ANNEX 2

GEAR SELECTION AND SHIFT POINT DETERMINATION FOR VEHICLES EQUIPPED WITH MANUAL TRANSMISSIONS

1. General Approach

The following shifting procedures apply to vehicles equipped with manual transmissions. In order to take into account technical progress and the increased variety of transmission design (e.g. 4-speed up to 7-speed gearboxes) shift points at fixed vehicle speeds are no longer appropriate. In order to reflect practical use as well as fuel efficient driving behaviour as much as possible, the prescribed gears and shifting points are based on the balance between the power required for overcoming driving resistance and acceleration, and the power provided by the engine in all possible gears at a specific cycle phase. In order to cover the wide range of rated engine speeds (e.g. 3200 to 8000 min⁻¹) depending of the engine technology, the calculation is based on normalised engine speeds (normalised to the span between idling speed and rated engine speed) and normalised full load power curves (normalised to rated power) versus normalised engine speed.

2. Required Data

The required data is described below and summarised in Table 1. The following data is required to calculate the gears to be used when driving the cycle on a chassis dynamometer:

(a) \( P_{\text{rated}} \), rated engine power. The maximum power of the engine as declared by the manufacturer.

(b) \( s \), rated engine speed. The engine speed at which an engine develops its maximum power. If the maximum power is developed over an engine speed range, \( s \) is determined by the mean of this range.

(c) \( n_{\text{idle}} \), idling speed as defined in Annex 1 of ECE R 83

(d) \( n_{\text{min\_drive}} \), minimum engine speed for short trips, and is used to define downshifts. The minimum value is determined by the following equation:

\[
 n_{\text{min\_drive}} = n_{\text{idle}} + (0.125) \times (s - n_{\text{idle}}) \tag{1}
\]

Higher values shall be used if requested by the manufacturer.

(e) \( i = 1 \) to \( n_{g_{\text{max}}} \), determine the gear number

(f) \( n_{g_{\text{max}}} \), the number of gears

(g) \( n_{vd_i} \), a ratios determined by dividing \( n \) in min⁻¹ by \( v \) in km/h for each gear \( i \), \( i = 1 \) to \( n_{g_{\text{max}}} \).

(h) \( m_t \), test mass of the vehicle in kg.
The calculation steps are described in the following paragraphs and summarised in Table 2.

3.1. Calculation of required power

For every second \( j \) of the cycle trace the power required to overcome driving resistance and to accelerate is calculated using the following equation:

\[
P_{\text{required},j} = \left[ f_0 \times v_j + f_1 \times (v_j)^2 + f_2 \times (v_j)^3 \right]/3600 + \left[ (kr \times a_j) \times v_j \times m_t \right]/3600 \tag{2}
\]

where:

- \( f_0 \) is the road load coefficient in N
- \( f_1 \) is the road load parameter dependent on velocity in N/(km/h)
- \( f_2 \) is the road load parameter based on the square of velocity in N/(km/h)^2
- \( P_{\text{required},j} \) is the power required in kW at second \( j \)
- \( v_j \) is the vehicle speed at second \( j \) in km/h,
- \( a_j \) is the vehicle acceleration at second \( j \) in m/s^2, \( a_j = (v_{j+1} - v_j)/3.6 \)
- \( m_t \) is the vehicle test mass in kg,
- \( kr \) is a factor taking the inertial resistances of the drivetrain during acceleration into account and is set to 1.1.
3.2. Determination of engine speeds

For each $v_j \leq 1$ km/h, the engine speed is set to $n_{idle}$ and the gear lever is placed in neutral with the clutch engaged.

For each $v_j \geq 1$ km/h of the cycle trace and each gear $i$, $i = 1$ to $n_{g_{max}}$, the engine speed $n_{ij}$ is calculated using the following equation:

$$n_{ij} = n_{dv_i} \times v_j$$  \hspace{1cm} (3)

All gears $i$ for which $n_{min} \leq n_{ij} \leq n_{max}$ are possible gears to be used for driving the cycle trace at $v_j$.

$$n_{min} = n_{min_{drive}}, \text{ if } i \geq 3,$$

$$= 1.25 \times n_{idle}, \text{ if } i = 2,$$

$$= n_{idle}, \text{ if } i = 1.$$

$$n_{max} = 0.9 \times (s - n_{idle}) + n_{idle}.$$  \hspace{1cm}

In cases where $v_j \geq 1$ km/h and $n_{1,j}$ drops below $n_{idle}$, the only possible gear is $n_{g} = 1$ and the clutch must be disengaged.

3.3. Calculation of available power

The available power for each possible gear $i$ and each vehicle speed value of the cycle trace $v_j$ is calculated using the following equation:

$$P_{\text{available,ij}} = P_{\text{norm,woe}}(n_{norm_{i,j}}) \times P_n \times SM$$  \hspace{1cm} (4)

where:

$$n_{norm_{i,j}} = (n_{dv_i} \times v_j - n_{idle})/(s - n_{idle}),$$

$P_n$ is the rated power in kW,

$P_{\text{norm,woe}}$ is the percentage of rated power available at $n_{norm_{i,j}}$ at full load condition from the normalised full load power curve,

$SM$ is a safety margin accounting for the difference between stationary full load condition power curve and the power available during transient conditions. $SM$ is set to 0.9.

$n_{idle}$ is the idling speed in min$^{-1}$

$s$ is the rated engine speed, the engine speed in min$^{-1}$ at which an engine develops its maximum power. If the maximum power is developed over an engine speed range, $s$ is determined by the mean of this range.

3.4. Determination of possible gears to be used

The possible gears to be used are determined by:

$$1 \leq n_{ij} \leq n_{max}$$

as defined in paragraph 4.1.4 of this annex and
(2) \( P_{\text{available},i,j} \geq P_{\text{required},j} \)

\( P_{\text{available},i,j} \) as defined in equation 2, \( P_{\text{required},j} \) as defined equation 4 of this annex.

The initial gear to be used for each second \( j \) of the cycle trace is the maximum final possible gear \( i_{\text{max}} \).

**Table 2: Calculation steps**

<table>
<thead>
<tr>
<th>Step</th>
<th>Task</th>
<th>Description/Requirements</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Calculation of required power</td>
<td>( P_{\text{required},j} = \frac{\left( f_0 \times v_j + f_1 \times (v_j)^2 + f_2 \times (v_j)^3 \right)}{3600} + \frac{\left( k_r \times a_j \times v_j \times m_j \right)}{3600} ) for each second ( j ) of the cycle trace, ( a_j ) is the vehicle acceleration, ( k_r ) is a factor taking the inertial resistances of the drivetrain during acceleration into account and is set to 1.1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Determination of engine speeds for each gear ( i )</td>
<td>( n_{\text{min}} = n_{\text{min},\text{drive}} ) if ( i \geq 3 ), ( = 1.25 \times n_{\text{idle}} ) if ( i = 2 ), ( = n_{\text{idle}} ) if ( i = 1 )</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Calculation of available power</td>
<td>( P_{\text{available},i,j} = P_{\text{norm},\text{wot}}(n_{\text{norm},i,j}) \times P_{\text{rated}} \times \text{SM} )</td>
<td>SM is a safety margin accounting for the difference between stationary full load condition power curve and the power available during transient conditions. SM is set to 0.9.</td>
</tr>
<tr>
<td>4</td>
<td>Determination of possible gears to be used</td>
<td>The possible gears to be used are determined by ( 1 \left( n_{\text{min}} \leq n_j \leq n_{\text{max}} \right) ) as defined in paragraph 4.1.4 of this annex and ( 2 \left( P_{\text{available},i,j} \geq P_{\text{required},j} \right) ) as defined in paragraph 4.1.5 of this annex, ( P_{\text{available},i,j} ) as defined in paragraph 4.1.3 of this annex</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Final gear choice</td>
<td>( i_{\text{max}} ) determines the highest possible gear</td>
<td></td>
</tr>
</tbody>
</table>

\( j \) is the index for the cycle time, \( i \) is the index for the gear number.

4. Additional requirements for corrections and/or modifications of gear use

The initial gear selection shall be checked and modified in order to avoid too frequent gearshifts and to ensure driveability and conformity with practical use. The requirements are described below and summarised in Table 3.

Corrections and/or modifications shall be made according to the following requirements:

(a) First gear shall be selected 1 second before beginning of an acceleration phase from standstill. Vehicle speeds below 1 km/h imply that the vehicle is standing still.

(b) Gears shall not be skipped during acceleration phases. Gears used during accelerations and decelerations must be used for a period of at least 3 seconds.

E.g. a gear sequence 1, 1, 2, 2, 3, 3, 3, 3, 3 is replaced by 1, 1, 1, 2, 2, 3, 3, 3, 3

(c) Gears may be skipped during deceleration phases. For the last phases of a deceleration down to a stop, the clutch may be either disengaged or the gear lever placed in the neutral position and the clutch engaged.
(d) There shall be no gearshift during transition from an acceleration phase to a deceleration phase. E.g., if \( v_j < v_{j+1} > v_{j+2} \) and the gear for the time sequence \( j \) and \( j+1 \) is \( i \), gear \( i \) is also kept for the time \( j+2 \), even if the initial gear for \( j+2 \) would be \( i+1 \).

(e) If a gear \( i \) is used for a time sequence of 1 to 5 s and the gear before this sequence is the same as the gear after this sequence, e.g. \( i-1 \), the gear use for this sequence is corrected to \( i-1 \).

That means:

1. a gear sequence \( i-1, i, i-1 \) is replaced by \( i-1, i-1, i-1 \)
2. a gear sequence \( i-1, i, i-1, i \) is replaced by \( i-1, i-1, i-1, i-1 \)
3. a gear sequence \( i-1, i, i, i-1 \) is replaced by \( i-1, i-1, i-1, i-1, i-1, i-1 \)
4. a gear sequence \( i-1, i, i, i, i-1 \) is replaced by \( i-1, i-1, i-1, i-1, i-1, i-1, i-1 \)
5. a gear sequence \( i, i-1, i \) is replaced by \( i, i, i, i, i, i \)

for all cases (1) to (5), \( g_{\text{min}} \leq i \) must be fulfilled.

(f) A gear sequence \( i, i-1, i, i-1 \) is replaced by \( i, i, i, i, i, i \) if the following conditions are fulfilled:

1. the engine speed does not drop below \( n_{\text{min}} \)
2. These corrections do not occur more often than 4 times each for the low, medium and high speed cycle parts and not more than 3 times for the extra high speed part.

Requirement (2) is necessary as the available power will drop below the required power when the gear \( i-1 \) is replaced by \( i \). This should not occur too frequently.

(g) If during an acceleration phase a lower gear is required at a higher vehicle speed, the higher gears before are corrected to the lower gear, if the lower gear is required for at least 2 s.

Example: \( v_j < v_{j+1} < v_{j+2} < v_{j+3} < v_{j+4} < v_{j+5} < v_{j+6} \). The originally calculated gear use is 2, 3, 3, 3, 2, 2, 3. In this case the gear use will be corrected to 2, 2, 2, 2, 2, 2, 3.

Since the above modifications may create new gear use sequences which are in conflict with these requirements, the gear sequences shall be checked twice.

Table 3: Additional requirements for corrections/modifications

<table>
<thead>
<tr>
<th>Step no</th>
<th>Step</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>First gear shall be selected 1 second before the beginning of an acceleration phase from standstill. Vehicle speeds below 11 km/h imply that the vehicle is standing still.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Skipping of gears during acceleration phases is not permitted. Gears used during accelerations and decelerations must be used for a period of at least 3 seconds.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Skipping of gears during deceleration phases is permitted. For the last phase of a deceleration down to stop, the clutch may be either disengaged or the gear lever in neutral position and the clutch engaged.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>There shall be no gearshift during the transition from an acceleration phase to a deceleration phase.</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>If a gear ( i ) is used for a time sequence of 1 to 5 s and the gear before this sequence is the same as the gear after this sequence, e.g. ( i-1 ), the gear use for this sequence is corrected to ( i-1 ).</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>If a gear sequence ( i, i-1, i ) is replaced by ( i, i, i ), if the following conditions are fulfilled:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1) the engine speed does not drop below ( n_{\text{min}} ) and</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(2) These corrections do not occur more often than 4 times each for the low, medium and high speed cycle parts and not more than 3 times for the extra high speed part.</td>
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<td>7</td>
<td>If during an acceleration phase a lower gear is required at a higher vehicle speed, the higher gears before are corrected to the lower gear, if the lower gear is required for at least 2 s.</td>
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Example: The originally calculated gear use is 2, 3, 3, 3, 2, 2, 3. In this case the gear use will be corrected to 2, 2, 2, 2, 2, 2, 3.

These modifications may create new gear use sequences which are in conflict with these requirements, so the gear sequences shall be checked twice.