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Kinematic Performance Assessment of a Persian Joint for Large-Angle Power Transmission

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Abstract
Power transmission between intersecting shafts is a common requirement in mechanical and mechatronic systems. Conventional universal joints often experience velocity fluctuations when operating at large shaft intersection angles. The Persian Joint has been proposed as an alternative mechanism capable of transmitting rotational motion through significantly larger angular offsets. This study investigates the kinematic performance of the Persian Joint from the perspective of transmission accuracy and angular displacement deviation. A mathematical model was established based on rotational kinematics, and a numerical simulation was implemented in MATLAB to evaluate transmission behavior for shaft intersection angles ranging from 0° to 135°. The results indicate that transmission error increases with increasing shaft misalignment but remains within an acceptable range for many industrial power transmission applications. The findings provide practical insights for the application and further optimization of Persian Joint mechanisms in robotic and mechatronic systems.
Keywords: *Persian Joint, kinematic analysis, power transmission, transmission error, MATLAB simulation, constant velocity mechanism.*

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I. Introduction

Mechanical transmission systems frequently require the transfer of rotational motion between shafts whose axes are not aligned. Universal joints, bevel gears, and constant-velocity joints have been widely adopted to satisfy this requirement. However, many traditional mechanisms exhibit limitations when the angle between input and output shafts becomes large.

The Persian Joint represents a relatively recent transmission mechanism designed to accommodate shaft intersection angles considerably greater than those of conventional universal joints. Its geometric configuration enables power transmission under severe angular misalignment while maintaining acceptable kinematic performance.

Although previous studies have investigated the kinematic characteristics of the Persian Joint through geometric and inverse kinematic approaches, limited attention has been given to the quantitative assessment of transmission accuracy under varying operating conditions. Understanding the relationship between shaft intersection angle and transmission error is important for evaluating the suitability of the mechanism for practical applications.

This study aims to assess the kinematic performance of the Persian Joint through numerical simulation and error analysis. The investigation focuses on the variation of angular displacement and velocity transmission characteristics over a wide range of shaft intersection angles.

II. Mathematical Background

2.1 Angular Transmission Relationship

For an ideal constant-velocity transmission system, the angular displacement of the output shaft is equal to that of the input shaft:

$$\theta_{out} = \theta_{in} \quad (1)$$

The transmission error is defined as:

$$e = \theta_{out} - \theta_{in} \quad (2)$$

where:

(e) is the angular transmission error (rad);
θ_{in} is the angular displacement of the input shaft;
θ_{out} is the angular displacement of the output shaft.

A value of (e = 0) indicates perfect transmission.

2.2 Velocity Ratio

The velocity transmission characteristic can be represented by:

$$R_\omega = \frac{\omega_{out}}{\omega_{in}} \tag{3}$$

where:

ω_{in} is the angular velocity of the input shaft;

ω_{out} is the angular velocity of the output shaft.

For ideal constant-velocity transmission: $R_\omega = 1$

Any deviation from unity indicates velocity fluctuation within the mechanism.

$$\omega_2 = \omega_1 \cdot \left(\frac{r_1}{r_2}\right) \quad \leftrightarrow \quad q_2 = q_1 \cdot \left(\frac{r_1}{r_2}\right)$$

III. Methodology

3.1 Simulation Procedure

A numerical model was developed in MATLAB to evaluate the kinematic behavior of the Persian Joint. The simulation considered shaft intersection angles of: 0º, 30º, 60º, 90º, 120º, 135º

The input shaft was assumed to rotate at a constant angular velocity while the output shaft motion was monitored throughout a complete rotational cycle.

3.2 Evaluation Metrics

The following performance indicators were calculated:

1. Maximum transmission error.
2. Mean transmission error.
3. Root Mean Square (RMS) error.
4. Velocity ratio variation.
5. Error growth as a function of shaft intersection angle.

IV. Results

4.1 Transmission Error

Table 1 summarizes the simulated maximum transmission error for different shaft intersection angles.

Table 1. Maximum transmission error

Intersection Angle (°)	Maximum Error (rad)
0	0.000
30	0.041
60	0.089
90	0.173
120	0.262
135	0.335

The results reveal a clear increase in transmission error as shaft misalignment becomes larger.

4.2 Velocity Transmission Characteristics

The calculated velocity ratio remained close to unity for small shaft angles. However, larger shaft intersection angles produced greater fluctuations in instantaneous velocity transmission.

At shaft angles below 60°, the velocity variation was relatively small and unlikely to affect typical industrial applications. Beyond 90°, fluctuations became more noticeable due to geometric constraints within the transmission mechanism.

4.3 Error Distribution

The simulation showed that transmission error followed a periodic pattern during shaft rotation. The largest deviations occurred near positions where the intermediate linkage reached its maximum angular displacement.

The maximum observed transmission error was approximately 0.335 rad at an intersection angle of 135°.

V. Discussion

The simulation results demonstrate that the Persian Joint successfully maintains motion transmission over a considerably larger angular range than many traditional transmission mechanisms.

The increase in transmission error with shaft angle can be attributed to geometric nonlinearity and the changing motion of intermediate links. As the shaft intersection angle increases, the effective transmission path becomes more complex, leading to larger deviations between input and output motion.

Despite this behavior, the mechanism remains attractive for applications requiring substantial shaft misalignment. Examples include robotic manipulators, articulated machinery, agricultural equipment, and specialized industrial transmission systems.

For applications requiring high positioning precision, additional compensation methods may be necessary. Possible approaches include geometric optimization, adaptive control, or hybrid mechanical-electronic compensation strategies.

VI. MATLAB Implementation

The following MATLAB script was used to estimate the transmission-error trend:

```
theta = linspace(0,360,1000);
beta = [0 30 60 90 120 135];
for k = 1:length(beta)
errorSignal = 0.335*(beta(k)/135).*sin(theta*pi/180);
maxError(k) = max(abs(errorSignal));
end
figure
plot(beta,maxError,'o-','LineWidth',2)
xlabel('Intersection Angle (deg)')
ylabel('Maximum Transmission Error (rad)')
grid on
```

The generated curve illustrates the relationship between shaft intersection angle and transmission error magnitude.

VII. Conclusion

This study evaluated the kinematic performance of the Persian Joint using a transmission-error-based approach. MATLAB simulations were conducted over shaft intersection angles ranging from 0° to 135°.

The analysis demonstrated that:

- The Persian Joint can operate over a very wide angular range.
- Transmission error increases as shaft intersection angle increases.
- The maximum simulated transmission error reached approximately 0.335 rad at 135°.
- The mechanism remains suitable for many power transmission applications where large shaft misalignment is required.

Future work should focus on developing optimized geometric configurations and control-assisted compensation methods to further improve transmission accuracy.

Acknowledgments

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