A Comparison of Stiff and Flexible Driveshafts During Accelerations

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Introduction

Performing fuel efficient accelerations is important due to environmental aspects. An acceleration is a dynamic event, where the engine dynamics such as the turbocharger has to be taken into account.

In previous works:

- A diesel engine model suitable for optimal control of the fuel injection and wastegate was developed. [3]
- An optimal control problem setup for solving an acceleration mission while changing gears was developed. [1]

In this work, a turbocharged diesel engine is used with a flexible driveline model. The optimal control for a fuel efficient acceleration is calculated and compared between a stiff and a flexible driveline. [2]

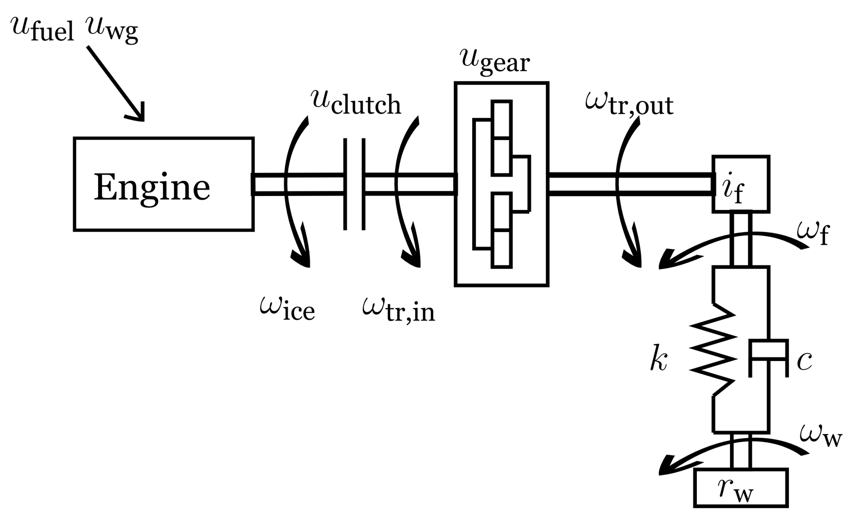

Figure 1: Schematic of a driveline where the control signals u and rotational speeds ω are displayed. k and c are the lumped drive shaft stiffness and damping. [2]

Research Questions

- How is a fuel efficient acceleration with flexible driveshaft performed?
- What are the main characteristics of the controls during the acceleration?
- Does the flexible driveline representation change the time instant when gear changes are made?

Chassis, driveline and engine models

The engine model used to examine the vehicle performance during an acceleration is developed in [3]. The engine is connected to a flexible driveline with a clutch, gearbox and final drive. All the driveline flexibilities are lumped together according to Figure 1. The spring and damper coefficients are estimated with data recorded from a truck, performing an acceleration. To solve the optimal control problem of accelerating the truck, the method in [1] is used, but with an updated clutch torque transfer function and system constraints to take the torsional state of the driveline into account. The traveling direction of the clutch is also restricted during the clutch closing maneuver.

Results

The results show a slightly faster acceleration with the stiff driveshaft, but a slightly higher fuel consumption using the flexible driveshaft. The engine air path dynamics are slower than the driveline oscillations, this is seen in the fuel-to-air ratio plot where the engine is smoke limited at the beginning of each gear. The general characteristics of the fuel injection profiles are similar between the two driveline representations.

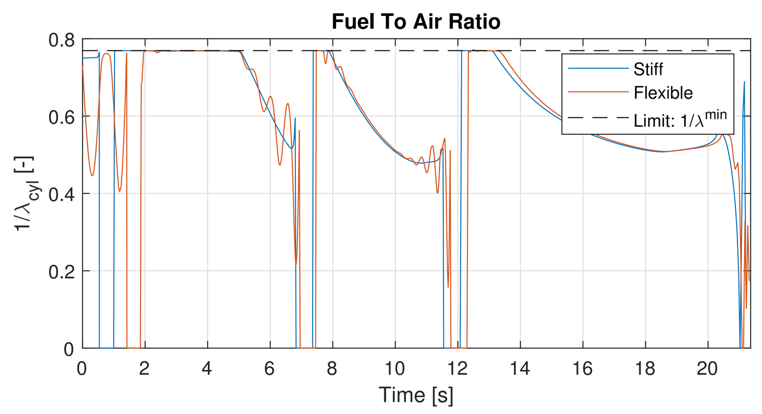

Figure 2: Fuel-to-air stoichiometry equivalence ratio during the acceleration. Note that the maximum stationary torque is not achieved in next figure, even though the injected fuel is at its maximum.

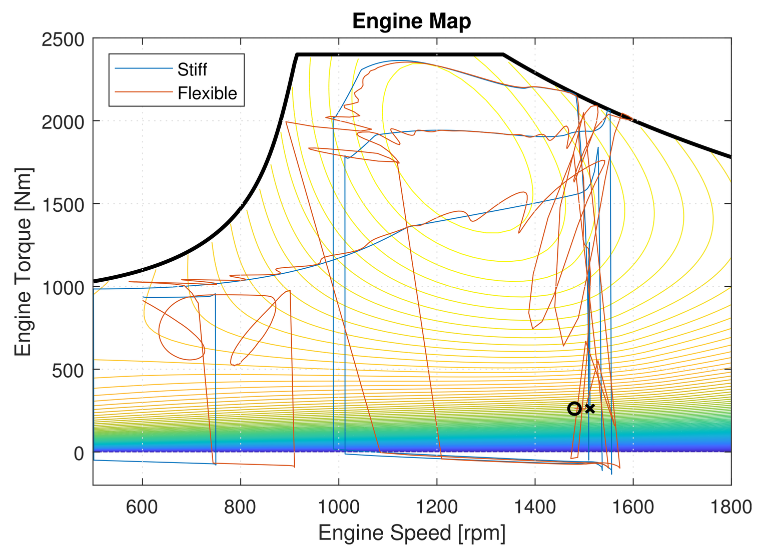

Figure 3: Engine load points during the acceleration. The oscillations in the driveline are visual. The maximum engine performance is restricted by the air fuel ratio λ^{min}=1.3, maximum torque and maximum power.

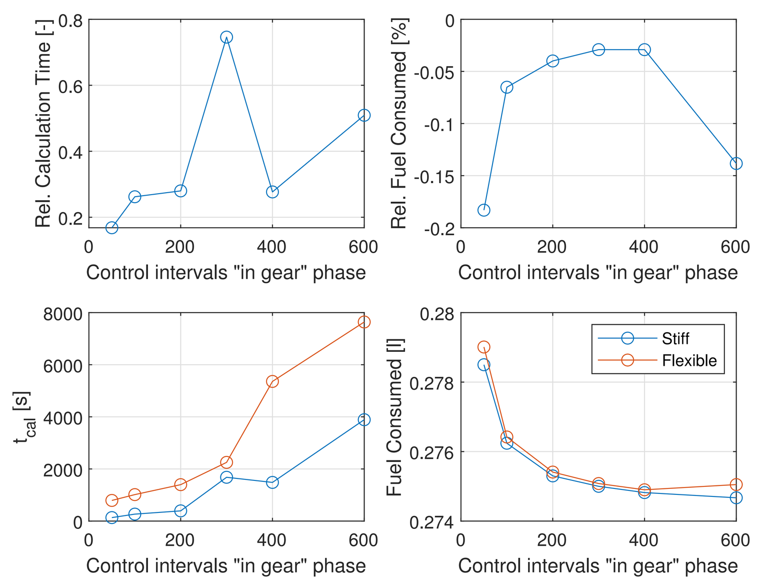

Figure 4: Calculation time and fuel consumption in relation to the number of control signal intervals in the in gear phase. The flexible driveshaft consumes slightly more fuel than the stiff representation. At 600 control Intervals the consumed fuel of the flexible driveline increase, probably due to a local optimum.

The knowledge of the results are valuable when deciding on the model complexity for solving fuel optimal accelerations. The smoke limiter criterion in the engine model λ^{min} is more dependent on the turbocharger dynamics during the acceleration, than the driveline oscillations. If the exact fuel injection profile is of interest, it is advantageous to include the flexible driveshaft in the model, to the cost of increased calculation time.

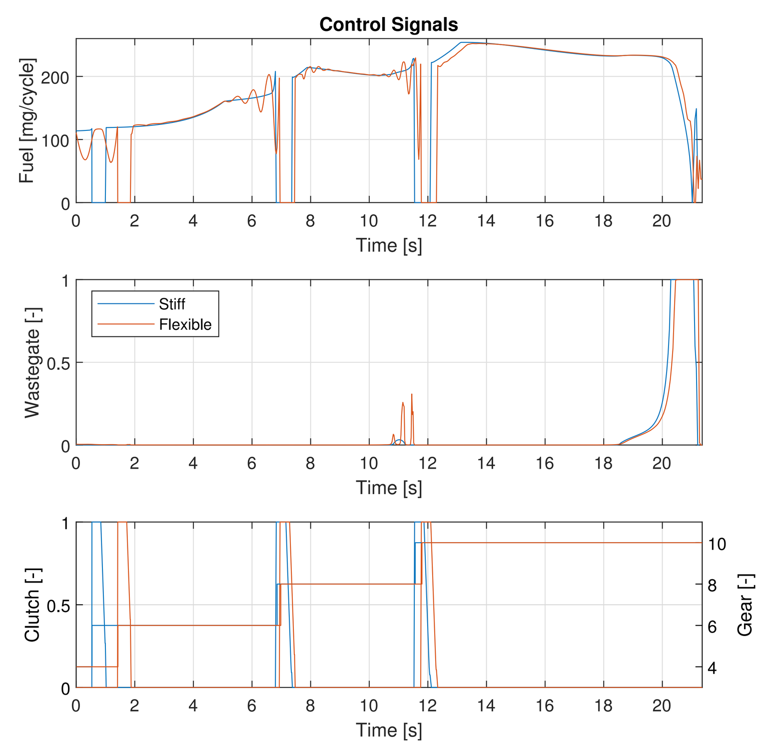

Figure 5: Control signals during the acceleration for the both driveline representations. The gear shifts are occurring at approximately the same time instances, except from the utilization of first gear which is longer when using the flexible driveline.

Conclusions

The results when comparing the fuel optimal control for the two driveline representations show:

- The flexible driveline requires slightly more fuel to perform the acceleration than the stiff driveline, since it also has a damping element dissipating energy in the system.
- The air-to-fuel ratio limit is the dominating property that restricts the fuel injection, at the beginning of each up-shift, independent of driveline.
- The gear shifting patterns are similar for the two drivelines, with some minor differences due to the oscillatory nature of the driveshaft dynamics.

References

[1] Kristoffer Ekberg and Lars Eriksson. Development and analysis of optimal control strategy for gear changing patterns during acceleration. 9th IFAC Symposium on Advances in Automotive Control AAC 2019, Orléans, France.

[2] Kristoffer Ekberg and Lars Eriksson. Presented at IFAC World Congress 2020: A comparison of stiff and flexible driveshafs during accelerations. 2020. 21st IFAC World Congress.

[3] Kristoffer Ekberg, Viktor Leek, and Lars Eriksson. Modeling and validation of an open-source mean value heavy-duty diesel engine model. *Simulation Notes Europe*, 28(4):197–204, December 2018.

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