SUB. F

DA CONSEGNARE AL <u>COORDINATORE DEL CORSO</u> 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: **Ali Moshrefzadeh**
- Titolo di studio posseduto: **Mechanical Engineering**

conseguito in data: **2011** presso: **Iran university of science and technology**

- Dottorato di Ricerca in: **Mechanical Engineering**
- Ciclo: **30th** Anni accademici di riferimento: **2014/2017**
- Dipartimento: **Department of Mechanical and Aerospace Engineering**
- Coordinatore: **Prof. Luigi Garibaldi**
- Tutore: **Prof. Alessandro Fasana**
- Titolo della Tesi di Ricerca (in Italiano e/o in Inglese):

Fault Detection in Rotating Machinery: vibration analysis and numerical modeling

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

The key motivation for this thesis is to improve the trustworthiness of rolling element bearings diagnosis. Moreover, increasing the understanding of the interactions between bearings and gears in a planetary gear set is another main motivation of this thesis.

Rolling element bearings (REBs) are one of the most used elements in rotating machinery and their failure is the most important cause of machinery breakdowns. Thus, correctly detecting and diagnosing bearing faults at stages prior to their complete failure is of vital importance. It avoids potential catastrophic damage not only to the apparatus but also to the personnel. Also, it reduces the machinery downtime which results in increasing the productivity.

Planetary gears, also recognized as epicyclic gears, are extensively used power transmission elements in numerous fields such as automotive, aerospace, wind turbines and marine applications. They have several benefits including compactness, high torque to weight ratio, high efficiency, multiple gear ratios and reduced noise in comparison with fixed-shaft gearboxes. Therefore, investigating planetary gear noise and vibration in healthy and faulty conditions is crucial to keep them functional, also to avoid any machinery breakdown as a result of a partial failure.

B. ATTIVITA' DI RICERCA SVOLTA NEL TRIENNIO

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

B.2 argomenti di ricerca specifici affrontati

This thesis investigates vibration based machine condition monitoring and consists of two parts: bearing fault diagnosis and planetary gearbox modeling.

In the first part, a new rolling element bearing diagnosis technique is introduced. Envelope analysis is one of the most advantageous methods for rolling element bearing diagnostics but finding the suitable frequency band for demodulation has been a substantial challenge for a long time. Introduction of the Spectral Kurtosis (SK) and Kurtogram mostly solved this problem but in situations where signal to noise ratio is very low or in presence of non-Gaussian noise these methods will fail. This major drawback may noticeably decrease their effectiveness and goal of this paper is to overcome this problem. Vibration signals from rolling element bearings exhibit high levels of 2nd order cyclostationarity, especially in the presence of localized faults. A second-order cyclostationary signal is one whose autocovariance function is a periodic function of time: the proposed method, named Autogram by the authors, takes advantage of this property to enhance the conventional Kurtogram. The method computes the kurtosis of the unbiased autocorrelation (AC) of the squared envelope of the demodulated and undecimated signal, rather than the kurtosis of the filtered time signal. Moreover, to take advantage of unique features of the lower and upper portions of the AC, two modified forms of kurtosis are introduced and the resulting colormaps are called Upper and Lower Autogram. In addition, a new thresholding method is also proposed to enhance the quality of the frequency spectrum analysis. Finally, the proposed method is tested on experimental data and compared with literature results so to assess its performances in rolling element bearing diagnostics.

The second part presents a newly developed lumped parameter model (LPM) of a planetary gear.
Planets bearings of planetary gear sets exhibit high rate of failure; detection of these faults which may result in catastrophic breakdowns have always been challenging. The objective of this paper is to investigate the planetary gears vibration properties in healthy and faulty conditions. To seek this goal a previously proposed lumped parameter model (LPM) of planetary gear trains is integrated with a more comprehensive bearing model. This modified LPM includes time varying gear mesh and bearing stiffness and also nonlinear bearing stiffness due to the assumption of Hertzian contact between the rollers/balls and races. The proposed model is completely general and accepts any inner/outer race bearing defect location and profile in addition to its original capacity of modelling cracks and spalls of gears; therefore, various combinations of gears and bearing defects are also applicable. The model is exploited to attain the dynamic response of the system in order to identify and analyze localized faults signatures for inner and outer races as well as rolling elements of planets bearings. Moreover, bearing defect frequencies of inner/outer race and ball/roller and also their sidebands are discussed thoroughly. Finally, frequency response of the system for different sizes of planets bearing faults are compared and statistical diagnostic algorithms are tested to investigate faults presence and growth.

B.3 risultati più rilevanti ottenuti nel triennio

1- a new rolling element bearing diagnosis technique is introduced
2- a new lumped parameter model for planetary gear sets is developed

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.)

None

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

None

B.6 brevetti conseguenti l'attività di ricerca

None

B.7 altre attività che si ritengono degne di menzione

None

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)

None

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

- Analysis of structures subjected to impulsive loading
- Experimental modeling: building experimental data models
- Dynamic gear design
- Prognostics and health management (PHM): an emerging technology
- Nonlinear structural dynamics
- Managing Ph.D. Thesis as a Project
- Topics in Internet & Society Interdisciplinary Studies
- Computer ethics

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

None

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

Journal Papers

1- Moshrefzadeh A, Fasana A "The Autogram: an effective approach for selecting the optimal demodulation band in rolling element bearings diagnosis" *Mechanical Systems and Signal Processing (submitted)*

2- Moshrefzadeh A, Fasana A "Planetary gearbox with localized bearings and gears faults: simulation and time/frequency analysis" *Meccanica*, *2017*

Conference Paper

1- Moshrefzadeh A, Fasana A, Garibaldi L "Using unbiased autocorrelation to enhance kurtogram and envelope analysis results for rolling element bearing diagnostics" *Surveillance 9, International Conference, 2017*

Data, 5/10/2017

_____ _____

Advisor's signature Ph.D. student's signature