SUB. F

DA CONSEGNARE AL COORDINATORE DEL CORSO PER LA PRESENTAZIONE DEL DOTTORANDO AL GIUDIZIO DEL COLLEGIO DEI DOCENTI IN VISTA DELL'ESAME FINALE

SCHEDA INFORMATIVA SULLE ATTIVITA' DEL TRIENNIO

- Cognome e Nome **Guido Ricardo Guercioni**
- Titolo di studio posseduto **Ingeniero Mecánico (five-year degree)** conseguito in data **14/07/2014** presso l'Università/Politecnico di **Universidad Simón Bolívar (Venezuela)**
- Dottorato di Ricerca in **Ingegneria Meccanica**
- Ciclo **XXX** Anni accademici di riferimento **2015/2016/2017**
- Dipartimento
  Dipartimento di Ingegneria Meccanica ed Aerospaziale (DIMEAS)
- Coordinatore
  Prof. Garibaldi Luigi
- Tutore
  Prof. Alessandro Vigliani
- Titolo della Tesi di Ricerca (in Italiano e/o in Inglese)

Integration of Dual-Clutch Transmissions in Hybrid Electric Vehicle Powertrains

A. DESCRIZIONE DELL'ARGOMENTO DELLA TESI (massimo 20 righe)

In the last few years, the automotive industry has experienced an increasing demand for improved vehicle dynamic performance and reduced fuel consumption.

Powertrain electrification provides energy efficiency benefits since it enables the possibility of performing regeneration during braking and engine downsizing. Furthermore, the presence of an extra power generation device enables improvements in the overall vehicle performance. However, these benefits can only be fully realized if the system is properly controlled.

In the field of transmission systems, new architectures have also been developed with the objective of fulfilling these requirements. For example, DCTs (Dual-Clutch Transmissions) while having a similar energy efficiency to MTs (Manual Transmissions) or AMTs (Automated Manual Transmissions) provide a substantial reduction of the torque gap during gearshifts. This fact together with their software tunability are some of the major drivers for DCTs electrification.

The research activity undertaken is focused on exploring the integration of DCTs in HEVs (Hybrid Electric Vehicles). Two main aspects related to automotive powertrains have been explored: dynamic performance and energy management of HEVs.

The first aspect is covered testing gearshift control logics by means of detailed nonlinear dynamic models that allow to assess the vehicle dynamic performance during these maneuvers. Furthermore, the possibility of substituting the DCT with an AMT is also studied.

On the other hand, optimal control theory is implemented for the energy management of HEVs equipped with DCTs. DP (Dynamic programming) is employed to determine the full potential of the powertrain systems of interest. This information is used as a benchmark and to develop sub-optimal control strategies which unlike DP are real-time implementable.

B. ATTIVITA' DI RICERCA SVOLTA NEL TRIENNIO

B.1 descrizione complessiva e sintetica dell'attività di ricerca

The research activity has been focused on the integration of DCTs in HEV powertrains. Two main aspects related to automotive powertrains have been explored: dynamic performance and energy management of HEVs.

Torsional vibrations analysis was undertaken to evaluate vehicle dynamic performance. Detailed nonlinear torsional models of automotive powertrains were developed and used to design a methodology for NVH (Noise Vibration and Harness) performance assessment of DCTs and to study the impact of different gearshift control strategies for HEV with AMTs and DCTs.

Optimal control theory was studied and implemented for the energy management of HEVs equipped with DCTs. A DP formulation was designed and the results were used for the development and benchmarking of real-time implementable control strategies.

B.2 argomenti di ricerca specifici affrontati

- Development of a post-processing algorithm for the correction of the smearing effect in order tracking operations
- Development and experimental validation of nonlinear torsional models of powertrains equipped with DCTs
- Development of a methodology for the assessment of the NVH performance of DCTs
- Modal analysis of the gearbox case of a DCT based on data from a FEM (Finite Element Method) model
- Development of gearshift control strategies for HEVs equipped with DCTs
- Calibration of the gearshift actuation system of an AMT
- Experimental characterization of an automotive dry clutch
- Development of nonlinear torsional models of MTs and AWD (All-Wheel Drive) powertrains
- Development of a gearshift control logic for a HEV equipped with an AMT during parallel and ICE-only vehicle operating modes
- Development and experimental testing of a control logic for backlash compensation during full electric vehicle operating mode
- Development of backward-looking models of HEVs
- Implementation of PMP (Pontryagin's Minimum Principle) for the energy management of HEVs
- Implementation of DP for the energy management of HEVs equipped with DCTs
- Development of real-time implementable control strategy for the energy management of HEVs equipped with DCTs. The control logic combines a rule-based approach designed from DP results with A-ECMS (Adaptive Equivalent Consumption Minimization Strategy).

B.3 risultati più rilevanti ottenuti nel triennio

Development of a post-processing algorithm for the correction of the smearing effect in order tracking operations

Order tracking is a method of analysis used by engineers in the diagnosis of rotating machinery.

The development of an algorithm for the correction of the smearing effect in order tracking operations resulted in a post-processing tool that proved to be a valid alternative to currently used techniques considering: the accuracy of the results, low requirements of computational resources and ease of implementation.

The results of this work were published on an international journal.

Development of a methodology for the assessment of the NVH performance of DCTs

The developed experimentally validated nonlinear torsional models of powertrains equipped with DCTs combined with the data from a FEM model of the gearbox case allowed to design a methodology for the assessment of DCTs NVH performance.

Through this methodology it is possible to assess the effect of changes in the transmission design parameters, e.g. torsional backlash in the synchronizers or clutch disc moment of inertia, on its NVH performance. As a result, the industrial partner in this activity was provided with a software tool that it's useful to make design decisions without the need of performing specific experimental tests.

Part of this work was presented on the 2016 SAE world congress and Exhibition.

Development of gearshift control strategies for HEVs equipped with DCTs and AMTs

Control algorithms for upshift and downshift maneuvers were developed for a HEV architecture in which an electric machine is connected to the output of the transmission obtaining torque filling capabilities during gearshift. Two different control logics were developed for the same vehicle depending on the type of transmission selected: AMT or DCT.

The results obtained for both transmission types are promising in terms of vehicle dynamic performance and energy consumption.

The developed strategies are very simple to implement and tune since they are based on the use of simple PI feedback controllers. Thus, transmission engineers without significant knowledge of advanced control theory will be able to use the developed tools.

The HEV architecture studied in which an AMT is used allows to almost eliminate the torque gap during gearshifts while keeping the mechanical complexity low with respect to its DCT counterpart. Since HEV equipped with DCTs are already on the market, a comparison between these two transmission systems becomes of interest. Furthermore, only a few articles on gearshift control strategies for HEVs with DCTs have been published and a work regarding a comparison with a similar system in which an AMT is used is not currently available.

Part of this work was presented on the 2017 International Conference of Electrical and Electronic Technologies for Automotive.

Implementation of DP for the energy management of parallel HEVs equipped with DCTs

DP was implemented for the energy management of a HEV equipped with a DCT with the objective of minimizing fuel consumption.

DCT gearshift losses and ICE start losses are considered in the developed DP formulation. The importance of considering these losses was demonstrated showing how gear hunting behavior and ICE state chattering are reduced with respect to the case in which losses are not taken into account.

Regarding the gearshift losses, a DP formulation with a detailed model of these losses for a DCT has not been published.

DP guaranties the optimal solution of a control problem. Therefore, the results obtained while not real-time implementable can be used as a benchmark for other control strategies or for their development.

Development of an online implementable control strategy for the energy management of HEVs equipped with DCTs

The novel control strategy uses a set of rules extracted from DP results for the selection of the gear number and A-ECMS to determine the torque split factor.

The results obtained are very close to the ones coming from DP. The developed control strategy has the advantage of being real-time implementable.

B.4 collaborazioni di ricerca avute con Università, Centri di ricerca ed Industrie nazionali ed internazionali (specificare il quadro entro cui sono avvenute: contratti di ricerca, periodi di formazione, ecc.)

- Research contract between DIMEAS and Fiat Chrysler Automobiles (FCA)
    - Topic: DCTs modeling and NVH performance assessment
    - Location: Torino (TO), Italy.
    - Period: November 2014 to July 2016
- Research activity in collaboration with Centro Ricerche FIAT (CRF)
    - Topic: AWD powertrain systems and control strategies for HEVs
    - Location: Cascina Mellano (TO), Italy.
    - Period: July 2015 to September 2016
- Research period abroad at the Ohio State University (OSU) Center for Automotive Research (CAR)
    - Topic
        - Hybridization of a 2016 Chevrolet Camaro (in collaboration with the OSU EcoCAR team)
        - Optimal control for the energy management of HEVs equipped with DCTs (in collaboration with BorgWarner)
    - Location: Columbus, Ohio, USA.
    - Period: October 2016 to June 2017

B.5 ulteriori attività di ricerca (progetti e contratti di ricerca nazionali ed internazionali)

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B. 6 brevetti conseguenti l'attività di ricerca

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B. 7 altre attività che si ritengono degne di menzione

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C. ATTIVITA' DI FORMAZIONE

C.1 partecipazione ad attività interne di supporto alla didattica (specificare su quali corsi, e se eventualmente il dottorando sia stato nominato cultore della materia)

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C.2 corsi e seminari più significativi seguiti (interni, esterni, ecc. - indicare solo il tipo ed il numero)

- Hard skills courses - Politecnico di Torino - 115 h
- Soft skills courses - Politecnico di Torino - 67 h
- Summer school: Multi-domain modeling of mechatronic systems for more electric vehicles M3EV - Politecnico di Torino - 18h

C.3 periodi di formazione esterni al Politecnico (tipo di formazione, luogo e durata)

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D. PUBBLICAZIONI FATTE E IN CORSO (indicarne il numero e il tipo: riviste nazionali ed internazionali, congressi, capitoli libri ecc.)

Journal

- Guercioni G.R., Galvagno E., Vigliani A., An alternative method for order tracking using autopower spectrum, Advances in Mechanical Engineering, 2015, vol. 7 (11), pp. 1-14. ISSN:1687-8140. DOI:10.1177/1687814015619277.

Congress

- Galvagno E., Guercioni G.R., Velardocchia, M., Experimental analysis and modeling of transmission torsional vibrations, Recent Researches in Mechanical and Transportation Systems, 2015, pp. 227-233. ISBN:978-1-61804-316-0.
- Galvagno E., Guercioni G.R., Vigliani A., Sensitivity Analysis of the Design Parameters of a Dual-Clutch Transmission Focused on NVH Performance, 2016 SAE world congress and Exhibition, Detroit (USA), April 12-14, 2016, pp. 1-12. ISSN:0148-71911. DOI:10.4271/2016-01-1127.
- Guercioni G.R., Vigliani A., Galvagno E., Midlam-Mohler S., Gearshift Control for Hybrid Powertrains with AMTs, 2017 International Conference of Electrical and Electronic Technologies for Automotive, Torino (Italy), June 15-16, 2017, pp. 1-9. ISBN:978-88-87237-26-9. DOI:10.23919/EETA.2017.7993202.

Accepted papers

- System Diagnosis and Mitigation Strategies for an Automated Manual Transmission
    - Authors: Simon J. H. Trask, Gregory J. Jankord, Aditya A. Modak, Brian M. Rahman, Giorgio Rizzoni, Shawn Midlam-Mohler, Guido R. Guercioni.
    - Conference name: Dynamic Systems and Control Conference 2017
    - Conference dates: October 11-13, 2017.
    - Conference location: Tysons Corner, Virginia, USA.

Data, 09/10/2017.

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(firma del dottorando)