Advanced Science and Technology Letters
Vol.111 (NGCIT 2015), pp.79-83
http://dx.doi.org/10.14257/astl.2015.111.16

The dynamic comparative analysis

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Abstract. This paper classifies the TBM thatmostly used in the practical engineering into TBM 1 and TBM 2, and comprehensively analyses the difference of cutter layout strategy, pinion layout strategy, shield support structure, etc between TBM 1 and TBM 2.The vibration periodicity of TBM 2 significantly reduces. The influence of shield vertical support on the horizontal and vertical vibration of TBM 2 is analyzed. The results show that settinga vertical support at the bottom of the shield reduces the TBM cutterhead vibration by about 12%.

Keywords: Comparative analysis; Dynamic model; Structure parameters

1 Introduction

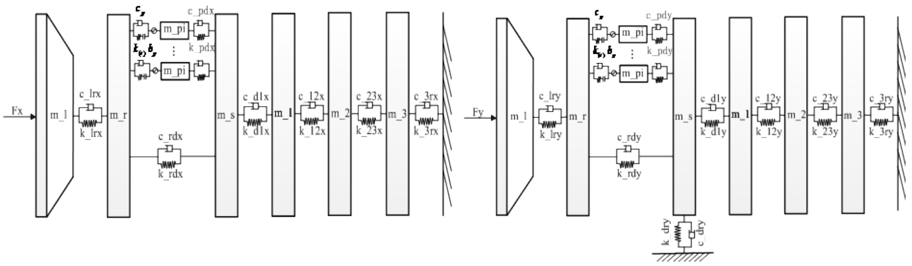
In hard rock, the construction process with big torque, thrust and large impact load. The excessive vibration of TBM will cause non-normal damage in critical components and shorten the life of TBM[1]-[2]. Among the component of TBM, the vibration situation of cutterhead is the most serious[3].This paper classifies the TBM thatmostly used in the practical engineering into TBM 1 and TBM 2. The comparative vibration analysis of TBM 1 and TBM 2 can accurately simulate the vibration of each component. These analysis results determine the reasonable structure and provide a theoretical reference for TBM anti-vibration design.

Some foreign and domestic scholars have analyzed the TBM driving rotary system and TBM cutterhead system from the angle of dynamic vibration[4]-[6].K.Z.Zhang[7]et al established a coupling dynamical model of shield machine considering redundant drive system, hydraulic propulsion system, geological conditions, etc, and the dynamical characteristics of the rotary system was studied based on the dynamical model. J.X.Lin and W.Sun[8] established a nonlinear dynamical model of cutterhead system, and analyzed the dynamical characteristics of cutterhead. The comparative analysis based on the TBM 1 and TBM 2 in engineering is not that deep.By considering the difference of cutter layout strategy, pinion layout strategy, shield support structure, etc between TBM 1 and TBM 2, this paper determines more reasonable shield support structure, pinion layout strategy, etc.

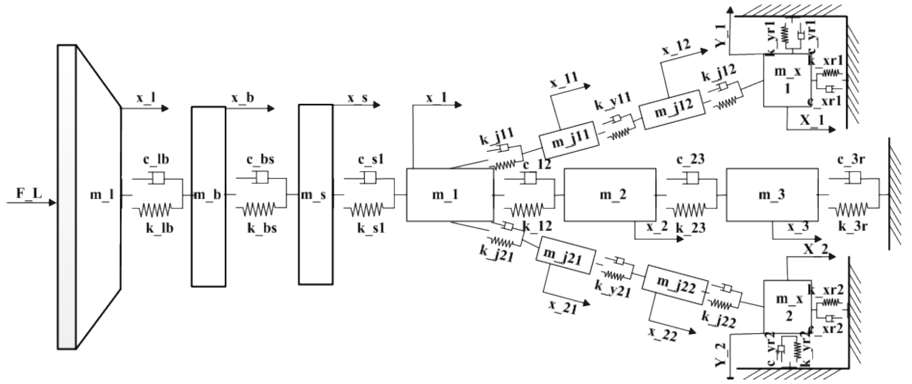
ISSN: 2287-1233 ASTL

2 Comparative analysis of parameters

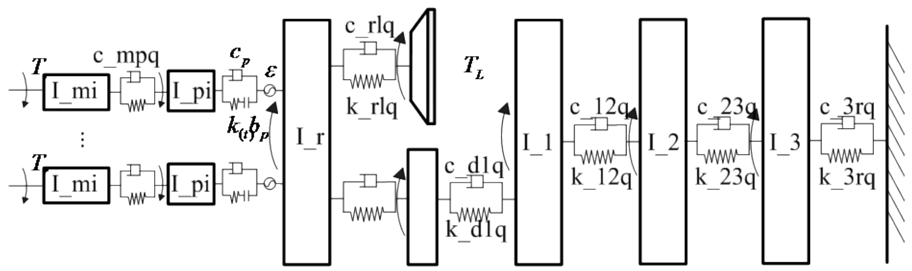
The dynamic model of TBM is shown in Figure 1.



(a)The horizontal degree of freedom (b) The vertical degree of freedom



(c)The axial degree of freedom



(d)The torsional degree of freedom

Fig. 1. The dynamic model of TBM

Different cutter layout strategies result in different equivalent force on cutterhead during boring process[10-11].The load on cutterhead contains axial force Pv, radial force Prand torqueTas shown in figure1. Each of the load is a resultant force which can be calculated according to the layout parameter of each cutter. The relationship between cutter layout position and angle is shown in figure 2. In the figure, lrepresents the distance between each cutter axis and the center of cutterhead, θrepresents the phase angle of each cutter on the cutterhead, βrepresents the angle between the vertical force of each cutter and the Y-axis, especially for the inner cutter and center cutter, the value of βis 0.

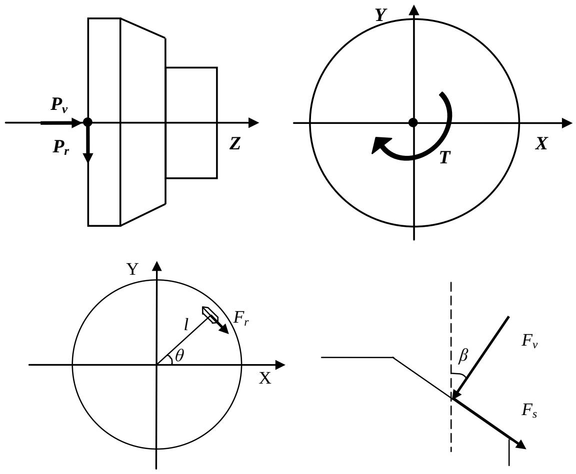


Fig. 2. The cutter layout position

The radial force on cutterhead is the sum of the Xand Y component force on each cutter. The calculation formula is

$$P_r = \sqrt{(\vec{F}_{vx\Sigma} + \vec{F}_{rx\Sigma} + \vec{F}_{sx\Sigma})^2 + (\vec{F}_{vy\Sigma} + \vec{F}_{ry\Sigma} + \vec{F}_{sy\Sigma})^2}$$

where $\vec{F}_{vx\Sigma}$ 、 $\vec{F}_{rx\Sigma}$ and $\vec{F}_{sx\Sigma}$ are the sun of the X component force of the vertical force, rolling force and side force on each cutter. $\vec{F}_{vy\Sigma}$ 、 $\vec{F}_{ry\Sigma}$ and $\vec{F}_{sy\Sigma}$ are the sun of the Y component force of the vertical force, rolling force and side force on each cutter.

$$\begin{cases} \vec{F}_{vx\Sigma} = \sum_{q=1}^{t} F_{vq} \sin\beta_q \cos\theta_q \\ \vec{F}_{rx\Sigma} = k_r \sum_{q=1}^{t} F_{vq} \sin\theta_q \\ \vec{F}_{sx\Sigma} = k_s \sum_{q=1}^{t} F_{vq} \cos\beta_q \cos\theta_q \end{cases} \quad \begin{cases} \vec{F}_{vy\Sigma} = \sum_{q=1}^{t} F_{vq} \sin\beta_q \sin\theta_q \\ \vec{F}_{ry\Sigma} = k_r \sum_{q=1}^{t} F_{vq} \cos\theta_q \\ \vec{F}_{sy\Sigma} = k_s \sum_{q=1}^{t} F_{vq} \cos\beta_q \sin\theta_q \end{cases}$$

The torque on cutterhead is the sum of all moments about Z-axis. The calculation formula is $\vec{T} = k_r \sum_{q=1}^{t} F_{vq} l_q$

There are 3 supports at the shield of TBM 1 while there is one vertical support at the shield of TBM 2. This paper assumes that the pressure of the gripper shoe is directly proportional to the support stiffness. In dynamic calculation, the pressure of the gripper shoe at main frame is 2.95MPa, and the support stiffness is $1\times e^{11}$ N/m. The pressure of the gripper shoe at shield is 1.2Mpa, therefore, the corresponding support stiffness is $4.06\times e^{10}$ N/m according to the proportional relation. The horizontal and vertical stiffness of shield is defined by the sum of structural stiffness and support stiffness: $K = K_{\sup port} + K_{structure}$. The structural stiffness of shield $5\times e^{10}$ N/m. The horizontal and vertical stiffness of shield is listed in table 1.

Table1. The horizontal and vertical stiffness of shield

	TBM 1	TBM 2
Equivalent horizontal support stiffness	$7.03\times e^{10}$	0
Equivalent vertical support stiffness	$8.12\times e^{10}$	$4.06\times e^{10}$
Equivalent horizontal stiffness of shield	$1.2\times e^{11}$	$5\times e^{10}$
Equivalent vertical stiffness of shield	$1.3\times e^{11}$	$9\times e^{10}$

3 The analysis results

The above parameters are taken as dynamic parameters, and the vibration responses are obtained. Take the vibration responses of cutterhead inaxial, horizontal, vertical and torsional DOF as example. In order to further analyze the influence of shield vertical support on the horizontal and vertical vibration of TBM 2, this paper calculates a dynamic model with unbraced structure.
The statistical parameters of thecutterhead vibration are listed in table 2.

Table 9. The statistical parameters of the cutterhead vibration

	TBM 2 with braced structure	TBM 2 with unbraced structure
The mean of horizontal vibration	-0.0013	-0.0013
The amplitude of horizontal vibration	0.0018	0.0018
The mean ofvertical vibration	4.7398×10^{-4}	5.4215×10^{-4}
The amplitude ofvertical vibration	7.2861×10^{-4}	8.3630×10^{-4}

It can be seen that: (1) The vertical support has no obvious influence on the horizontal vibration of cutterhead. (2) The vertical support affects the vertical vibration of cutterhead to some extent. The mean of vertical vibration reduces by12.57%, and the amplitude of vertical vibration reduces by12.88%.

4 Conclusion

The cutterhead dynamic responses of TBM 1 and TBM 2 are obtained by considering the parameters and structure of these two TBM. The results show that the mean of the horizontal cutterhead vibration of TBM 1 is around 0.3mm while that of the TBM 2 is 1.4mm which is 4 times of the former one. The mean of the vertical cutterhead vibration of TBM 1 is around 0.2mm, and that of the TBM 2 is 0.5mm. It indicates that the shield support structure of TBM 1 is more reasonable than TBM 2. A dynamic model with unbraced structure is analyzed and the results show that a vertical shield support can reduce the cutterhead vertical vibration by about 12%.

Acknowledgments. This project is supported by National Natural Science Foundation of China (Grant No. 51375001, 51309045).

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