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Human factors analysis of manual gear shifting performance in passenger vehicles

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Abstract

Driver sensation during a gearshift in a manual transmission is one of the most remarkable actions in terms of comfort perception in motor vehicles. This importance has increased in a reasonable way in the last years mainly because of higher quality requirements demanded by the market.All movements and efforts, mainly the so-called double bump, are directly transferred to the drive's hand thru the gearshift lever inside the vehicle and cables that make the connection of the lever with the shifting tower.Having said that, it is possible to verify in the available literature that no human interaction analysis with the gearshift system considering human factors and ergonomics (HFE) are used to define its relation to the physical values observed during the process of gearshifting (e.g. efforts, impulses, times, etc.) to support changes in the transmission hardware.Therefore, using a HFE approach for the gearshift system, this study analyzes the models of the available literature and check its considerations, and applying HFE concepts proposes a different approach to estimate human perception about shift comfort.

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*Keywords:*Manual transmission; Shift quality; Shift comfort; Human factors; Ergonomics

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1. Introduction

Driver'stactile sense during a gearshift operation is one of the most remarkable activities in terms of comfort perception in cars equipped with manual transmissions. This importance has grown in a considerable manner in the last years mainly due to the continuously increase in quality requirements imposed by the market.

A deeper study in the gearshift system and, more specifically, the synchronization system was initiated in a pioneer manner by M'Ewen [1] who analyzed the manual transmissions of combat tanks, just after the 2nd Great World War. Once at that time the majority of the synchronization systems developed for passenger cars were created thru the try-and-error method without any literature to explain/exemplify, the study published by M'Ewen [1]analyzed the events that take place during a gearshift and defined an "elementary" theory to size the synchronizers of a given manual transmission. And, the differential and algebric equations presented by the author can be found in several recent studies about the subject, being the fundamental base of current developments.

Several factors affect the gearshift quality, as for example the scratch during engagement phase, effort, harshness, precision, others, with great interaction with the anthropometric (e.g. height) and behavioral (slow or sporty gearshift?) differences of the drivers and the ergonomics of the passenger compartment. This analysis showed to be extremely complex to be done during the design phase of a manual transmission [2].

Abel, Schreiber and Schindler [3]andRazzackiandHottenstein[4] studied the synchronization system and engagement/selection mechanisms in details in order to improve the project of the control systems of the manual transmission autoshifted (MTA), however few literatures, like the one published by Kim et al. [2], consider some kind of interaction of the entire gearshift system with the driver. And, once the very first interaction of a driver with a new gearshift system happens in a late phase of the vehicle development timing,in case of any problem detected in this moment that leads to design changes is extremely expensive for the vehicle program.

It is valid to mention the deep studies performed by Hannemann [5] which had the objective to define a model that would consider just the objective aspects during a shift to predict a human rating of the entire system removing the inherent variability due to the natural HFE differences of a given population. Following this path, it would be possible to estimate the drive's satisfaction about the system considering just impulses, force, number of peaks, etc. felt during a gearshift.

Another point to evaluate is the ergonomics of the gearshift lever inside the passenger compartment, which was analyzed by Barbosa [6] who performed an extensive research considering ergonometric parameters to determine the characteristics of the system that affect the drive most in terms of reachability. But, even this thesis was very restricted to analyze only reachability, not covering the other HFE aspects that affect directly the quality perception for the driver.

In this study, these points are analyzed using a subjective evaluation of shift comfort (better detailed in chapter 3), done by two trained drivers, and compared to math models used to predict human rating using objective characteristics of the system (e.g. impulse). A non-linear model considering HFE aspects is proposed and compared to the mentioned available models.

2. Manual transmission gearshift system

As mentioned by Lechner and Naunheimer [7], one of the functions of an automotive manual transmission is the power matching, which is an activity totally dependent of driver's action. The authors also mention that the gearshift system, since the shift lever inside the vehicle compartment till the synchronization system inside the transmission, has a considerable importance in terms of perception, once it is one of the primary interfaces among the driver and the car.

Also, according to Lechner and Naunheimer [7], the gearshift system can be divided in:

- Internal: forks, sleeves, synchronizers, struts, selection bars, etc.;
- External: cables, rod, compensation device and shift lever.

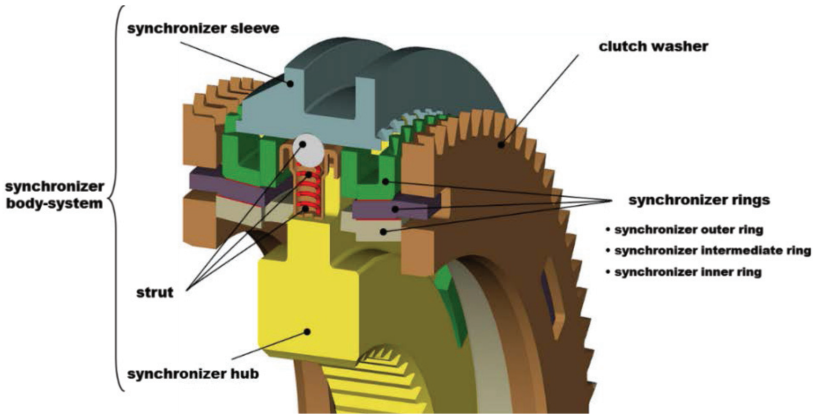

Fig. 1.Triple cone synchronization system representation.

In Fig. 1 presents the internal elements regarding the synchronization system. Basically, the sychronization system of a manual transmission is responsible for synchronizing the speed difference among input and output shafts of the transmission.

The entire synchronization process can be divided in nine stages (GM Powertrain, 2013):

- Stage 1: free travel from neutral position, which has no torque transfer. This stage can also start from a disengagement from a previous gear called here as start of disengagement (SoD);
- Stage 2: beginning of the contact among strut and synchronization ring, initiating the indexing process or pre-synchronization (PrS);
- Stage 3: indexing process concluded;
- Stage 4: contact of synchronization ring with the sleeve cone, initiating the synchronization phase (SoS);
- Stage 5: end of synchronization ring blocking (EoS) and beginning of ring and gear turn due to cone friction;
- Stage 6: second free travel;
- Stage 7: tip contact (TpC) of the sleeve against the gear clutch washer. In this stage is possible to detect the double bump phenomena;
- Stage 8: end of gear angular movement;
- Stage 9: full engagement (FuE).

All movements and forces generated by synchronization system are directly transferred to the drive's hand thru the linkage system also called gearshift system. Nowadays, in majority, this system is basically composed by the lever inside the vehicle compartment and cables connecting the lever to the gearshift tower in the transmission (Fig. 2).

Fig.2.Cable gearshift system.

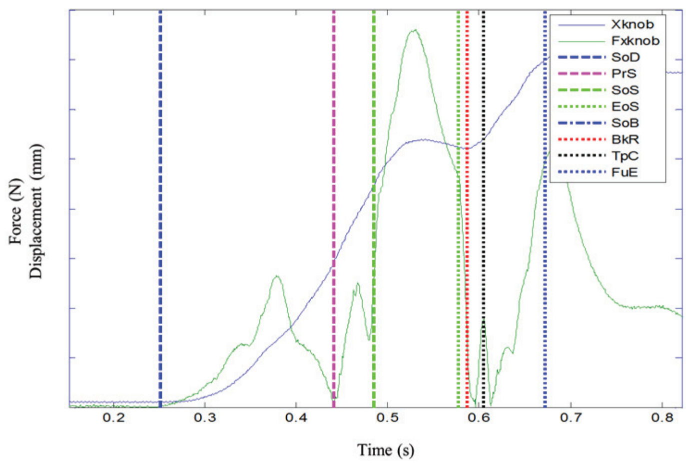

Fig. 3.Force and displacement behavior in the lever knob.

It is possible to see in Fig. 3 a typical force and movement measurement in the lever knob during a gearshift (e.g. first to second gear), where $F_{x,knob}$ represents disengagement or engagement force in X_{knob} direction.

Once being this type of measurement exactly what the driver feels during a gearshift, it is used for several types of analyses and/or calculations, such as impulses, double bump detection F_{bump}, maximum synchonization force F_{max} scratch index, etc. And, to support all analyses done in this work, a GM Powertrain code written in Matlab called Shift Quality Analysis Tool (SQAT) is used to post-process data, generate graphics (such as Fig. 3) and provide indexes from each gearshift event.

3. Human factors and ergonomics related to gearshift quality

It is possible to find in the available literature several definitions about gearshift quality, but definetely all articles found lead to a very "wide" definition and has "evolved" in the last years mainly due to the more demanding market requirements [5, 6, 8]. And, since the pioneer study performed by M'Ewen [1]until most recent works, like the ones presented bySzadkowski [9] and Szadkowski and McNerney [10], the main concern was in the analysis of the influence of the maximum effort demanded to shift gears.

From these recent works, the article published by Santosh and Chekuri [11] shows that other parameters must be considered in gearshift quality subjective evaluation.The authors performed selection and engagement effort measurements in three vehicles called "A", "B" e "C", and drivers gave subjective rating for the gearshift.

The numbers in Fig.4 are:

1) Gear disengagement;
2) Passage by neutral position;
3) F_{max};
4) TpC;
5) FuE.

It is possible to see in Fig. 4 that both vehicles "A" and "B" present pretty similar F_{max} values (see point 3), but vehicle "A" was better evaluated by test drivers. The authors noticed vehicle "B" was not so good in terms of effort profile between points 3 to 5, even considering that F_{max} was just 0.3 kgf higher than "A". Basically, Santosh and Chekuri [11]conclude that the sudden effort increase in 3 followed by 2 additional peaks in a very reduced course led to a worse rating to vehicle "B" when compared to vehicle "A".

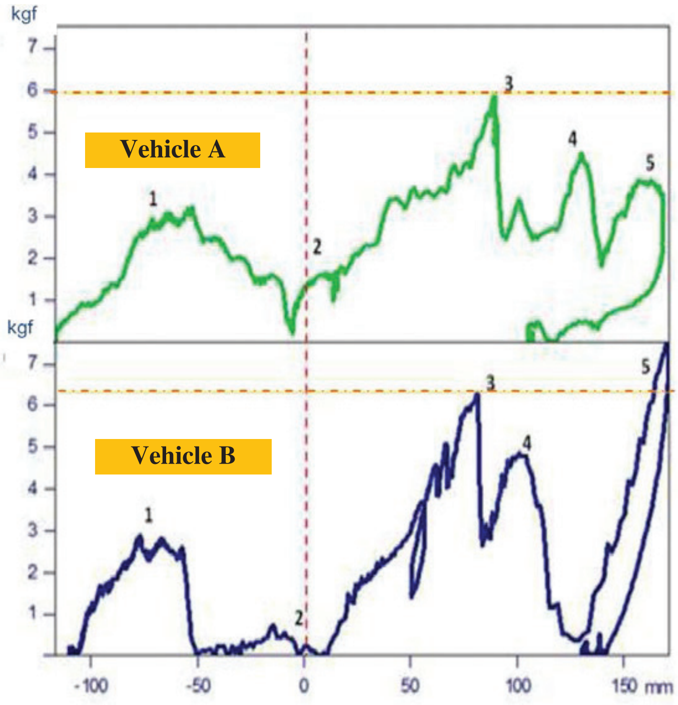

Fig. 4.Disengagement and engagement forces comparison among vehicle “A” versus “B”.Adapted from Santosh and Chekuri [11], p. 4.

This characteristic is mentioned by Sporleder, Mohlinand Olsson [12] andHau [8] as shift comfort, and comprehends the required force to overcome the double bump effort F_{bump} and scratching from EoS and FuE. Other authors consider also the number of peaks n_p and the ratio among F_{bump} and F_{max}, a.k.a. double bump ratio or *DBR* [5, 8], as events that affect directly the subjective rating.

About HFE, Proctor and Proctor [13] mention that one proved way to transmit complex information to a human being is using the vibration perception thru tactile sense. This perception may vary with frequency and amplitude of the vibration, additionally to the size of the contact area of the object that vibrates.

This concept was also worked by Frisoli, AvizzanoandBergamasco [14] to develop a 2-degree-of-freedom joystick which simulates a manual gearshift in a bench, aiming to generate the tactile feeling from the real transmission using haptic feedback.

Another study that followed this concept was done by Rosario et al. [15] in a research to determine frequencies and amplitudes to be aplied in a vehicle brake pedal as a warning to front collision. This work had as main objective to reduce the visual load of the driver using advanced driver assistance systems (ADAS) applying also haptic feedback, showing that muscular and tactile systems are a very efficient way to transmit “data” and is considered as powerful human-machine interface.

4. Evaluation Model

The baseline model used to estimate the shift comfort is seen in Eq.(1), which was developed by Dr. Burkhardt Pinnekamp during his doctorate [5]:

$$x_k = \frac{1}{21}\left[4(10t_s) + 5n_p^{0.8} + 8\left(\frac{F_{bump}}{F_{máx}}\right)^{1.2} + 4\left(2.5\sum s_r\right)^{1.5}\right] \quad (1)$$

Where x_k is the Pinnekamp index, t_s is the time among EoS and FuE, n_p the number of peak in the same t_s, F_{bump} divided by F_{max} is *DBR* and s_r is the number of back travels that may occur during t_s.

Once General Motors Uniform Specification (GMUTS) is used to rate each shift, the calculated Pinnekamp index from SQAT needs to be converted to a common scale as proposed by Hannemann [5]. And, considering GMUTS as the scale to be considered, rating 1 means too bad and 10 means that even trained drivers could not detect an aspect under evaluation.

Applying this concept in the subjective evaluation of shift comfort, variation of the amplitude of the efforts and the frequency of the peaks that occur among EoS and FuE may be other ways of perception of a given driver. So, as an initial proposal, a non-linear model using these HFE concepts is represented by Eq.(2):

$$PHR = 10 - DBR^{\hat{\beta}_1} - f_p^{\hat{\beta}_2} - t_s^{\hat{\beta}_3} \quad (2)$$

Where, f_p is the frequency of peaks during t_s, while $\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_3$ are the sample estimators of Eq.(2).

As mentioned before, an instrumented vehicle was evaluated by two trained drivers, and each driver performed a first to second gear shift 30 times. All shifts were gathered, and had its own Pinnekamp index calculated after post-processing with SQAT, and a regression using the real data and GMUTS ratings from Driver#1 are used to define $\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_3$. The model obtained using Driver#1's data will be used also to "predict" Driver#2's ratings just to check its potential.

Afterwards, acomparison of the converted Pinnekamp index versus the model proposed by Eq.(2) versus the GMUTS ratings given by each driver is presented.

5. Results

It is possible to see clearly in Fig. 5 the differences in GMUTS ratings for both drivers even considering that they evaluated the same car with the very same gearshift system and transmission assembly.

For Driver#1, the proposed model presented smaller errors when compared to the converted Pinnekamp, and also in general provided ratings slightly lower than real rating. This can be seen as one more advantage to the proposed model, once it would not lead to wrong "excellent" evaluation as indicated by the converted Pinnekamp in this comparison.

This is extremely important in order to not hide any real problem of the system, but also cannot denigrate too much a given design proposal leading to not required changes. For Driver#1, the proposed model showed to not overestimate the rating, but keeping itself not too low.

In Fig. 5b, the proposed model also presented a reasonable behavior, but not so good as seen in Fig. 5a, which was expected once Driver#1 was used to generate the estimators from Eq.(2). But, the proposed model showed to be more robust than converted Pinnekamp (as seen in shifts 6, 7, 10 and 26), which was directly affected by inherent objective parameters (e.g. *DBR*)considered in Eq.(1). Meanwhile, the proposed model managed to predict ratings not so far to real GMUTS ratings from Driver#2, and delivered it in a more robust way.

6. Conclusions and future works

Definitively, the non-linear-HFE-based model shows to be slightly better when compared to the converted Pinnekamp, showing a good correlation (Driver#1) with a more stable behavior (Driver#2). For Driver#1, converted Pinnekamp ratings present about 1 unit higher when compared to real GMUTS ratings, which may lead to wrong assumptions (too good) that would cause a problem when evaluating the real vehicle. Meanwhile, for Driver#2 the converted Pinnekamp shows to be closer to the real ratings, but shows an unexpected sensitivity to the objective parameters it is made of as seen in shifts 6, 7, 10 and 26 which are clearly not representing the actual evaluations of the system in these shifts.

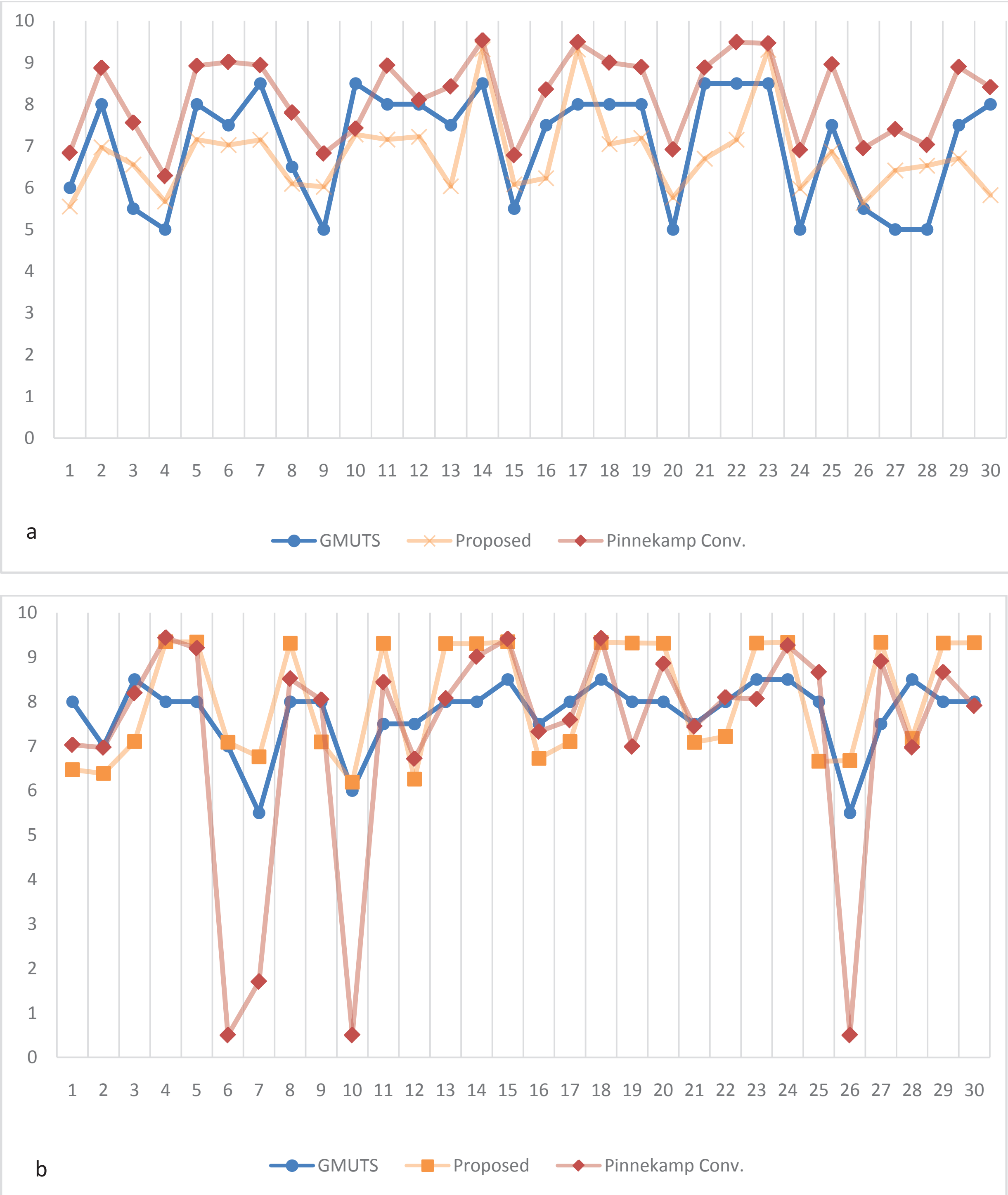

Fig. 5.(a) Driver #1; (b) Driver #2 – comparison of real rating vs. proposed model.vs.Pinnekamp converted.

Regarding the proposed model from Eq.(2),once $\hat{\beta}_1$, $\hat{\beta}_2$ and $\hat{\beta}_3$ were calculated using measurements done by Driver#1,when comparing against this last one shows a better behavior, as expected, and reasonable results when applied against the data from Driver#2value-wise without showing any sensitivity as presented by converted Pinnekamp model.

But, although the proposed model presents better results generally, it clearly has more room to be developed, considering additional HFE aspects related to the entire car. So, for future works, the proposed model could be enhanced considering anthropometric differences of the drivers from a given population, such as general body dimensions and muscular composition. Another alternative is to add some in-vehicle-ergonomic-related characteristics of the vehicle under analysis (e.g. "H" point position) that affect directly the condition that each driver accommodates him/herself inside the vehicle, interacts with driving wheel and clutch pedal using both as support during the shifting action and how handles the shift lever.

Another point that affects directly the shift quality perception is the expectation of the costumer about a given car, considering its price, brand, previous vehicle that makes a direct comparison, etc. This situation could be somehow measured and analyzed how to be added in a prediction model additionally to all HFE aspects discussed previously.

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