Dynamic influence of assembly and cam profile machining errors in the modulator of dobby

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ABSTRACT – REZUMAT

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This study delves deeply into the dynamic performance of modular dobby systems used in the textile industry, underscoring the pivotal role of assembly errors in high-speed environments. It uncovers that such errors significantly escalate the vibration of follower components at elevated speeds, with the impact becoming more pronounced as speed increases. Whether employing interference or clearance fits, discrepancies between the cam and roller substantially influence the mechanism's dynamic behaviour. Although interference fits can partially mitigate vibration, they may intensify during high-speed operations. In contrast, clearance fits not only heighten vibration but also reduce contact stiffness, thereby affecting the mechanism's precision and longevity. Drawing from these findings, the study advocates for the preferential use of ideal or interference fits during design and assembly to minimise or eliminate the need for clearance fits. Ideal fits are conducive to maintaining low vibration levels, while interference fits bolster contact stiffness and diminish vibration. Additionally, maintaining optimal lubrication is imperative for curbing friction, wear, and vibration, thereby directly enhancing system performance and stability. In conclusion, a comprehensive grasp of how assembly errors affect modular dobby machines is of paramount theoretical and practical significance, facilitating design optimisation and bolstering the mechanism's performance and reliability.

Keywords: *dobby, modulator, assembly errors, dynamic performance, vibration amplitude*

Influența dinamică a erorilor de asamblare și de prelucrare a profilului camei în modulatorul ratierei

Acest studiu analizează în profunzime performanțele dinamice ale sistemelor modulare cu ratieră utilizate în industria textilă, subliniind rolul esențial al erorilor de asamblare în medii de mare viteză. Studiul scoate la iveală faptul că astfel de erori sporesc semnificativ vibrațiile componentelor tachetului de camă la viteze ridicate, impactul devenind mai pronunțat pe măsură ce viteza crește. Indiferent dacă se utilizează ajustări cu interferență sau cu joc, discrepanțele dintre came și role exercită o influență substanțială asupra comportamentului dinamic al mecanismului. Deși ajustările prin interferență pot atenua parțial vibrațiile, acestea le pot intensifica în timpul funcționării la viteze mari. În schimb, ajustările cu joc nu numai că sporesc vibrațiile, dar reduc și rigiditatea de contact, afectând astfel precizia și longevitatea mecanismului. Pornind de la aceste constatări, studiul pledează pentru utilizarea preferențială a ajustărilor ideale sau de interferență în timpul proiectării și asamblării pentru a minimiza sau elimina necesitatea ajustărilor cu joc. Ajustările ideale sunt favorabile menținerii unor niveluri scăzute de vibrații, în timp ce ajustările cu interferență consolidează rigiditatea contactului și diminuează vibrațiile. În plus, menținerea unei lubrifieri optime este imperativă pentru reducerea frecării, uzurii și vibrațiilor, sporind astfel în mod direct performanța și stabilitatea sistemului. În concluzie, o înțelegere cuprinzătoare a modului în care erorile de asamblare afectează mașinile modulare cu ratiere este de o importanță teoretică și practică capitală, facilitând optimizarea proiectării și sporind performanța și fiabilitatea mecanismului.

Cuvinte-cheie: *ratieră, modulator, erori de asamblare, performanță dinamică, amplitudinea vibrațiilor*

INTRODUCTION

In the field of modern mechanical engineering, system dynamics is a discipline that investigates the behaviour of complex systems, with a focus on constructing accurate mathematical models to simulate and analyse the kinematic and dynamic characteristics of mechanical systems. As technology advances and industrial demands increase, optimising the performance of dobby modulators has become a prominent research area. The modulator in dobby machines transfers motion to the reed frame through linkages, directly impacting the weaving machine's opening performance [1, 2]. Therefore, it is crucial to study the dynamic performance of this mechanism.

Currently, the kinematic and dynamic analysis of the dobby often overlooks the influence of elastic deformation in the components on the motion characteristics of the reed frame [3, 4]. However, as dobby machines move towards lightweight and high-speed development, the inertia force and system flexibility significantly increase, and the effects of component elastic deformation on overall performance become more pronounced. The elastic deformation of key components in the modulator not only affects the dynamic behaviour of the take-up mechanism but also has important implications for the dynamic characteristics of dobby systems due to vibration responses [5, 6]. Therefore, studying the influence of component flexibility deformation on the opening performance of the reed frame in dobby modulators holds great theoretical and practical significance in addressing issues such as low motion stability and poor reliability. In the modulator, assembly errors between the cam and the follower are inevitable and directly impact the mechanism's dynamic response. Analysing the dynamic behaviour of the cam and follower under ideal fit, interference fit, and clearance fit reveals that assembly errors have a significant influence on the follower's vibration amplitude. This influence becomes more prominent, particularly at high speeds, necessitating precise control of assembly accuracy between the cam and follower in engineering applications to reduce clearance errors. Further research demonstrates that as the gear rotation cycle lengthens, the impact of assembly errors between the cam and the follower on the follower's dynamic behaviour in the modulator becomes more significant [7, 8]. In low-speed dobby operation, interference fit reduces follower vibration compared to clearance fit. However, at high speeds, both interference fit and clearance fit result in significant follower vibration. Therefore, during the assembly of the cam and follower, emphasis should be placed on ideal fit and interference fit, while clearance fit should be avoided or minimised, and appropriate lubrication conditions should be ensured. In conclusion, studying component flexibility deformation and its effect on the opening performance of the reed frame in dobby modulators not only provides theoretical support for optimising dobby design but also guides assembly and maintenance work in practical engineering, thereby enhancing overall performance and reliability [9, 10].

DYNAMIC MODEL OF THE FRAME

The schematic diagram in figure 1 depicts the modulator in the dobby. A centralised mass approach was used to construct the dynamic model, simplifying it to two mass elements, three spring elements, and three damper elements. This simplified model enables thorough analysis of dynamic characteristics like vibration, impact, and stability, supporting theoretical and practical evaluation. Ignoring the rolling friction coefficient streamlines the model to focus on essential dynamic factors. Deriving motion differential equations from Newton's second law allows for an accurate description of component motion, aiding in analysing dynamic behaviour, predicting performance, and optimising design, as shown in equation 1. The equation serves as the core of dynamic analysis, offering insights into the mechanism's dynamic response characteristics like vibration frequency, amplitude, and damping ratio during operation, ensuring safe and stable performance.

$$\begin{cases} m_1\ddot{y}_1 = k_1[S(\theta) - y_1] - F(\theta) + b_1[\dot{S}(\theta) - \dot{y}_1] - \\ \qquad - k_2(y_1 - y_2) - b_2(\dot{y}_1 - \dot{y}_2) \\ m_2\ddot{y}_2 = -k_3[y_2 - T(\theta)] + F(\theta) - b_3[\dot{y}_2 - \dot{T}(\theta)] + \\ \qquad + k_2(y_1 - y_2) + b_2(\dot{y}_1 - \dot{y}_2) \end{cases} \tag{1}$$

Several key parameters and variables are pivotal in the dynamic model of the modulator, collectively influencing its dynamic behaviour and performance:

- $S(\theta)$ represents the actual displacement of the main cam, impacting the follower's motion trajectory and velocity.

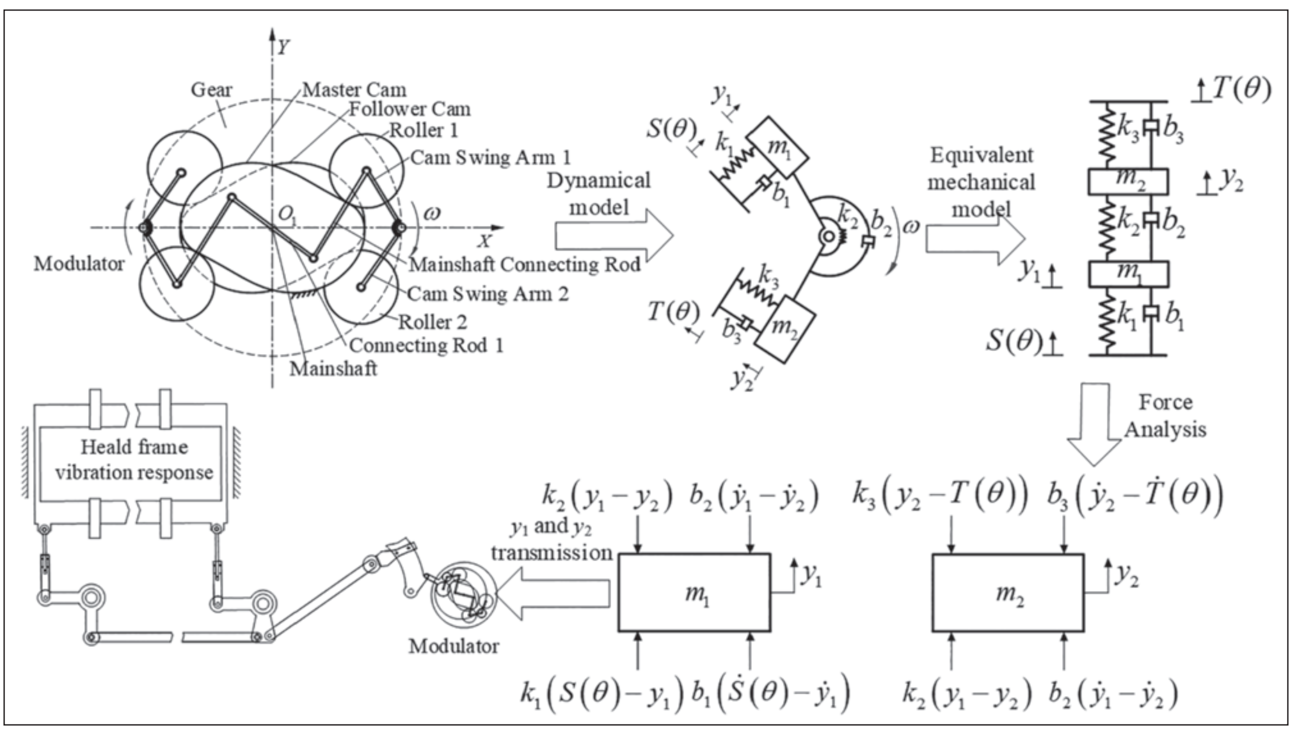

Fig. 1. The schematic diagram of the modulator in the dobby

- $T(\theta)$ represents the displacement coordinates of the secondary cam, influencing the complex motion patterns of the mechanism.
- $F(\theta)$ represents the applied load, directly affecting dynamic response and stability.
- y_1 and y_2 represent the displacements of follower mass blocks m_1 and m_2, reflecting dynamic characteristics.
- k_1, k_2 and k_3 represent the stiffness of the three springs, impacting deformation and vibration.
- b_1, b_2 and b_3 represent the damping coefficients of the three dampers, enhancing stability and reliability by reducing vibration and impacts.

These interconnected parameters and variables form a complex system in the modulator's dynamic model. Precise modelling and analysis of these components provide insights into their working principles, performance prediction under various conditions, and a scientific basis for optimisation design. Additionally, various errors in the modulator should be considered.

$$S(\theta) = S_1(\theta) + \Delta S(\theta) \tag{2}$$

In the equation, $S_1(\theta)$ represents the ideal displacement of the main cam in the modulator, and $\Delta S(\theta)$ represents the displacement variation of the main cam.

Vibration amplitude Δy: more context or information is needed to provide a specific definition or description of the vibration amplitude Δy.

$$\Delta y = y_1 - S_1(\theta) \tag{3}$$

Vibration amplitude F_u refers to the maximum displacement or distance travelled by a vibrating system from its equilibrium position. It represents the extent of oscillation or vibration experienced by the system.

$$F_u = \max \Delta y(\theta_i) - \min \Delta y(\theta_i) \tag{4}$$

where $\theta_i \in \left[36i°, 36(i+1)°\right)$, $i = 0,1,2,\ldots,19$.

The random error of the cam profile is shown in figure 2, and table 1 defines the range and magnitude of the random machining errors that occur.

In the design and analysis of the modulator, the assembly accuracy between the cam and roller has a significant impact on the dynamic performance of the mechanism. Assembly errors, including interference fit and clearance fit, can cause variations in the vibration amplitude of the follower, thereby affecting the stability and efficiency of the entire system.

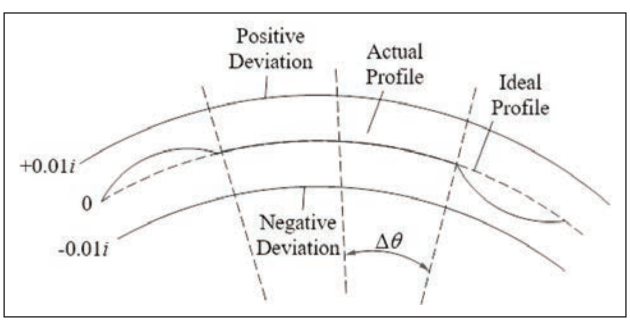

Fig. 2. The random error of the cam profile

Table 1

THE INTERVAL AND SIZE OF RANDOM MACHINING ERRORS		
Serial number	**Margin of error (°)**	**Magnitude of error (mm)**
1	(43.2 – 45]	$0.01 * S_1(\theta)$
2	(45 – 50.4]	$-0.01 * S_1(\theta)$
3	(129.6 – 135]	$0.01 * S_1(\theta)$
4	(135 – 140.4]	$-0.01 * S_1(\theta)$

Firstly, when the cam and roller are in an ideal fit state, where the assembly error is zero ($\Delta S_1(\theta) = 0$), the vibration amplitude of the follower is minimised. This ideal fit state ensures efficient and stable operation of the mechanism. However, in practical production, an ideal fit is often difficult to achieve due to various limitations during manufacturing and assembly processes.

When the cam and roller are assembled with an interference fit, the assembly error is negative ($\Delta S_1(\theta) = -0.01i * S_1(\theta)$, $i = 1,4,8,10$), meaning that the roller is excessively pressed into the cam groove, leading to an increase in the vibration amplitude of the follower. Although interference fit can improve contact stiffness and reduce looseness, excessive interference can cause additional friction and stress, thus exacerbating vibration.

Conversely, when a clearance fit is used, the assembly error is positive ($\Delta S_1(\theta) = 0.01i * S_1(\theta)$, $i = 1,4,8,10$), indicating that there is a certain gap between the roller and cam. In this case, the vibration amplitude of the follower is maximal. While a clearance fit can reduce assembly difficulties, it can also lead to decreased contact stiffness, increased vibration and impact, and adverse effects on the accuracy and lifespan of the mechanism.

By considering the dynamic model parameters in table 2 and without considering the load, this study investigated the vibration of the follower gear over two operating cycles. Experimental data revealed the variation of the follower's vibration amplitude in a dobby at different speeds, with particular emphasis on the influence of assembly errors. As shown in

Table 2

DYNAMIC PARAMETERS OF MODULATOR		
Parameters	**Value**	**Unit**
m_1	6.0	kg
m_2	2.5	kg
K_1	2.5×10^7	N/m
K_2	3.0×10^8	N/m
K_3	2.5×10^7	N/m
b_1	2.0	N s/m
b_2	3.0	N s/m
b_3	2.0	N s/m
F_0	1.0×10^3	N

figure 3, assembly errors ($i=1,4,8,10$) exhibit a distinct trend in their impact on vibration amplitude. Under low-speed operation and for cam profile errors $i \le 4$, interference fit assembly significantly reduces the vibration amplitude of the frame compared to the clearance fit assembly. However, as the speed of the dobby increases, especially beyond 800 rpm, both interference fit and clearance fit assembly significantly increase the vibration amplitude of the frame. When the cam profile error $i>4$, the situation is different. Under low-speed operation, interference fit assembly leads to a higher frame vibration amplitude compared to a clearance fit assembly. When the speed of the dobby exceeds 600 rpm, both assembly methods cause significant frame vibration amplitude. This finding emphasises that as the speed increases, the influence of assembly errors on vibration amplitude intensifies, especially under high-speed operating conditions, requiring stricter assembly accuracy between the cam and roller.

To provide a more intuitive demonstration of the influence of the rotating speed on the vibration of the follower in the dobby, figures 4, 5 and 6 present the calculated results of the follower's vibration at speeds of 300 r/min, 600 r/min, 800 r/min, and 1000 r/min. These data serve as important references for engineers in designing and optimising the modulator, emphasising the significance of accurately controlling the assembly errors between the cam and roller in engineering practice. This is crucial for reducing clearance errors and improving the overall performance of the mechanism.

When studying the dynamic behaviour of the modulator, the influence of assembly errors between the cam and roller becomes more significant as the gear operating cycle lengthens. This continuous impact of assembly errors during prolonged operation highlights their importance in maintaining stability and efficiency.

In general, interference fits result in smaller vibration amplitudes compared to clearance fits. This is mainly due to increased contact stiffness and reduced relative sliding between moving parts, which mitigates vibration. However, there are exceptions, such as when the dobby speed exceeds 800 r/min, where interference fits can increase vibration amplitudes. This could be attributed to excessive friction and stress generated by interference fits under high-speed operation, leading to stronger vibrations.

Based on these findings, we can conclude that both interference fits and clearance fits have a significant impact on the modulator's follower, regardless of speed. Under low-speed conditions, interference fits generate smaller vibrations compared to clearance

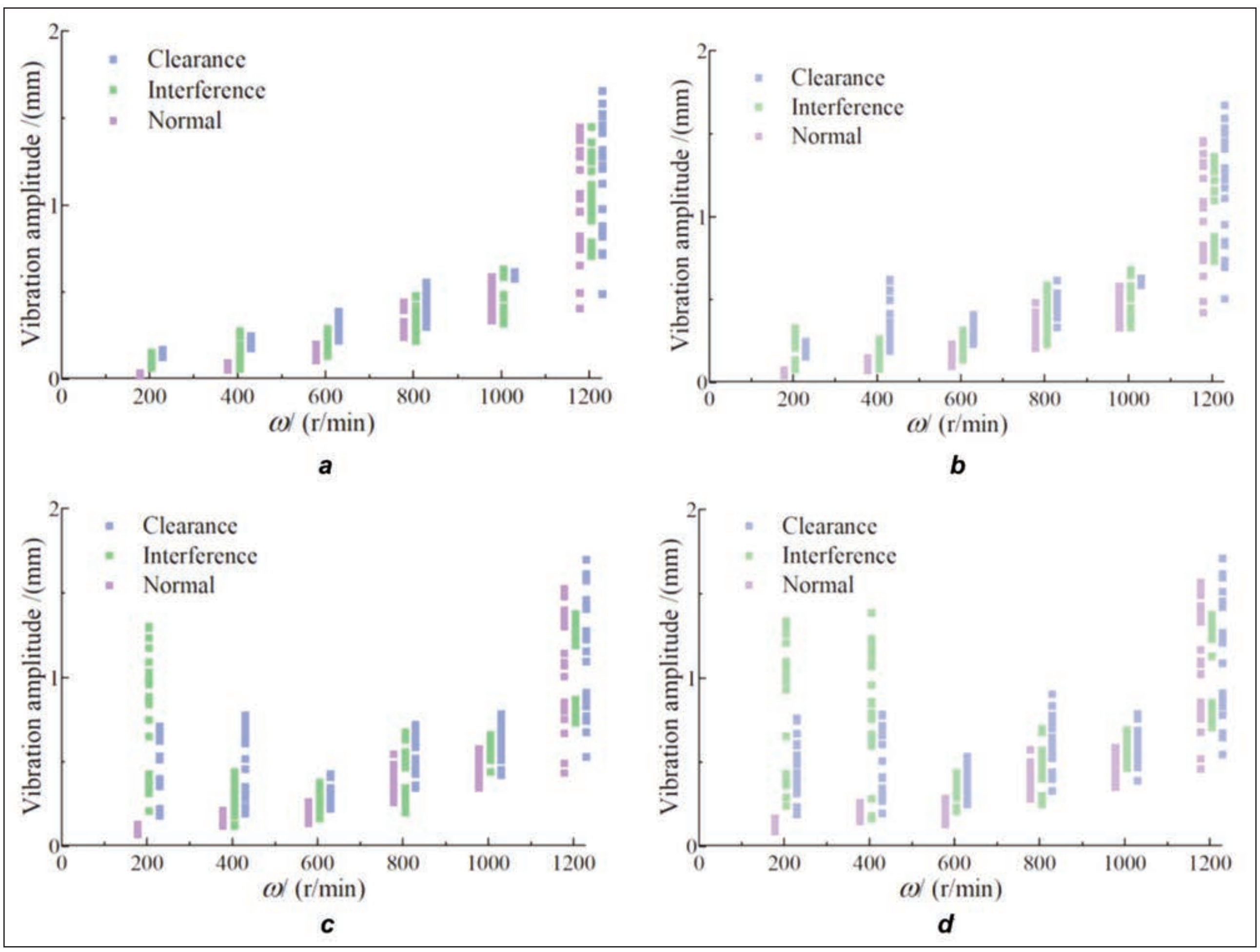

Fig. 3. The vibrational response model of the heald frame:
a – ω = 0.01 rpm; *b* – ω = 0.04 rpm; *c* – ω = 0.08 rpm; *d* – ω = 0.1 rpm

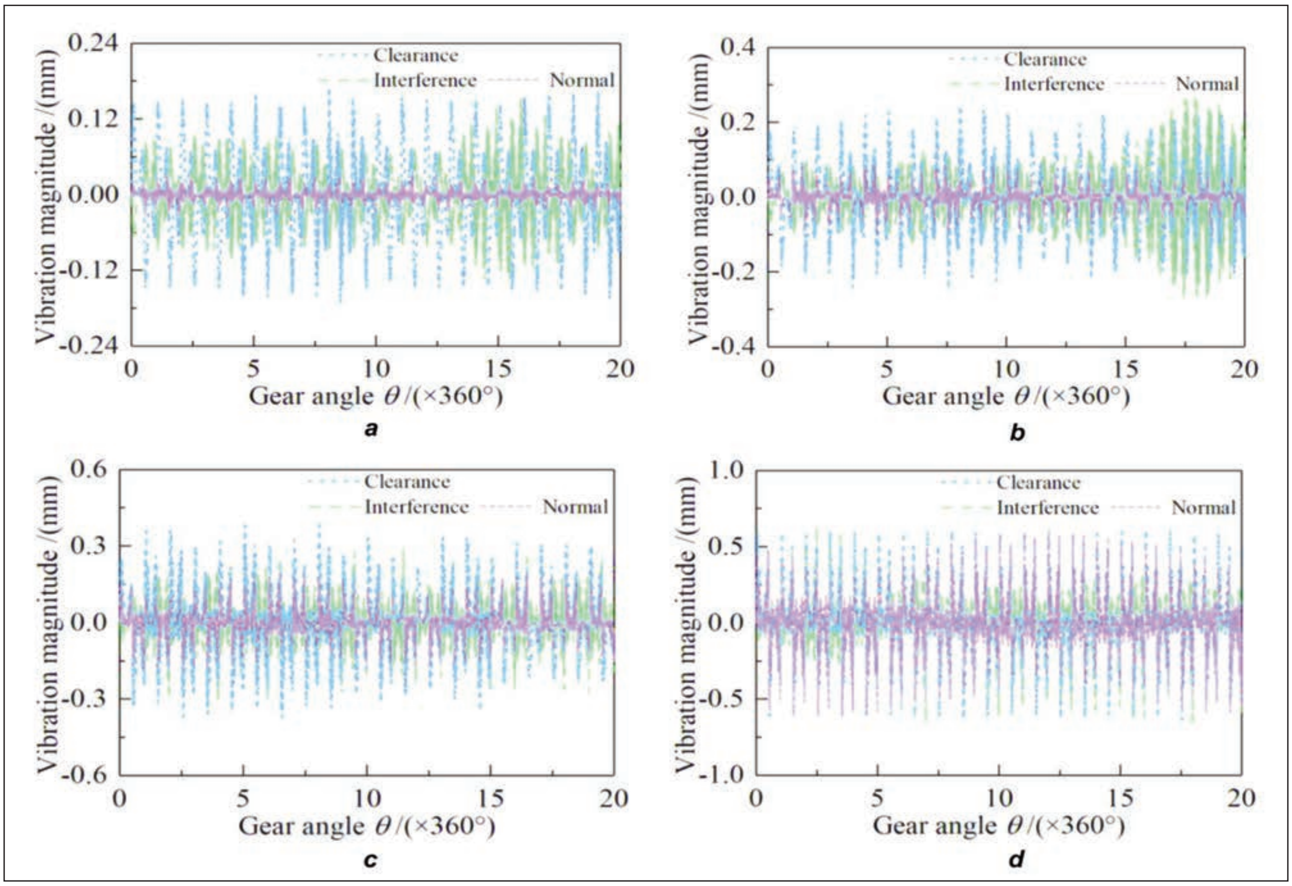

Fig. 4. The vibrational response model of the heald frame 0.01 ($i = 1$):
a – ω = 200 rpm; *b* – ω = 400 rpm; *c* – ω = 600 rpm; *d* – ω = 1000 rpm

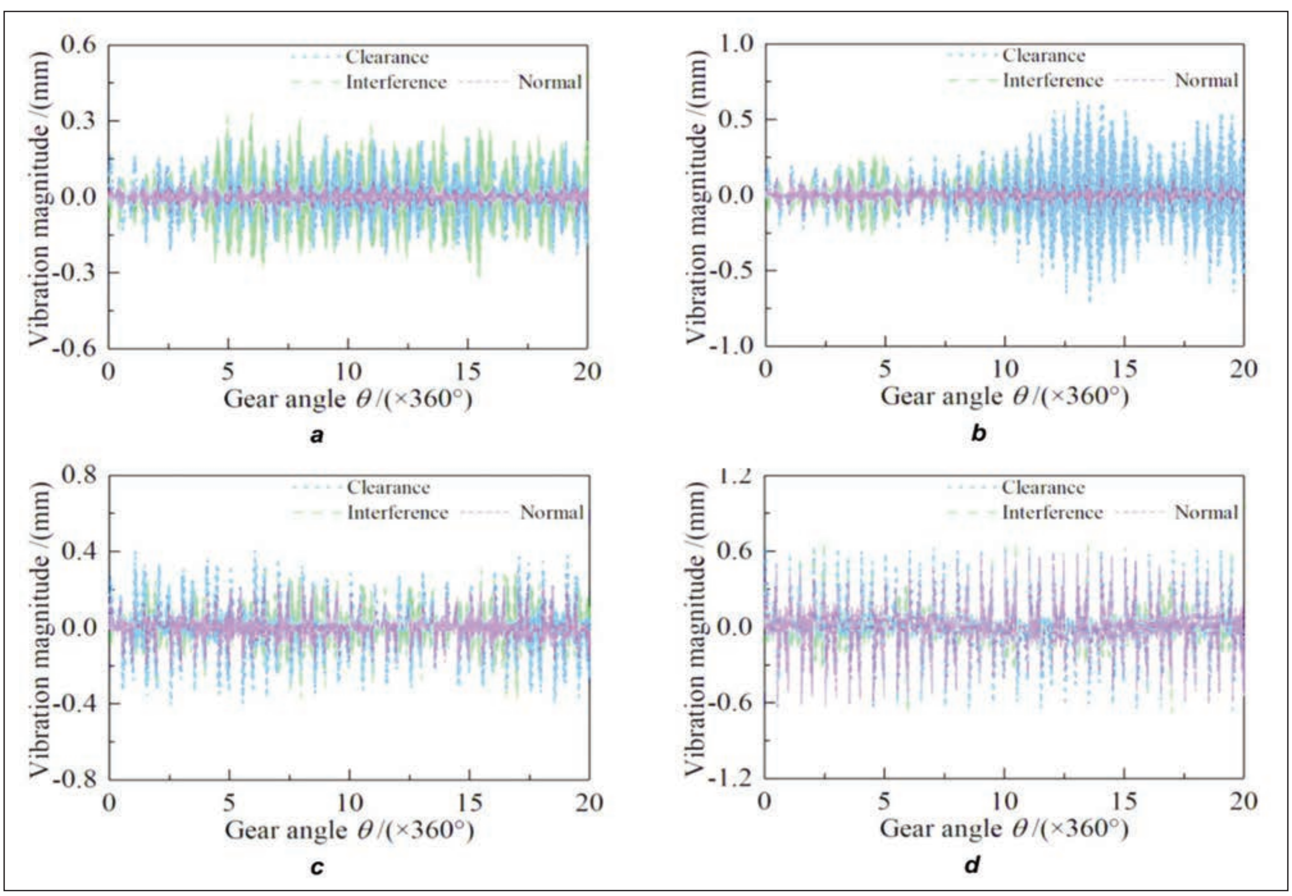

Fig. 5. The Vibrational response model of the heald frame ($i = 4$):
a – ω = 200 rpm; *b* – ω = 400 rpm; *c* – ω = 600 rpm; *d* – ω = 1000 rpm

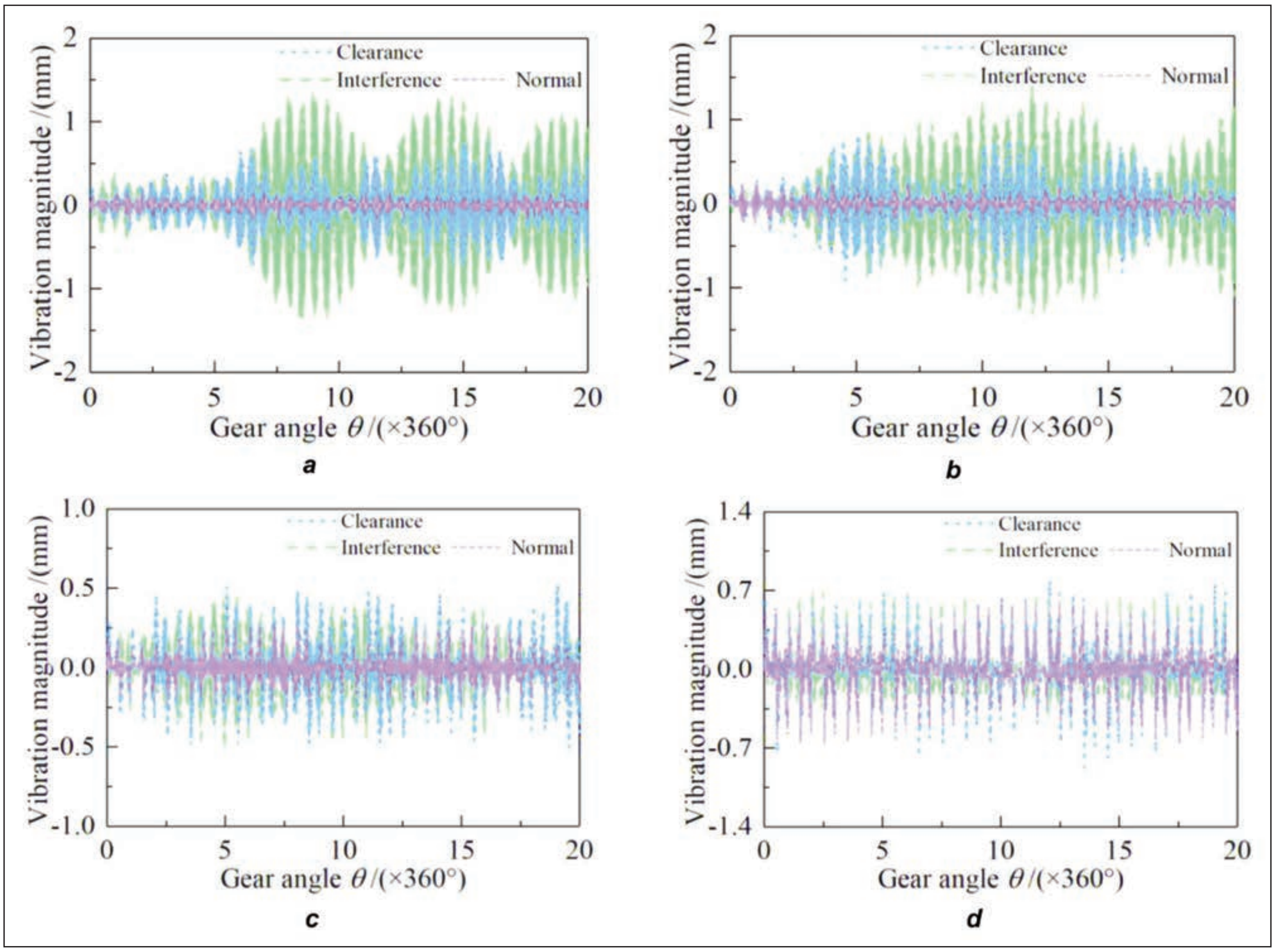

Fig. 6. The Vibrational response model of the heald frame ($i = 10$):
a – ω = 200 rpm; *b* – ω = 400 rpm; *c* – ω = 600 rpm; *d* – ω = 1000 rpm

fits. However, at high speeds, both types of fits can result in larger vibrations, affecting stability and efficiency. To optimise the modulator's performance, it is recommended to choose an ideal fit or an interference fit during the cam and roller assembly, while minimising clearance fits. An ideal fit ensures minimal vibration, while an interference fit increases contact stiffness and reduces vibration. Additionally, maintaining good lubrication conditions is crucial as it reduces friction, minimises wear, and further suppresses vibration, thus improving the overall system's performance and stability.

CONCLUSIONS

The analysis of the dynamic performance of the dobby's modulator reveals the critical influence of assembly errors on system performance. In high-speed operating environments, assembly errors significantly amplify the vibration amplitude of the follower, with this effect becoming more pronounced as the speed increases. Assembly errors between the cam and roller, whether it is an interference fit or a clearance fit, have a significant impact on the dynamic characteristics of the mechanism. While an interference fit helps reduce vibration, it can lead to increased vibration under high-speed conditions. On the other hand, a clearance fit not only increases the vibration amplitude but also decreases contact stiffness, affecting the accuracy and lifespan of the mechanism.

Therefore, when designing and assembling the modulator, it is preferable to use an ideal fit or an interference fit while avoiding or minimising the use of a clearance fit. An ideal fit helps maintain the lowest vibration level, while an interference fit contributes to increased contact stiffness and reduced vibration. Additionally, good lubrication conditions are crucial for reducing friction, wear, and suppressing vibration, directly impacting the improvement of system performance and stability. By optimising assembly fits and lubrication conditions, it is possible to significantly reduce the vibration and wear of the modulator, thereby improving the operational stability and efficiency of the dobby machine. This not only extends the lifespan of the dobby machine but also reduces downtime and maintenance costs, ultimately enhancing overall productivity and economic benefits.

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REFERENCES

[1] Gatti, G., Mundo, D., *On the direct control of follower vibrations in cam-follower mechanisms*, In: Mechanism and Machine Theory, 2010, 45, 23–35, https://doi.org/10.1016/j.mechmachtheory.2009.07.010

[2] Özgün, C., Gabil, A., *Design of a new rotary dobby mechanism*, In: Industria Textila, 2018, 69, 6, 429–433, https://doi:10.35530/IT.069.06.1484

[3] Singh, S., Tiwari, R., *Model based identification of crack and bearing dynamic parameters in flexible rotor systems supported with an auxiliary active magnetic bearing*, In: Mechanism and Machine Theory, 2018, 122, 92–307, https://doi.org/10.1016/j.mechmachtheory.2018.01.006

[4] Dupac, M.H., Beale, D.G., *Dynamic analysis of a flexible linkage mechanism with cracks and clearance*, In: Mechanism and Machine Theory, 2010, 45, 2010, 1909–1923, https://doi.org/10.1016/j.mechmachtheory.2010.07.006

[5] Hurtado, J.E., *Analytical dynamics of variable-mass systems*, In: Journal of Guidance Control and Dynamics, 2018, 41, 3, 701–709, https://doi.org/10.2514/1.G002917

[6] Gokarneshan, N., Jegadeesan, N., Periasamy, D., *Recent innovations in loom shedding mechanisms*, In: Indian Journal of Fibre & Textile Research, 2010, 35, 1, 85–94

[7] Mueller, A., *Screw and Lie group theory in multibody dynamics recursive algorithms and equations of motion of tree-topology systems*, In: Multibody System Dynamics, 2018, 42, 2, 219–248, https://doi.org/10.1007/s11044-017-9583-6

[8] Ma, J., Qian, L.F., *Modeling and simulation of planar multibody systems considering multiple revolute clearance joints*, In: Nonlinear Dynamics, 2017, 90, 3, 1907–1940, https://doi.org/10.1007/s11071-017-3771-z

[9] Abdullah, G.M., Hasçelik, B., Palamutcu, S., Soydan, A.S., *Synthesis work about driving mechanism of a novel rotary dobby mechanism*, In: Tekstil ve Konfeksiyon, 2010, 20, 3, 218–224

[10] Cardozo, W.S., Weber, H.I., *Dynamic modeling of a 2-dof parallel electrohydraulic-actuated homokinetic platform*, In: Mechanism and Machine Theory, 2017, 118, 1–13, https://doi.org/10.1016/j.mechmachtheory.2017.07.018

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