Shift System Components in Manual Transmissions

Automotive Product Information API 09
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INA's expertise in developing shift systems and components is based on many years of experience working closely with automobile and transmission manufacturers.

Because of the continuous development of components and the use of cutting-edge technologies in manufacturing our products, INA is a well-known engineering partner and a full service supplier. INA employs the most modern engineering and quality assurance methods currently used.

These methods include:

- **QFD – Quality Function Deployment**
  - To establish customer requirements and translates these requirements into a design concept

- **CAE – Computer Aided Engineering**
  - The use of state-of-the-art analysis and calculation methods for component design and function simulations respectively

- **Tests to Verify Function and Operation MEOST (Multiple Environment Overstress Testing)**
  - To evaluate a manual transmission in terms of the following:
    - shifting characteristics
    - shift forces – under extreme temperatures
    - friction characteristics
    - component strength
    - service life
    - corrosion resistance
    - transmission testing under simulated operating conditions to fine-tune components to the desired performance level

**Modern Manufacturing Technology**

INA's technology allows a cost-effective component design by means of the following:

- high precision machining or cold forming of components
- extrusion methods
- heat treatment
  (e.g. hardening)
- surface plating
  (INA Corrotect® plating and DSV thin layer chrome plating)
- in-house plastic molding
- fine blanking techniques
- state-of-the-art welding and bonding technology
The customer’s acceptance of a vehicle is greatly influenced by the positive operation of the transmission and how well it is adapted to the vehicle. However, with increasing comfort demands, additional criteria are now being used to evaluate the quality of manual transmissions such as ease of use, shift comfort and positive shift feel.

**Transmission Operation: Driver Requirements** – Figure 1
Since the shift system is the only direct connection between the driver and the transmission, the perceived shift quality is important in the driver’s assessment of the vehicle.
The driver wants:
1. to know the shift lever position at all times
2. to feel precise resistance when shifting
3. to use minimal and consistent force when shifting gears
4. minimum shift lever throw

**Gear Shifting: Design Requirements**
The perceived quality of shifting can be achieved through the proper design of the shift system.
Gear changes are judged positively if they have the following characteristics:
- precise
- quick
- require little effort
- smooth

**Ideal Shifting** – Figure 2
It is extremely difficult to base technical requirements on a “positive shift feel” since this is necessarily a subjective evaluation.
One solution is to evaluate the mechanics of the shift system and plot the shift lever displacement, lever force and shift time in a graph. Observing the time and speed of the gear shift allows technically feasible “ideal shifting conditions.”

**Gear shifting operation**
Shifting gears involves two orthogonal motions of the shift lever the “selection” stroke and the “shift” stroke:
1. the shift rail is chosen in the “selection” stroke
2. in the “shift” stroke, a gear is synchronized and engaged
Ideal Shift Lever Moment Curve during the Selection Stroke

In order for the driver to get the ideal lever feel when selecting a shift rail, the following conditions must be given:
- The gearshift lever must be in neutral.
- The motion curve must be smooth across the entire pivoting range.
- The force required must be minimal and increase gradually.

Theoretical Ideal Shift Lever Moment Curve

Figure 3 shows the theoretical ideal moment curve when the gear shift lever is pivoted left and right from the neutral position. Positive and negative directions are indicated in the graph.

Positive direction
When the lever is pivoted to the 5th/reverse gear shift gate, the lever is said to pivot in the positive direction.

Negative direction
Pivoting the shift lever into the 1st/2nd gear shift gate corresponds to the negative direction. Reversing the pivot direction also reverses the moment direction.

Interpreting the moment curve
- The sharp rise in the curve from the horizontal axis results from the clearance-free lever support in the neutral position.
- The remainder of the curve is smooth and rises gradually. A horizontal curve – corresponding to a constant shift force – would be assessed as being undefined and unstable.
- The final position of the shift lever is marked by another increase in moment. This final effort spike is favored by the driver.
- The moment values are on the return stroke, the hysteresis, is from the lever inertia.

Figure 3 · Moment curve during the selection stroke

1 = Neutral position
2 = Selection motion
3 = Final position
4 = Return motion
5 = Shift travel
6 = Return displacement
Shift elements in vehicle transmissions such as selector shafts, shift rails, shift rods and reversing levers must have the best bearing supports possible. To do this, their function in the transmission housing must be considered. The type of bearing support – plain bearing or rolling bearing arrangements – has a significant effect on the shift process, the shift curve and thus the feel the driver has when shifting.

**Shift Lever Moment Curves for Shift Systems Supported by Plain Bearings and in Rolling Bearings** – Figure 4

The shift system of a manual transmission used for comparison is mounted in an aluminum housing and incorporates a selector shaft, shift rails as well as a steel reversing lever. The selector shaft and shift rods have plain bearing supports in machined bores of the transmission housing.

**Shift system with plain bearing supports**
The reversing lever has plain bearing supports on steel studs on both sides.

**Shift system with some rolling bearing supports**
As a means of comparison, the reversing lever has rolling bearing supports on the steel stud.

**Measuring conditions**
The selection motion was measured in the shift gate neutral position and in 1st/2nd gears to the opposite positions 3rd/4th gears and 5th/reverse gears respectively. The pivoting motion occurred in less than two seconds. The maximum pivot angle of the selector shaft was $12^\circ$. The moment was checked at the selector shaft at the transmission entry.

Several overlapping motion measurements are given in Figure 4.

**Interpreting the moment curve**

1. The design containing only plain bearings displays an imprecise neutral position of the shift lever. The friction between the movable components leads to significant losses in aligning force (hysteresis).
2. Due to the significantly lower internal friction of the rolling bearings, the moment curve is much better and hysteresis is lower. Even the return stroke of the shift lever to the neutral position is more precise.

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**Figure 4** - Comparing the moment curves during the selection stroke:
reverse lever with plain bearing supports versus rolling bearing supports
Positive and negative shift forces occur across the shift curve or shift path.

**Positive shift forces**
The positive shift forces counteract the motion of the driver's hand.

**Negative shift forces**
The negative shift forces result when the direction of the shift force is reversed. The driver notices a reduction in resistance.

### Theoretical Ideal Shift Lever Force Curve

The theoretical ideal shift forces curve – see also section entitled Ideal Shifting, p. 5 – for the necessary shift motion when engaging a particular gear is described in Figure 5.

#### Interpreting the shift lever force curve

1. The shift stroke is initiated by moving the gear out of the neutral position with the shift lever.
2. The increase to the first force peak – the synchronization of speeds – follows. It is not too high and does not stop abruptly.
3. The second force peak characterizes smooth gear clutch teeth engagement.
4. Reversing the force conveys the feeling that the gear has reached the final position on its own. The shift stroke is now complete since the shift lever locks.
5. When shifting the gear back from the final position, a precise force increase occurs followed by a force reverse.

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**Figure 5** · Theoretical ideal force curve during the shift stroke

- \( \equiv \) Neutral position
- \( \equiv \) Synchronization
- \( \equiv \) Gear engagement
- \( \equiv \) Final position
- \( \equiv \) Return displacement
The earlier and more precise the force reversal occurs (i.e. the shift lever is back in the initial position in the shift gate), the higher the driver’s assurance that the gear has been disengaged properly.

**Shift Lever Force Curve – Comparative Measurements**

Figure 6 shows force curves for shift strokes from 1st to 2nd gear and from 2nd to 3rd gear.

**Measuring conditions**

Several measurements were made on the selector shaft of a manual transmission containing rolling bearings. The measurements are shown in the figure below projected on top of each other.

Interpreting the shift force curve

The movement to the right in the figure shows the shift curve for 1st and 3rd gears and the movement to the left the curve for the opposite 2nd gear. Since the direction is reversed here, the direction of force also changes.

The shift points described in the section entitled *Theoretical Ideal Shift Lever Force Curve*, p. 8 can clearly be seen here. Although the required force is at different levels depending on the gear, it is not the ideal force.

When shifting from 1st to 2nd gear, the force difference between the points “speed synchronization” and “engagement” is still too large to be evaluated as favorable.

Figure 6 · Comparison of force curves during shift travel
Separate optimization attempts will not bring about the required comfort for the entire shift system, even when expensive and flawless bearing are used.

For this reason INA develops and manufactures specific products for vehicle shift systems that are adapted to the entire transmission application. A selection of these products is given in Figure 7.

Automobile Shift System Component Selection

1. Permaglide® plain bearings for rotary and linear motion
2. Rolling bearings for rotary and limited linear motion for round shaft cross sections
3. Rolling bearings for limited linear motion for rectangular cross-sectioned shafts
4. Rolling bearings for limited linear motion with torque transmission
5. Rolling bearings for rotary and oscillating motion for bearing supports in the shift fork, such as drawn cup needle roller bearings (open/closed end) and angular contact ball bearings
6. Detent pins
7. Intermediate rings for multiple-cone synchronization
8. Gear shift modules

Development Trends

Because of the increasing demand for systems solutions, INA also supplies components or assemblies. These products have the following advantages:

- combine several functions in one assembly
- fit the mating parts exactly
- reduce manufacturing complexity at the transmission assembly.

Figure 7 · Selection of products for manual transmissions
### Addresses

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