is justified with the practical fact that, if the torque and power characteristics of an engine would be geared directly to the working bodies of a consumer machine (such as road wheels) it could not ensure enough torque throughout the vehicles operational speed range. According to the operational task that the vehicle should manage, several solutions are used. Automatic (planetary) gearboxes and CVTs (Continuously Variable Transmission) allow gear ratio changes without power interruption. In other cases such as race car technology, multiple ratio gearboxes are caused by rules and regulations. In order to optimise gearbox performance, a wide range of analytical methods are used. One of the most frequently used, is the traditional straight line plot of road speed against engine rpm (rounds per minute) as a method of choosing ratios. Unlike this method, tractive effort curves include much more information and so they can publish how well ratios are suited to the engine`s characteristics as well as the fundamental track parameters that driven their choice.
This paper should state out the benefits of tractive effort curves in gearbox analyse. In order to maintain this, an instance from the Formula 1 was taken. Based on onboard video records of different tracks (in this example the tracks in Monaco and Monza were chosen), authors could approximately determine points of gear change and top speeds achieved within a certain ratio. These information allow to set a group of tractive effort curves (as well as several road speed – engine rpm diagrams). A huge amount of data, related not just to the gearbox, can be obtain when comparing results of these two methods and using them together.
Keywords: tractive effort curves, gearbox, torque, rpm, formula 1, ratio drop

1. INTRODUCTION

Every wheeled vehicle has to manage the power transfer from the engine to the working bodies. In order to achieve this, a set of devices is used, starting from the engine throughout the clutch, gearbox, differential and finaly the wheels (the term "Power train" is used). In order to achieve a high maximum vehicle speed, combined with good acceleration over the whole speed range, a gearing system is required, which permits the engine to operate at the speeds corresponding to its best performance. When speaking about engine performance, three main quantities have to be kept in mind: Power P (KW), engine rotation speed n (rpm) and Torque T (Nm). The main task is to transform rotational motion and potential energy at the engine flywheel into linear motion and kinetic energy at the vehicle tyre contact patch. These requirements are especially hard to achieve in race car design. In order to obtain and maintain top engine performance gearing is used to obtain twin objectives. On the

one hand if a lower gear ratio is chosen then the output shaft will rotate with a lower rotation speed (the term rev reduction is used) having more torque (tractive effort) left to overcome up or downhills. On the other hand, if a higher gear ratio is chosen then the output shaft rotates at higher rotation speed having less torque remain for up or downhills. Depending on the instantaneous driving situation, the driver is choosing the appropriate gear ratio he needs. Lower gears, with the highest numerical ratio, insure the highest torque multiplication so that they can provide high tractive effort from a standing start, or to get out of a slow corner, but the vehicle will be speed limited in them. The mid range gears provide a balance between tractive effort and speed, whilst at the top of the range, force is sacrificed force for velocity. To visualise this process and to estimate what gear ratios would be required, the traditional straight line plot of road speed against engine rpm is used (Figure 1).
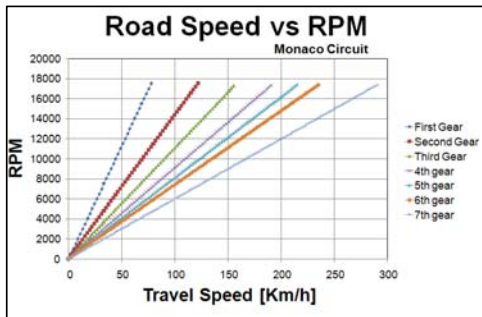

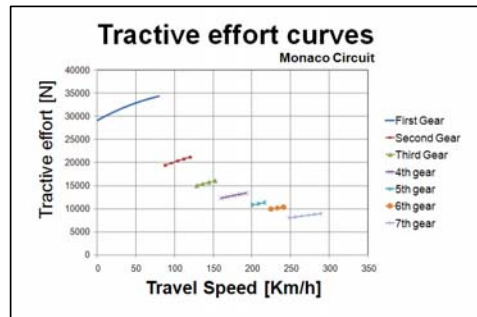Figure 1. Straight line plot against engine rpm

Figure 2. Tractive effort curves

Whilst this gives an indication of maximum speed in each gear and helps to assess the drop in engine rpm associated with changing up into the next ratio, its use is otherwise limited. It does not represent any engine parameters, and so the estimation of rpm drop is only as good as the driver's intuitive feel for how well the engine performs in this rpm range. The tractive effort curves, which quantify applied motive force at the ground, include all of this information and more, and so they can tell us how well our ratios are suited to the engine's characteristics as well as the fundamental track parameters that have driven their choice.

2. USE OF TRACTIVE EFFORT CURVES

Tractive effort is obtained by multiplying engine torque and the overall gear ratio (gear and final drive), and dividing by tyre radius (equation1). Road speed in each gear can be obtained from engine rotational speed using engine rotational speed, overall gear ratio, tyre radius, and so in effect we obtain scaled versions of the engine torque curve in each gear, plotted against the road speed range that we obtain through the engine rev range in that gear (Figure 2).

$$TE = \frac{M_E \cdot i_a}{r_T} [N] \qquad \qquad \dots \quad (1)$$

According to figure 2, in the lower gears these will appear to be scaled up along the vertical axis (which represents Tractive Effort) and down along the horizontal, or travel speed axis. In effect they look „squashed" horizontally and stretched vertically. In the higher gears the opposite occurs.
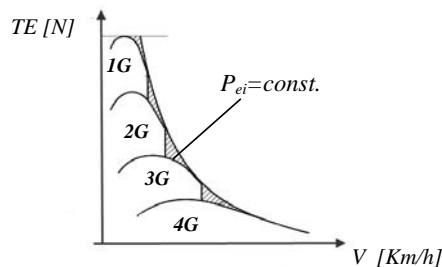

Figure 2. Tractive effort curves for ideal engine Power curve

As figure 2 shows, engine power will rise to a peak before starting to fall. After this peak the tractive effort curve develops a negative slope which increases. This negative slope causes that if the engine is taken to maximum rpm a point can be reached at which less tractive effort is produced as if the next gear would be selected one. That means that the acceleration would be would be faster i higher gears once past the point were the curves cross over. The area below a tractive effort curve is the product of Forces ad Velocities. The key to optimise the power of the engine throughout the vehicles speed range on a the track, is to maximise this area. If maximum rpm is reached in a gear before crossing the next tractive effort curve then a vertical boundary can be add to the set of curves which will intersect this curve. If a cross over the tractive effort curve would appear for the next gear by remaining in gear until maximum rpm, then a small, roughly triangular shaped section would be cut out of the available area every time when gear is changed. This areas would represent wasted power (hathed areas on figure 2).

3. PRACTICAL EXAMPLE FROM FORMULA 1

In order to confirm such theoretical settings given in the upper text, a practical example was taken from the Formula 1 race scene. Based on onboard video records of different tracks (tracks in Monaco and Monza were chosen), authors could approximately determine points of gear change and top speeds achieved within certain gear ratios.

Track parametars (lenght, speed, gear ratios in individual curves etc.) could be easily found on the internet. Formula 1 regulations limit their engine power to about 900 hp by maximum rotational speed of 18000 rpm (according to the year when the regulation appeared). Based on this informations and using the Lederman equations (2), basic engine parametars such as power and torque could be estimate.

$$P_e = P_m \cdot \left[\frac{n}{n_{max}} + \left(\frac{n}{n_{max}} \right)^2 - \left(\frac{n}{n_{max}} \right)^3 \right]$$

$$\dots \quad (2)$$

$$M_e = \frac{P_e}{\omega} = \frac{30 \cdot P_e}{n \cdot \pi}$$

Having used informations such as tyre radius in combination with basic engine performance, a series of tractive effort curves could be drawn for each of the discussed tracks (figure 3).
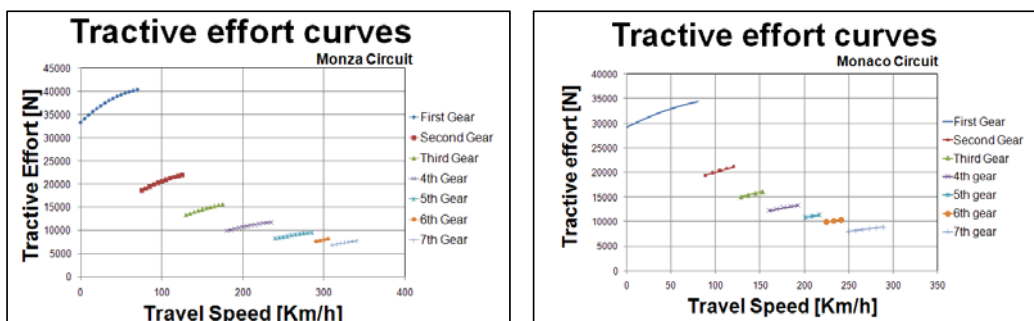

Figure 3. TE curves comparation for two different tracks

3.1. Data evaluation

Having in mind that the Monza track is a high speed circuit, achieved top speed of 340 Km/h, is ordinary. Unlike the Monaco track were climbs and hills prevail and a top speed of 289 Km/h can be achieved according to the TE curves. According to the TE curves, the hilly track in Monaco requests the use of the first gear more then the Monza track. In order to optimize gearbox performance a correct drop ratio between each gear change, must be chosen. Drop ratio is the rev drop between each gear. A to huge rev drop causes higher impact loads on the gearbox during gear changes. So the gears in first gear ratio have to take the highest stress. Authors find out, from the track info in Monaco, that the whole race takes over 3600 gear changes. All these information, and much more, could be obtained

from the TE curves. One other example is the drop ratio between first and second gear. According to the diagrams from figure 3, the rev drop between first and second gear, in Monza is much higher than the same one in Monaco. This is easily explained by the fact that the first and second gear is used much more in Monaco then in Monza. According to this, the impact load derived from high drop ratio in Monza should not cause any gearbox damage if well suited for the specific track parameters, especially race duration.

4. DISCUSSION AND CONCLUSION

Tractive effort curves have proven their use far away. A huge amount of data, not just about the gearbox, can be derived from it. Furthermore, TE curves can be described as "analytical signature" of the vehicle itself, which incorporate all it`s parts including the gearbox. Not only that it gives a huge amount of gearbox data away, it describes the fundamental track parameters which cause their existence. One short overview off the most important data which can be acquired from the TE curves could be given as:

- Evaluation of the drop ratio
- Diapason of rpm in each gear ratio
- Estimating stress of each gear
- Fundamental track parameters, is it either a high speed circuit or a city track with much gear change etc.

The area which lies below the tractive effort curves in the TE curves graph is the product of Forces and Velocity. The key to optimizing the power of the engine throughout the speed range of the track in question is to maximize this area. A curve can be drawn that will run from top left top to bottom right on the graph and which is tangential to each tractive effort curve. This curve could be obtained if an infinite number of gear ratios would be available, instead of the discreet number as shown. In other words it represents the power exploited if we had a continuously variable transmission system (CVT) which is in most race car regulations forbidden so that tractive effort curves will stay essential in analyse of gearbox performance.

5. REFERENCES

[1] Harald Reichenbächer: "Gestaltung von Fahrzeuggetrieben", Springer Verlag, Berlin 1955
[2] Peter Elleray:" Using tractive effort curves to analyse gearing", RET-Monitor.com
[3] Peter Elleray:" Tractive Effort", RET-Monitor.com
[4] Ivan Filipović:" Motori i Motorna vozila", Tuzla, februar 2006
[5] P. Knor: „Projektovanje i konstrukcija motornih vozila", Sarajevo 2005/2006
[6] N.Repčić: "Prenosnici snage i kretanja";