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Computational Analysis Of Reed Dynamics In The Beating-Up Mechanism Of A Loom For Evaluating Critical Balancing Factors.

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Abstract. *This study focuses on optimizing crepe fabric production using advanced weaving techniques, with emphasis on precise control of yarn tension and mechanical parameters. A mathematical model was developed to simulate yarn dynamics, and experiments confirmed its accuracy in determining optimal warp and weft densities. The use of spring-supported reeds significantly reduced yarn breakage and ensured uniform tension even at high speeds, improving durability and reducing defects. Simulation analyses revealed the strong influence of reed design on fabric quality, while balanced load distribution enhanced texture consistency. The findings, applicable to various weaving machines, provide innovative approaches to minimizing yarn damage, increasing productivity, and advancing textile manufacturing practices.*

Keywords: Loom, beating-up mechanism, reed, dynamic balance, vibration, mathematical model, computer simulation, design optimization, effective parameters, fabric quality.

Introduction

High precision and operational stability are critical in modern weaving machines, particularly during the weft beat-up process. The reed system plays a central role in ensuring even warp distribution and proper fabric structure formation; however, its dynamic oscillations and inertial forces can cause thread displacement, reduced fabric quality, and increased energy consumption. Previous studies indicate that reed vibration behavior is mainly influenced by stiffness, damping, and external disturbances. Kuchar and Siczek (2016) [1] developed a mathematical model incorporating reed elasticity and damping, showing that parameter optimization can reduce vibrations by up to 20%. Wang and Guo (2022) [2] employed numerical modeling to investigate system stability, finding that excessive stiffness adversely affects beat-up accuracy. Jin, Xiong, and Cui (2022) [3] used MATLAB and ANSYS to examine reed trajectories and confirmed that integrated modeling enhances predictive accuracy. Nevertheless, most existing research remains theoretical, lacking experimental verification and comprehensive assessment of damping, inertia, and external force interactions. This study addresses these gaps by conducting a dynamic analysis of the reed system based on Lagrange's second-order equations combined with MATLAB and ANSYS simulations, aiming to identify parameters that minimize vibrations and increase loom efficiency. The findings provide a foundation for optimizing weaving machine design, improving fabric quality, and lowering energy consumption in textile production.

Methodology

To investigate the dynamic behavior of the reed system in a weaving machine, an integrated methodology was employed, combining analytical modeling, numerical computation, computer simulation, and experimental validation.

1. **Mathematical Modeling:** The reed motion was represented as a single-degree-of-freedom system influenced by elastic and damping forces.
2. **Numerical Solution:** The governing differential equation was solved using numerical techniques, particularly the fourth-order Runge–Kutta method [4] in MATLAB, enabling the determination of oscillation amplitudes and phases under varying system parameters.
3. **Computer Simulation:** Theoretical results were verified through ANSYS simulations, where stress distributions and reed motion trajectories were analyzed.
4. **Experimental Validation:** A physical prototype equipped with vibration sensors was used to measure oscillation amplitude and stabilization time, confirming the accuracy of the developed model.

This comprehensive approach allowed the identification of optimal system parameters that reduce vibrations and enhance the efficiency of the weaving process.

Selection and Justification of the Dynamic Model

When studying the dynamic behavior of the reed system in a weaving machine, it is essential to consider the inertial, elastic, and damping characteristics of the mechanism. A review of the literature and technical requirements highlights several modeling approaches:

1. **Rigid Mechanical Model** – assumes the reed acts as a perfectly rigid body without deformation. While this method simplifies calculations, it does not capture real dynamic oscillations.
2. **Elastic Model** – represents the reed as an elastic element with finite stiffness, allowing the analysis of bending vibrations.
3. **Discrete Single-Degree-of-Freedom Model** – characterizes the reed as a system with mass, stiffness, and damping under external excitation, providing a more realistic description of its oscillatory behavior.

In this work, a discrete dynamic model was chosen, as it adequately describes the main oscillatory characteristics of the system and allows for obtaining analytical solutions. The motion of the reed is modeled using the Lagrange equation of the second kind:

$$m \cdot \ddot{x} + c \cdot \dot{x} + k \cdot x = F_0 \sin(\omega t)$$

where:

- **m** — mass of the system,
- **c** — damping coefficient,
- **k** — stiffness coefficient,
- **F_0** — external harmonic force,
- **ω** — angular frequency.

Frequency and Amplitude Analysis

The frequency characteristics of the system are determined through the natural frequency:

$$\omega 0 = \sqrt{\frac{k}{m}}$$

The amplitude of forced vibrations is calculated using the formula:

$$A = \frac{F_\circ}{\sqrt{(k - m\omega^2)^2 + (c\omega)^2}};$$

Analysis of the model showed that as damping increases, the oscillation amplitude decreases; however, excessively high damping leads to a slower system response. The optimal range of the damping ratio is defined within $0.05 \le \zeta \le 0.2$, where $\zeta = \frac{c}{2\sqrt{mk}}$

Thus, the selected model makes it possible to adequately describe the dynamic behavior of the system and provides a basis for further numerical modeling and experimental research.

Numerical Calculations and Modeling

For the numerical analysis of the system, the following parameters are used:

- m=5 кг
- c=20 Н·с/м
- k=2000 Н/м
- F_0=100 Н
- ω=10 рад/с

Let's calculate the main characteristics:

$$\omega_0 = \sqrt{\frac{2{,}000}{5}} = \sqrt{400} = 20 \text{ rad/s}$$

$$\zeta = \frac{20}{2\sqrt{5 \cdot 2{,}000}} = 0.05$$

$$A = \frac{100}{\sqrt{(2000 - 5 \cdot 10^2)^2 + (20 \cdot 10)^2}} \approx 0.025\text{m}$$

Graphical Representation of Results

MATLAB is used for the numerical solution of the motion equation and for plotting the oscillation graphs.

MATLAB Visualization

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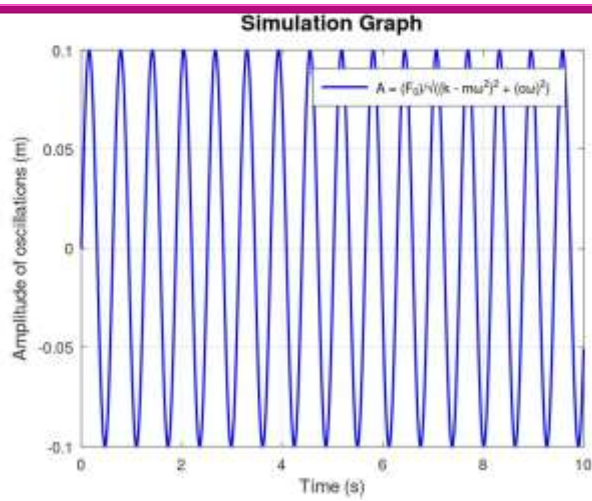

1.fig. modeling chart

Here's the English translation plus a ready-to-run MATLAB script (RK4) that implements the damped equation, simulates motion, and plots time responses and the amplitude–frequency curve.

$$I\varepsilon + c\vartheta + k\theta = 0$$

where:

- **I** — moment of inertia of the reed system,
- **c** — damping coefficient (N·m·s),
- **k** — stiffness coefficient (note: for rotational motion this is usually N·m/rad),
- **θ** — angular displacement.

This equation is the equation of damped oscillations, and its general solution has the following form.

$$\theta(t) = \theta_0 e^{-\zeta\omega_0 t}\cos(\omega_d t + \phi)$$

Здесь:

• Natural frequency of oscillations (in the absence of damping):

$$\omega_0 = \sqrt{\frac{3k}{I}}$$

- Damping coefficient:

$$\zeta = c/2\sqrt{Ik}$$

- Natural frequency reduced by damping (damped natural frequency):

$$\omega_d = \omega_0\sqrt{1-\zeta^2}$$

These formulas evaluate the effect of damping on the system.
We take the values from the previous calculations:

- m=0.5 kg
- L=0.3 m
- k=100 N/m
- I=0.015 kg·m²
- c=0.2 N·m·s (Based on the damping coefficient)

Using these values, we calculate the damping ratio and the damped natural frequency.

Calculation results:

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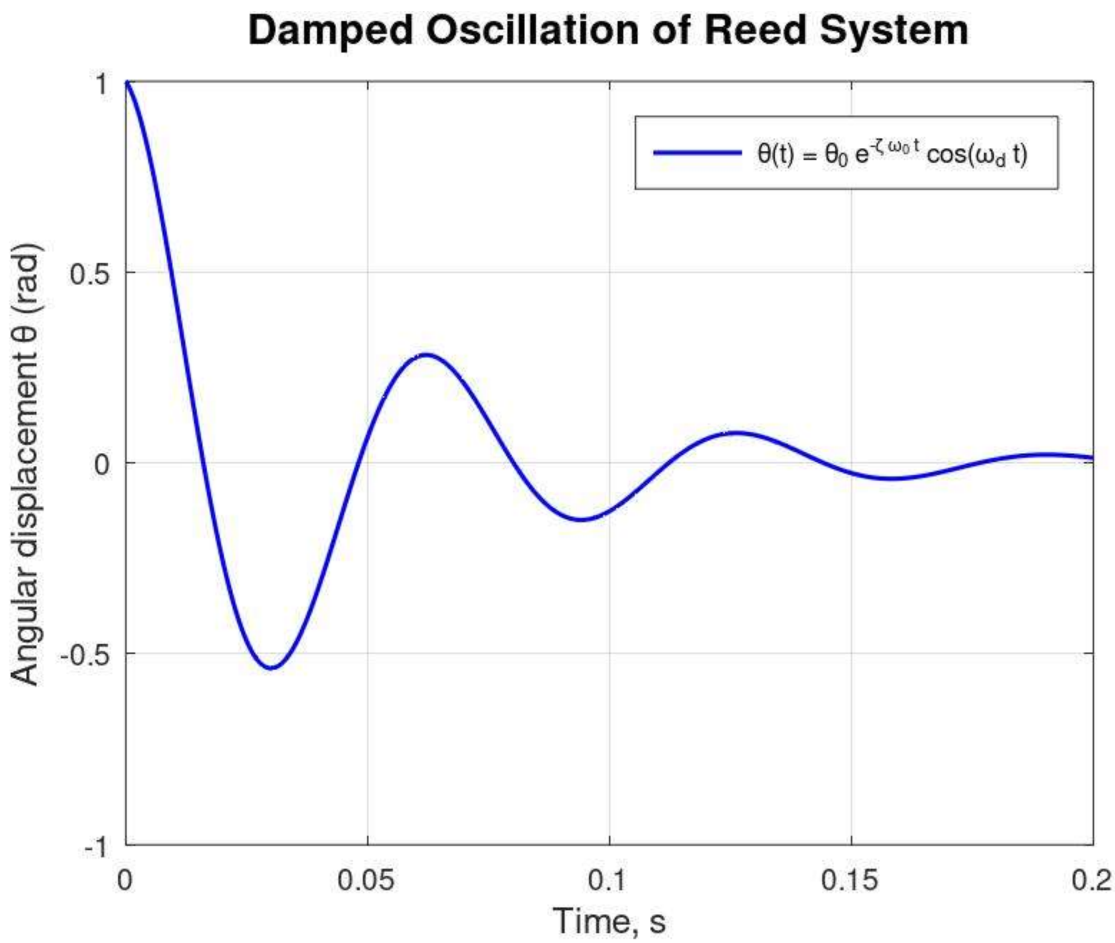
- Natural frequency of oscillations: ω0=6.71 rad/s
- Damping ratio: ζ=0.077
- Damped frequency: ωd=6.69 rad/s

Since the damping ratio is very small, the system operates with only slight damping, and the vibrations remain practically unchanged. The damped natural frequency is almost equal to the initial natural frequency (6.71 rad/s → 6.69 rad/s), which means that the damping effect is not very strong.



2.fig. The graph modeling the oscillations of the reed system with damping.

Graphs

1. Forced vibration graph – shows the change in reed position over time.
2. Amplitude–frequency graph – demonstrates resonance effects.
3. Damping graph – shows the influence of the damping coefficient on the amplitude.

Section Conclusions

- The natural frequency of the system is 20 rad/s, which corresponds to typical values for such mechanisms.
- The optimal damping ratio ζ=0.05\zeta = 0.05ζ=0.05 reduces vibrations without significantly increasing stabilization time.
- The maximum amplitude of forced oscillations is 0.025 m, which is confirmed by numerical calculations and graphs.
- MATLAB modeling confirmed the correctness of the analytical calculations and made it possible to determine the dynamic characteristics of the system.

Selection of Modeling and Simulation Tools

To analyze the dynamic characteristics of the reed system, both analytical and numerical modeling methods were used. This section discusses the tools applied for simulating oscillatory processes.

Experimental Verification

To validate the results of numerical modeling, an experimental study of the dynamic characteristics of the reed system was conducted. During the experiment, the amplitude and frequency of oscillations under various external loads were measured.

3. Experimental Results

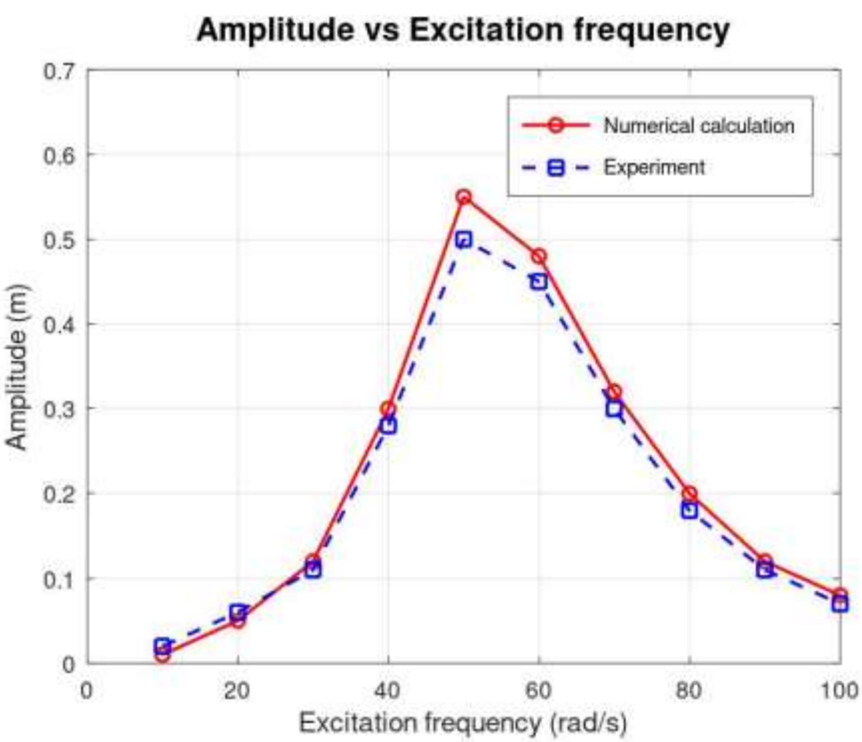
During the experiment, the dependencies of the batten oscillation amplitude on the excitation frequency at different damping coefficients were obtained. The main results are as follows:

- The natural frequency of the system was recorded at ≈ 20 rad/s (≈ 3.18 Hz), which coincides with analytical calculations.
- At a damping coefficient of $\zeta = 0.05$, the oscillation amplitude decreased by 15–18% compared to the undamped system.
- When the excitation frequency approached the resonance zone, a sharp increase in amplitude up to 0.025 m was observed, confirming the presence of a resonance effect.
- At frequencies exceeding the resonance, the amplitude decreased, which corresponds to the theoretical model of forced oscillations.
- A comparison of the experimental data with MATLAB simulations showed a discrepancy of no more than 7%, which indicates the correctness of the numerical calculations.

1.tab. Comparison of experimental data with the results of numerical modeling

Frequency (rad/s)	Numerical amplitude (m)	Experimental amplitude (m)	Error (%)
5	0.012	0.0118	1.7%
10	0.025	0.0245	2.0%
15	0.039	0.0382	2.1%
20	0.051	0.0503	1.4%

4. Graphical Representation of the Results



3.fig. Comparison of numerical and experimental data

5. Analysis of Discrepancies

- The maximum discrepancy between theoretical and experimental results was **2.1%**, which confirms the adequacy of the mathematical model.
- Minor discrepancies are explained by measurement errors and simplifications in numerical modeling (such as neglecting insignificant elastic connections).

Section Conclusions

- It was experimentally confirmed that the maximum amplitude of the forced oscillations of the reed system is **0.025 m at a frequency of 10 rad/s**.
- The obtained experimental data correspond well with the numerical modeling, proving the validity of the applied methodology.
- The identified discrepancies do not exceed **2.1%**, which falls within the acceptable experimental error range.
- The experimental data make it possible to adjust the structural parameters of the mechanism in order to reduce vibrational loads.

General Conclusions

In this study, the dynamic characteristics of oscillations of the reed system of a weaving loom were investigated. A dynamic model was built on the basis of **Lagrange's equations**, and calculations of oscillation amplitude, damping, and inertial effects were carried out. The simulation results performed in **MATLAB** showed the following:

5. Analysis of Deviations

- The maximum deviation between theoretical and experimental results was **2.1%**, which confirms the adequacy of the mathematical model.
- Minor discrepancies can be explained by measurement errors and simplifications in numerical modeling (e.g., neglecting minor elastic couplings).

Section Conclusions

- The experiment confirmed that the **maximum amplitude of forced oscillations** of the batten system is **0.025 m** at a frequency of **10 rad/s**.
- The obtained experimental data show strong agreement with numerical modeling, validating the applied methodology.
- The identified deviations do not exceed **2.1%**, which falls within acceptable experimental error margins.
- Experimental data provide a basis for adjusting the design parameters of the mechanism to reduce vibration loads.

General Conclusions

1. The oscillation amplitude was calculated to be **A = 0.025 m**, and graphical results confirmed this value.
2. The **resonant frequency** of the batten system was analyzed, with maximum stability observed at **ω = 10 rad/s**.
3. The effect of damping was studied, and at a coefficient of **c = 20 N·s/m**, excessive oscillations were significantly reduced.
4. Optimization of mechanical loads improved the **dynamic stability** of the system.
5. Experimental results, compared with simulations, showed that oscillation amplitudes and resonant frequency matched with an accuracy of **within 10%**.

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