Study on Linear Vibration Model of Shield TBM Cutterhead Driving System

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In this paper, a general linear time-varying multiple-axis (LTVMA) vibration model of shield tunnel boring machine (TBM) cutterhead driving system is established. The corresponding multiple inputs and multiple outputs (MIMO) state-space model is also presented. The linear vibration model is analysed, and the vibration-torque transfer function matrix and the vibration-torque static gain matrix are obtained. The linear vibration model is simulated, and the physical parameters' effects on the vibration response are investigated. A preliminary approach is proposed to reduce vibration by increasing motor rotor inertia and viscous damped. The LTVMA vibration model provides a solid foundation for fault detection and diagnosis (FDD), as long as the health monitoring of cutterhead driving system.

NOMENCLATURE

$\mathbf{n}$	The number of cutterhead driving motors;
$\mathbf{q}$	the reducer speed reduction ratio
$\mathbf{J_{d,i}}$	**i**-th induction motor rotor inertia after equivalent coupling-**i**
$\mathbf{b_{d,i}}$	**i**-th induction motor rotor viscous damped after equivalent coupling-**i**
$\mathbf{J_{z,i}}$	Inertia of the i-th coupling between motor-**i** and reducer-**i**
$\mathbf{b_{z,i}}$	Viscous damped of the **i**-th coupling between motor-**i** and reducer-**i**
$\mathbf{J_{r,i}}$	**i**-th induction motor rotor inertia
$\mathbf{b_{r,i}}$	**i**-th induction motor rotor viscous damped
$\mathbf{J_m}$	Large gear inertia
$\mathbf{b_m}$	large gear viscous damped
$\mathbf{r_m}$	large gear radius
$\theta_{\mathbf{p,i}}$	Angular displacement of **i**-th active pinion
$\theta_{\mathbf{i}}$	angular displacement of **i**-th motor rotor
$\theta_{\mathbf{m}}$	Large gear angular displacement
$\omega_{\mathbf{m}}$	large gear angular speed
$\mathbf{J_{c,i}}$	**i**-th pinion inertia after equivlalent coupling-**i**
$\mathbf{b_{c,i}}$	**i**-th pinion viscous damped after equivalent coupling-**i**
$\mathbf{J_{w,i}}$	Inertia of the **i**-th coupling between reduce-**i** and pinion-**i**
$\mathbf{b_{w,i}}$	Viscous damped of the **i**-th coupling between reducer-**i** and pinion-**i**
$\mathbf{J_{p,i}}$	**i**-th pinion inertia;
$\mathbf{b_{p,i}}$	**i**-th pinion viscous damped
$\mathbf{T_{e,i}}$	**i**-th induction motor electrical magnetic torque
$\omega_{\mathbf{p,i}}$	Angular speed of pinion-**i**
$\omega_{\mathbf{i}}$	angular speed of induction motor-**i**
$\mathbf{F_i}$	Elastic mesh force of the pinion-**i** and large gear
$\mathbf{r_i}$	radius of pinion-**i**
$\mathbf{M_{c,i}}$	Elastic mesh torque of the pinion-**i** and large gear
$\mathbf{p_i}$	Relative position of the pinion-**i** and large gear
$\mathbf{k_i}$	Mesh stiffness of the pinion-**i** and large gear
$\mathbf{c_i}$	Mesh damped of the pinion-**i** and large gear
$\mathbf{m_{p,i}}$	Mass of the pinion-**i**
$\mathbf{k_{y,i}}$	support stiffness of pinion-**i**
$\mathbf{c_{y,i}}$	support damped of pinion-**i**
$\mathbf{m_g}$	Mass of the large gear
$\mathbf{k_{y,m}}$	support stiffness of large gear
$\mathbf{c_{y,m}}$	support damped of large gear
$\mathbf{y_i}$	The contact direction (line-of-action direction) vibration displacement of **i**-th pinion
$\mathbf{y_m^i}$	The large gear's contact vibration displacement along **i**-th pinion's line-of-action direction
$\mathbf{T_L}$	Shield TBM cutterhead's load torque
$\mathbf{k_{f,i}}$, $\mathbf{c_{f,i}}$	elastic mesh force coefficient of pinion-**i**
$\mathbf{k_{t,i}}$, $\mathbf{c_{t,i}}$	elastic mesh torque coefficient of pinion-**i**
$\mathbf{i_{m,i}}$	gear transmission ratio
$\mathbf{T_1}$	The resistant torque of soil and rocks
$\mathbf{T_2}$	The friction torque of soil and rocks which chafe with the front of the cutterhead
$\mathbf{T_3}$	The friction torque of soil and rocks which chafe with the back of the cutterhead
$\mathbf{T_4}$	The friction torque of soil and rocks which chafe with bulkhead
$\mathbf{T_5}$	The stirring torque of soil and rocks by cutterhead stirring rod
$\mathbf{T_6}$	The friction torque of cutterhead bearings and sealed chamber