IOSR Journal of Engineering (IOSRJEN) **www.iosrjen.org**
ISSN (e): 2250-3021, ISSN (p): 2278-8719
Vol. 05, Issue 08 (August. 2015), ||V1|| PP 08-14

The Modal Analysis of Vibro Ripper Gear based on CATIA

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Abstract: - Through the parametric design and FEA function of CATIA, we build 3D model and finite element modal of Vibro Ripper gear. Meanwhile, we make modal analysis of gear and get natural frequency and modal shape of it.The analysis shows when the gear rolls at a high speed, gear will create a centrifugal stiffening effect on account of the centrifugal elastic deformation. Besides, the natural frequency increases with gear's speed and some modal shape changed. Moreover, the radius and thickness of block have a great impact on gear's modal analysis, and radius impactsfrequency more intricate than thickness.

Key words: *Vibro ripper gear; block; natural frequency, modal shape*

I. INTRODUCTION

The high efficiency and low noise of Vibro Ripper have attracted a widespread attention in engineering field. But now there are no more references about Vibro Ripper all over the world, it is new machinery[1]. Vibro Ripper creates force by gear with block and breaks stone or beton. The block roll by gear and becomes the main source of force, gear and block are the core of Vibro Ripper. On account of the special design of Vibro Ripper, it always vibrate heavily and some componentsare easy to be destroyed in the work.Fig.1 shows the structure of Vibro Ripper gear, helical gear and eccentric block are made by integration as well as with high strength[2-4].In this paper, we make an emphasis on modal analysis of Vibro Ripper gear, include the impact of gear's speed, radius and thickness of block to the modal of Vibro Ripper gear.Meanwhile, we get some conclusions and which will provide some guidance to the production of our factory.

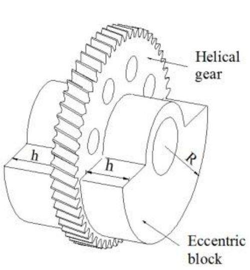


Fig.1 Structure of Vibro Ripper gear

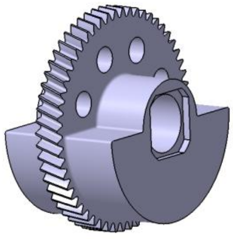


Fig.2 3D model

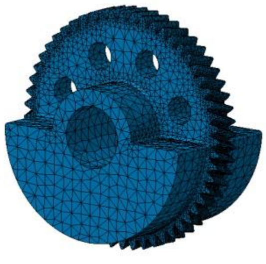


Fig.3 Finite element model

II. ESTABLISHMENT OF MODEL

2.1 3D model

The geometric parameters of Vibro Ripper gear are as follows, teeth Z=56, module m_n=7mm,tooth width b=50mm, pressure angle $\alpha_n=20^o$, helix angle $\beta=18^o$,block radius R=288mm, block thickness h=100mm, arbor hole radius r=56mm.

In order to get an accurate model and can be modified easily, we use parametric design of CATIA to draw the involute tooth profile and solid[5-6]. The rectangular equation of involute tooth profile:

$$\begin{cases} x = r_b sina_k - r_b a_k cosa_k \\ y = r_b cosa_k + r_b a_k sina_k \end{cases} \quad (1)$$

Among them,$r_b$is the basic circle radius of involute tooth profile, $a_k$is the pressure angle of K point on involute tooth profile. Fig.2 is the 3D model of Vibro Ripper gear.

2.2 Finite element model

Using plug-in AFC (ABAQUS For CATIA) to enlarge the FEA function of CATIA.The AFC includes twoparts, ANL(nonlinear structural analysis) and ATH(thermal analysis).

Leading 3D model into the ANL part and set material as steel, MOE (modulus of elasticity) E=2.06e11pa,poisson ratioμ=0.3,density ρ=7800kg/m3[7-8].As the helical gear's surface is curved face, it's difficult to divided into hexahedron gridding, we need to use tetrahedron gridding and adjust the SIZE and SAG parameters. Size is 20mm,SAG is 2mm,and select parabolic gridding style, we can get 109163 nodes and 69233 unites.Fig.3 is the Finite element model.

The traditional modal analysis of gear is mainly to limit the bore of gear and with no consideration of rotation. As rotationcreates large centrifugal force, to some extent,it makesimpact to the contact characteristics and model characteristics of gear. If we want to make a modal analysis accurately, it's not only to consider the impact of rotation, but also the block structure[10]. Thus, we need to set loads and constraints of gear as follows:

(1)Set the static modal analysis as reference and limit all bore's DOF of gear.

(2)As the impact of gear speed, we need to search the stress-strain response by statics at the background of speed and limit the radial and axial DOF of gear bore, and reserve the circumferential DOF and make a modal analysis with various speeds.

(3)Set the static results as preload added on the modal analysis and solve natural frequency and modal shape in each step.

(4)In static, change the structure of block and search the impact of block radius and thickness to natural frequency.

III. THE CALCULATION AND ANALYSIS

3.1 The finite element method of modal analysis

According to the finite element method of elastic mechanics, the motion differential equation of gear system with n DOF is:

$$M\ddot{X} + C\dot{X} + KX = F(t) \quad (2)$$

$X = \{x_1, x_2, x_3, \dots x_n,\}^T$,M is mass matrix, C is damping matrix, K is stiffness matrix,$\ddot{X}$ is vibration acceleration vector,$\dot{X}$is velocity vector,X is displacement vector,$F(t)$ is vibration force vector.

$F(t) = 0$, it means there is no external force, we can neglect the damping matrix C , and the motion differential equation is:

$$M\ddot{X} + KX = 0 \quad (3)$$

The characteristic equation is:

$$(K - \omega_i^2)X = 0 \quad (4)$$

Among them,ω_i is natural frequency of the i step ($i = 1,2,3 \dots n$).And the vibration system always have n natural frequencies and$n$ model shapes, each pair of frequency and model shape represent free vibration of single - degree - freedom system, and the free vibration of multiple - degree - freedom system can be divided Sintosimple harmonic vibration with n DOF. This kind of vibration can be represented as linear combination by each natural shape, and among them the lower step modal shape has a greater impact on the vibration as well as makes a great decision to the dynamic behavior[11]. Thus, we choose the first 10 step modals as the targets of our analysis.

3.2 The modal analysis of Vibro Ripper gear in static

As the block covers half part of the helical gear, we search model shape on the other half part of the helical gear. In static,table.1 shows the natural frequency and modal shape of the half part of the helical gear. From table.1 we can see the first 10 steps,natural frequency increases with step.

Table.1 Modal characteristics of first 10 step in static

Step	Vibro Ripper gear	
	Natural Frequency/HZ	Mode Shape
1	1891	step 1Folding vibration
2	2322	Torsional vibration
3	2401	Circumferential vibration
4	3323	step3 Bending vibration
5	3603	step3 Bending vibration + Torsional vibration
6	3623	Circumferential vibration
7	3957	Radial vibration
8	4541	Circumferential vibration
9	4737	step2 Folding vibration
10	4969	step2 Folding vibration

Fig.4 shows the first 10 step of typical modal shape in static, from pictures we can see the typical modal shape include folding vibration, torsional vibration, circumferential vibration, bending vibration, radial vibration.

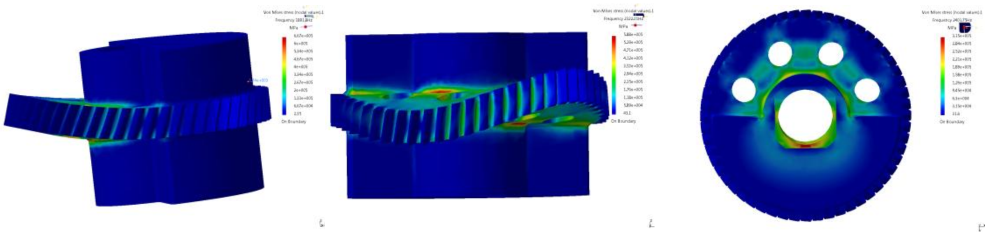
3.3 The modal analysis of Vibro Ripper gear in rotation

At present, the high speed of gear reached 1800r/min. To search the impact of speed to gear's modal, we select 1800r/min, 1500 r/min，1200 r/min， 900r/min，600r/min，300r/min as targets and find the natural frequency.Table.2 shows the natural frequency in different rotations.

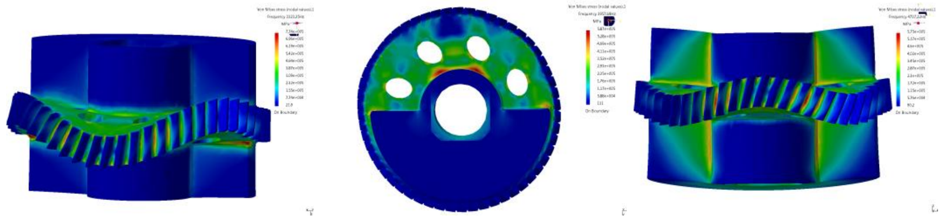
From table.2 we can see the natural frequency increased with gear's rotation. Comparing the modal shape in static and rotation and we can see the most modal shapes have changed.According the natural frequency:

$$\omega = \sqrt{K/M} \quad (5)$$

$\omega$is natural frequency, K is gear's stiffness, M is gear's mass. When M keeps unchanged and ω increases gradually, we can infer K is increased. It is said that K increases with gear's speed and we call it centrifugal stiffening effect.



step1 Folding vibration Torsional vibration Circumferential vibration



step3 Bending vibrationRadial vibrationstep 2Folding vibration

Fig.4 Typical modal of Vibro Ripper gear in static

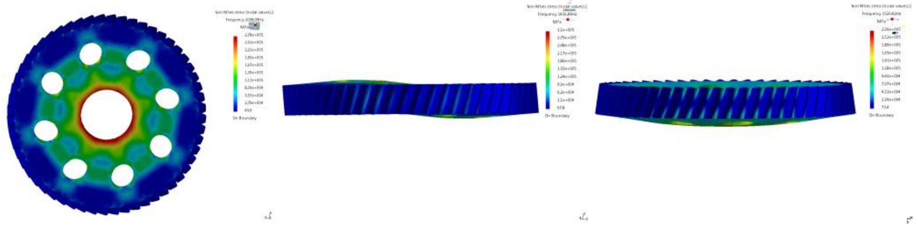
Table.2 The first 10 step natural frequency of Vibro Ripper gear

Rotation step	1	2	3	4	5	6	7	8	9	10
0r/min	1891	2322	2401	3323	3603	3623	3957	4541	4737	4969
300 r/min	1898	2330	2449	3331	3611	3631	3965	4549	4745	4978
600 r/min	1910	2341	2458	3342	3624	3643	3974	4560	4756	4991
900 r/min	1931	2363	2481	3362	3646	3662	3994	4582	4777	5011
1200 r/min	1950	2383	2500	3380	3665	3682	3412	4601	4799	5033
1500 r/min	1987	2419	2539	3417	3701	3718	3448	4638	4836	5069
1800 r/min	2028	2457	2578	3456	3740	3760	3489	4676	4878	5110

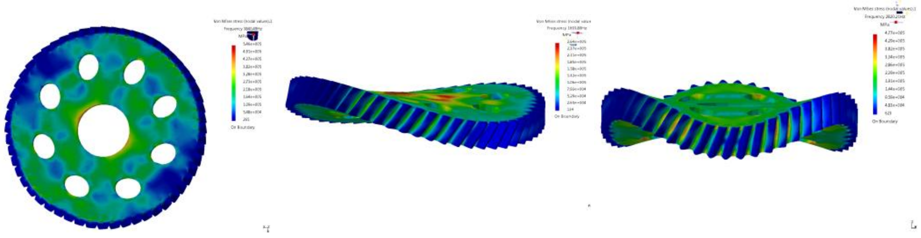
3.4 Impact of block to gear's modal

The main structure of Vibro Ripper gear includes a helical gear and a pair of blocks. Change the size of block in static and search the impacts of thickness h and radius R to gear's natural frequency.

Fig.5 shows the typical modal shape of helical gear in static, it mainly include circumferential vibration, torsional vibration, umbrella vibration, radial vibration, folding vibration, bending vibration.Compared with table.1 we can infer that block makes a great impact to each modal shape of helical gear.



Circumferential vibration Torsional vibration Umbrella vibration



Radial vibrationstep1 Folding vibrationstep 3 Bending vibration

Fig.5 Typical model shape of helical gear in static

Fig.6 shows the first 10 step natural frequency of both helical gear and Vibro Ripper gear in static. From the picture we can see that gear's natural frequency both increased with step and Vibro Ripper gear's natural frequency is higher than helical gear's natural frequency in each step.

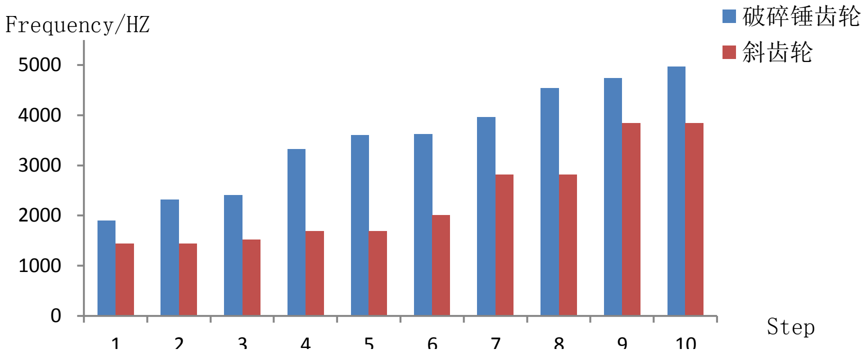
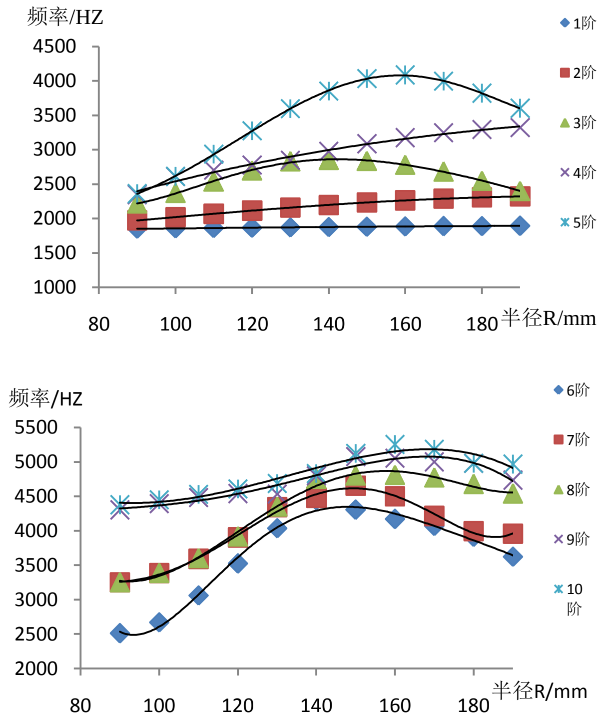


Fig.6 Natural frequency of Vibro Ripper gear and helical gear

Fig.7 shows the impact of radius R to Vibro Ripper gear's natural frequency.Block thickness h=100mm,R=90mm,100mm,110mm,120mm,130mm,140mm,150mm,160mm,170mm,180mm,190mm separately.In step 1 and step 2, radius R impacts natural frequency unclearly. In step 4,step 9 and step 10, radius R impacts natural frequency clearly. In step 5,step6,step 7,step8, radius R impacts natural frequency significantly.

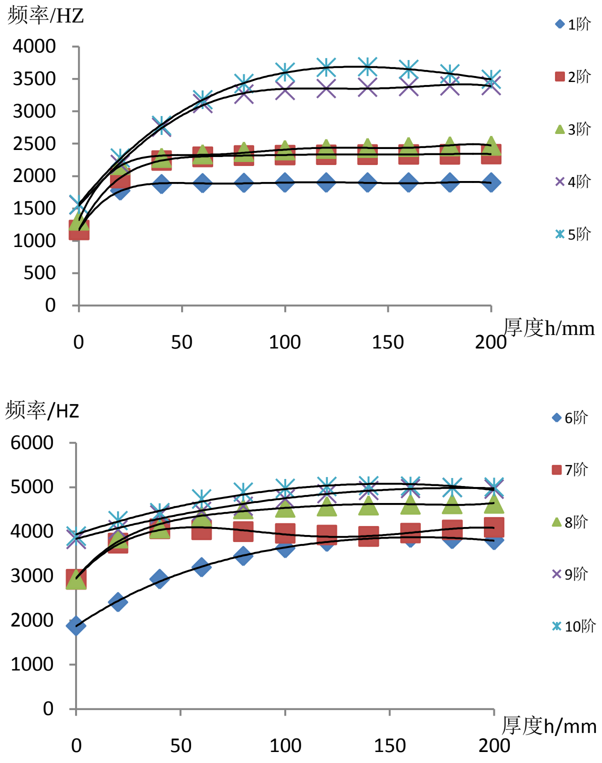
Fig.8 shows the impact of thickness h to Vibro Ripper gear's natural frequency. Block radius R=190mm, h=0mm,20mm,40mm,60mm,80mm,100mm,120mm,140mm,160mm,180mm,20mm. The natural frequency of Vibro Ripper gear increases with thickness h generally, but there are some differences between each step.

According Fig.7 and Fig.8,radius R impacts natural frequency more complex than thickness h and natural frequency of Vibro Ripper gear increases with thickness h generally. According formula (5),we can infer that stiffness K of VibroRipper gear increases with thickness h generally.



（a）step1-5 （b）step6-10

Fig.7 Impact of block radius R to natural frequency of Vibro Ripper gear



（a）step1-5 （b）step6-10

Fig.8 Impact of block thickness h to natural frequency of Vibro Ripper gear

IV. CONCLUSION

3D model and finite element model of Vibro Ripper gear built by parametric design of CATIA, the model can be corrected by ourselves and we can research the modal characteristics in static and different rotations as well as the impacts of block to modal. In static, the typical modal shape of helical gear includesstep 1 folding vibration, torsional vibration, circumferential vibration, step 3 bending vibration, radial vibration and compared with modal characteristic in rotation, we infer that the centrifugal stiffening effectcan change the model and the natural frequency increases with rotation.

The change of blockhas a great impact on helical gear’s model characteristics. Radius R impacts natural frequency intricately and differently in each step. But to thickness h, natural frequency of Vibro Ripper gear increases with thickness h generally, it is said that stiffness K increases with thickness h.

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