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Research paper

Comparison of experimental and operational modal analysis on a back to back planetary gear

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ABSTRACT

Several modal analyse techniques are widely used to study the dynamic characteristics of a structure by identifying the modal parameters. This paper presents a comparison between an Experimental Modal Analysis (EMA) test, an Operational Modal Analysis (OMA) test and an Order Based Modal Analysis (OBMA) applied on a recirculating energy planetary gear. The OMA and OBMA offer a test of the planetary gear under its real boundary conditions, whereas the EMA is based on the frequency response function estimation. Using these different techniques, the back to back planetary gears modal parameters were identified. In a first step, the experimental results determined by EMA and OMA were correlated to the numerical results model obtained by a three-dimensional lumped parameter model. In a second step, the OBMA estimated modal parameters were compared to those of the EMA.

According to the obtained results, OMA cannot excite all the modes. However, it was noticed that there is no significant difference between the modal parameters obtained by the EMA and the OBMA. The natural frequencies and damping ratios were deviating by 11% and 2.43%, respectively.

1. Introduction

Nowadays, planetary gear transmissions are widely used in different mechanical applications such as cars, wind turbine and a lot of rotating machinery. These systems are characterized by complex kinematic and dynamic compositions. The diagnosis of these systems could be a very important task for research. Many developments were achieved to characterize these systems. The modal properties determination is one of the main investigated issues.

The different available modal analysis kinds are the Experimental Modal Analysis (EMA), Operational Modal Analysis (OMA) and Order Based Modal Analysis (OBMA). EMA techniques are based on impact test, and an excited mechanical structure by means of a hammer or shaker. The frequency response functions are determined, and modes as well as modal damping are estimated. The EMA has three critical drawbacks: firstly, the impact test needs to be repeated to accurately

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Nomenclature

r	Ring
c	Carrier
s	Sun
P1	Planet 1
P2	Planet 2
P3	Planet 3
K_{rp}	The ring-planet mesh stiffness
K_{sp}	The sun-planet mesh stiffness
k_{cf}	The carrier 's shaft flexural stiffness
k_{sf}	The sun 's shaft flexural stiffness
k_{ct}	The carrier 's shaft torsional stiffness
k_{st}	The sun 's shaft torsional stiffness
k_{ca}	The carrier 's shaft axial stiffness
k_{sa}	The sun 's shaft axial stiffness
w_i	Natural pulsations
φ_i	Vibrations modes
q	Degree of freedom vector
M	Global mass matrix
K_b	Bearing stiffness matrix
$K_e(t)$	Time varying mesh stiffness matrix
K_c	Coupled matrix
C	Damping matrix
F(t)	External force
ψ_r	Ring-planet pressure angle
ψ_s	Sun-planet pressure angle
α_i	Planet i angular position
α_s	The sun pressure angle
α_r	The ring pressure angle
R_{br}	The rings base radius
R_{bs}	The suns base radius
R_{bp}	The planets base radius
m_{ij}	Masses of component i of gear j
I_{ij}	Inertia of component i of gear j
k_{ijk}	Bearing stiffness of component i of gear j in k direction
fs	Sampling frequency

Subscripts

i = r,c,s,p1,p2,p3	Denotes respectively ring, carrier, sun, planet1, planet2, planet3
j = r,t	Denotes respectively reaction gear and test gear
$k = u,v,w,\phi,\Psi,\theta$	Denotes axis direction

understand the dynamic behaviour. Secondly, in many engineering applications, and under real operating conditions the obtained results may differ significantly from those achieved in lab testing with an artificial excitation. Thirdly, the use of shaker can be an additional load for structures and may lead to erroneous results.

Many researchers implemented this technique to study the dynamic properties of planetary gears. Hammami et al. [1] studied a modal analysis of back to back planetary gear. They validated their experimental results using those issued from the lumped parameters model. Ericson and Parker [2] applied an experimental modal analysis to characterize the dynamic behaviour of two spur planetary gears. They validated the experimental results by those obtained from both of the finite elements model and lumped parameter model.

Kahraman [3] proposed a simplified rotational lumped-parameter model, providing closed-form expressions for the torsional natural frequencies in terms of system parameters. Zhang et al. [4], however, established a translational-rotational coupled dynamic model of a two-stage planetary gear set to anticipate natural frequencies and vibration modes.

Lin and Parker [5] used a two-dimensional planetary gear model with equal planet spacing to explain the unique modal properties. The compound planetary gears vibration modes were studied by Kiracofe and Parker [6] and Guo and Parker [7].

The second technique is the OMA also known as an output-only modal analysis. It is based on the determination of the modal proprieties under operational tests. It is widely used for the rotating machinery to characterize their modal proprieties. Chauhan et al. [8] studied the dynamic characterization of a wind turbine gearbox. They identified its modes shapes through the finite element model and correlated the numerical modes shapes with those obtained experimentally.