The Influence of Temperature on Manual Transmission Shiftability

In Europe, the classic manual transmission has been able to maintain its dominant position until today, while in the USA and in Japan, the automatic transmission has long since become widely established. The customer also expects a continuous improvement in the manual transmission. Within this context, one of the main disturbance factors is the ambient temperature, which might cause considerable deviations from the ideal shift force vs. shift time behaviour. This paper by Ford and Getrag Ford Transmissions discusses the related phenomena.

1 Introduction
Modern automotive technology is characterized by increasing comfort and automation. This also affects the transmission. The market share for automatic transmissions is 90% in the US and 54% in Japan [1]. In Europe, however, the classic manual transmission has been able to hold its dominant position until today. The customer also expects a continuous improvement in shiftability in this case too. In effect, this means a shift force vs. shift time behaviour which is associated with a pleasant shift feel and an acceptable force level applied by the driver. Within this context, one of the main disturbance factors is the ambient temperature, which might cause considerable deviations from the ideal force vs. time behaviour. This paper discusses related phenomena.

2 Basics
For the investigations, an analysis of the driveline and gearshift controls, the shift force characteristics and the dynamic effects was carried out.

2.1 Driveline and Function of a Gearshift Control
Assuming that a vehicle is equipped with a manual transmission, the driveline con-

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sists of the engine, clutch, transmission and differential gear and – in the case of rear wheel drive – an additional prop shaft. Manual passenger car transmissions are usually designed with two or three shafts, which carry the torque-transmitting gears. Each pair of meshing gears determines a certain gear ratio, also called a “gear” or “speed”. One of the two gears is directly connected to its carrier shaft (fixed gear), whereas the other one may rotate freely on its shaft, although axially fixed (loose gear). Connecting the loose gear with the carrier shaft will engage the gear.

The gearshift controls make up the mechanism that converts the shift lever motion into the connection of the loose gear and carrier shaft. The connection is made by a synchronizer sleeve which docks into appropriate teeth (clutch ring) on the loose gear. The synchronizer sleeve travel is directly linked to the shift lever motion via the controls.

A detent system stabilizes the shift lever in neutral and in-gear positions. This detent system also influences the shift force characteristic perceived by the driver. The rotational speeds of the loose gear and its carrier shaft have to be synchronized before the sleeve can dock into the loose gear. This synchronization is performed by the so-called synchronizer ring, which is pushed against a friction cone at the side of the loose gear. The complete detent system consists of the synchronizer hub, synchronizer sleeve, synchronizer ring and clutch ring. Figure 1. The synchronizer unit performs a variety of complex functions, in spite of its low number of components.

During the synchronization phase, the axial travel of the synchronizer sleeve has to be inhibited in order to prevent the sleeve from docking into the clutch ring of the loose gear while still rotating relative to it. Figure 2 explains the phases of the synchronization. During this phase, the tooth chamfers of both the synchronizer blocker ring and the synchronizer sleeve contact each other. This axial force acting on the sleeve generates a relative torque between the two parts. Choosing an appropriate chamfer angle will result in this torque being smaller than the friction torque resulting from the same axial force. This torque difference will position the synchronizer blocker ring at a predetermined angular end stop, thus “blocking” any further sleeve travel during the synchronization phase [2].

The angular positioning of the blocker ring has to be completed before the sleeve reaches its blocking position. This is achieved by the pre-synchronization device, which pushes the blocker ring onto the cone at the very beginning of the gearshift. Thus, a small friction torque is generated, which initiates the positioning process. Usually, this is achieved by means of struts and springs.

2.2 Shift Force Characteristics
Assuming a quasi-static shift event with a constant shift speed and the absence of dynamic interference, one will have the idealized shift force behaviour as shown in Figure 3, Table 1 and Table 2. This behaviour is based on the assumption that the input shaft drag torque acts against the synchronizer friction torque, which is usually the case during downshifts. The characteristic between points 0 and 1 (Figure 3) is the result of free play, and no force is transmitted to the synchronizer sleeve. In the next phase (phase 1–2), the driver operates the shift lever until a sufficient force level is reached, which releases the detent device and the sleeve starts its initial free travel towards the loose gear (phase 2–3). This is followed by the pre-synchronization phase (phase 3–4), after which the synchronization of the transmission input shaft takes place (phase 4–5). The shift force ramps up due to the inhibited sleeve travel while the driver continues to push the lever towards the in-gear position. The sleeve is released when the speeds of the loose gear and the sleeve are the same. It then starts moving again, thus reducing the system tension and subsequently the force (phase 5–6). The force remains at almost zero during the following “free travel phase” (phase 6–7). The next stages (phase 7–11) are the dock-in and the final engagement phases, once again showing a force peak, the so-called second peak.

The force characteristics according to Figure 3 are extremely dependent on the properties of the technical subsystems involved and the driver’s behaviour. For example, the maximum synchronization force peak is a function of the shift speed determined by the driver. A driver-independent parameter has therefore been introduced: the so-called synchro-force integral (force vs. time integral). This parameter is dependent on the system only; the driver can either shift at a high force level in a short time or at a low force level and accept a longer shift duration.

The dock-in phase (phase 8–10) shows a force peak which is almost proportional to the shift speed. Further influencing parameters are the shift system ratio and the stiffness. In addition, it is necessary to consider the minimum required shift force in any functional phase that is required to accomplish the shift event. Considering this, the most critical phases are the push-by phase (phase 5–6) and the dock-in phase (phase 8–9).