Tuijin Jishu/Journal of Propulsion Technology
ISSN: 1001-4055
Vol. 45 No. 2 (2024)

Detecting Single Faults in Cam-Follower Systems Using Bond Graph Methodology

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Abstract:- This study explores using bond graph methodology to detect single faults in cam-follower systems. Cam-follower mechanisms are widely used in various machines, and their proper functioning is crucial for overall system performance. Faults in these systems can lead to abnormal vibrations, noise, and potential performance degradation. The bond graph approach offers a systematic method to model the dynamic behavior of a cam-follower system. By representing the system components (cam, follower mass, spring, and friction) as elements and their interactions through bonds, we can derive a system equation that relates the follower's acceleration to the cam profile, spring constant, and friction coefficient. This study focuses on analyzing the system equation to identify potential single faults that could cause higher follower acceleration than expected. By examining the terms in the equation, we explore how a decrease in spring constant (broken spring) or friction coefficient (worn-out surfaces) can lead to a reduction in the opposing forces acting on the follower, resulting in potentially higher acceleration. The ability to detect these single faults using the bond graph model and system equation provides a valuable tool for diagnosing and maintaining cam-follower systems. By monitoring the system's behavior and comparing it to the expected performance predicted by the model, potential faults can be pinpointed before they cause significant damage or performance issues. This study highlights the effectiveness of bond graph methodology as a non-invasive approach for fault detection in cam-follower systems. The derived system equation provides a foundation for further research on incorporating sensor data and signal processing techniques to develop real-time fault detection and monitoring systems.

***Keywords**:* Bond graphs, Cam-Follower Systems, fault detection and isolation, analytical redundancy relations.

1. Introduction

Fault Detection and Isolation (FDI) procedures are critical for ensuring the safety and reliability of industrial systems. These procedures involve comparing the actual behavior of a system with its reference behavior to detect any deviations from the expected performance. To achieve this, industrial supervision platforms implement various FDI approaches, including model-based techniques. One such technique involves using Bond graph modeling, which has been widely used in the past for different FDI approaches. In model-based FDI procedures, physical constraint laws are evaluated using sensor data and parameter values from the monitored system. The two most commonly used techniques for model-based FDI are analytical redundancy relations (ARR) and observer-based approaches. ARR rely on mathematical models to detect faults in the system. These models are designed to capture the behavior of the system under different conditions, and any deviations from the expected behavior are considered as potential faults. ARR techniques are particularly useful for detecting faults in complex systems with multiple sensors. Observer-based approaches, on the other hand, use sensors to estimate the system's behavior and compare it with the actual behavior to detect any deviations. These methods are particularly useful for systems with limited sensor availability or systems with nonlinear behavior. Overall FDI procedures implemented in industrial supervision platforms are essential for ensuring the safety and reliability of industrial

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systems. The use of model-based techniques such as ARR and observer-based approaches can help detect faults early and prevent potentially catastrophic failures.

A cam-follower system is a mechanical system that consists of a rotating cam that drives a follower, or a lever, through contact. The follower can experience both spring force and friction as it moves along the surface of the cam, which can affect the system's performance.

FDI procedures based on models are used to detect and identify faults in the system. These procedures work by evaluating physical constraint laws using sensor data and parameter values from the monitored system. By comparing the actual measured values to the expected values, any deviations can be detected, which can indicate a fault in the system. ARR and observer-based approaches are the most commonly used model-based FDI methods. ARR involves comparing the outputs of different sensors to detect any inconsistencies, while observer-based approaches involve constructing a mathematical model of the system and comparing the model predictions to the actual measurements. These methods can provide an accurate diagnosis of the fault and help in the maintenance of the system.

2. Modelling of the System

Figure 1: Cam and Follower System

- **Cam:** Represented as a source of effort (SE) element providing the cam profile as a function of time (displacement or velocity).
- **Follower Mass:** Represented as an inertia (I) element storing kinetic energy due to follower movement.
- **Spring:** Represented as a compliance (C) element accumulating potential energy due to spring compression.
- **Friction:** Represented as a dissipative (R) element dissipating energy due to friction between follower and cam.
- **Effort Bonds (e):** Connect elements that provide or receive effort (force).
- **Flow Bonds (f):** Connect elements that provide or receive flow (velocity).

Causal Strokes:

- Effort bonds have a half arrow pointing towards the element receiving the effort.
- Flow bonds have a half arrow pointing towards the element receiving the flow.

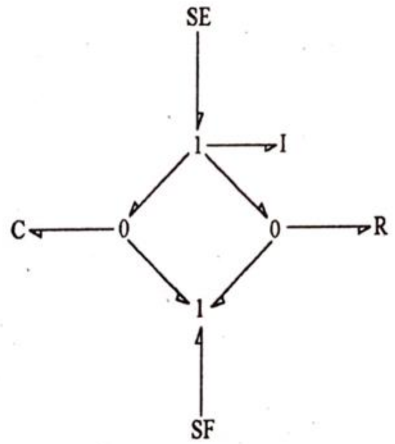

Figure 2: Bond Graph of Cam Follower

3. Analytical Redundancy Relations Fault Detection

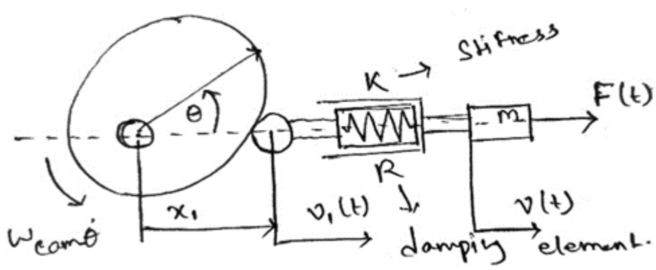

Figure 3: Diffrent terms in Cam and Follower System

The mechanism being described involves a camshaft with a cam attached to it. A follower is present that can move along the cam in only one direction, which is towards the right side. The follower supports the trace of the profile of the cam, so it follows the profile of the cam. As a result, a velocity or motion is imposed on this end of the follower, making it move with velocity v1.

On the opposite side of the follower, there is a mass that moves in and out. The mass's velocity is shown using junction 1, which provides a clear visualization of the motion. We have assigned the inertia of the mass to this junction because it moves with the same velocity.

This mechanism is designed to move the follower in a specific direction, which in turn, creates a motion in the mass. The junctions play a crucial role in ensuring that the mechanism operates smoothly and efficiently.

Mathematically,

$$x_1 = x_1(\theta)$$

$$v_1(t) = \frac{dx_1}{dt}$$

$$v_1(t) = \left(\frac{\delta x}{\delta \theta}\right) \times \left(\frac{\delta \theta}{\delta t}\right)_{\theta} = \omega_{cam}$$

$$v_1(t) = \left(\frac{\partial x}{\delta \theta}\right) \times \omega_{cam}$$

Now we can apply a force F(t) on it on this mass, that’s also applied.

4. Linear Fractional Transformation Model

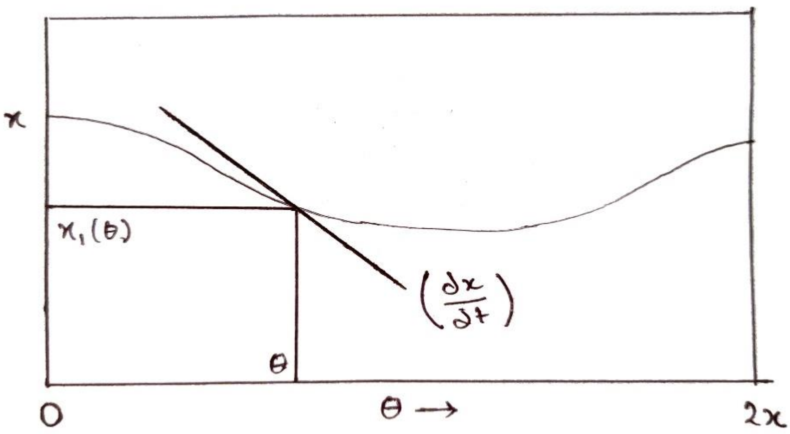

Figure 4: Distance vs Angle Diagram

The cam is just rotating with an angle of velocity omega (ω) the angular velocity is imposed on the cam by whatever prime mover that we can using now based on the profile of the cam, If we open the profile of the full cam from 0 to 2π, then we will obsessed that the profile of the cam looks like this we can plot it how the distance X1 is going to change for the follower based on the profile of the cam. The rate change of this deformation to the angle of the cam we will get the profile and the slope the partial difference of X with respect to Ө that is the angle turn that is actually the slope of this curve. Now we can see that X this distance which moved by the follower, is the function of the angle which is turned by the cam. So we can write its rate of change of this X and X1 that is the velocity actually equal to the Ө because of the Ө is the implisity of the time so X1 is depend upon Ө so the partial derivative of X with respect to Ө multiplied by total derivative of Ө with respect to time. this is actually equal to the angular velocity of the cam so,

$$v_1(t) = \left(\frac{\partial x}{\delta \theta}\right) \times \omega_{cam}$$
………..(Velocity equation with the respect of cam).

After obtaining this equation, we can generate a bond graph simulation based on the curve and equation provided. Therefore, the bond graph model is:

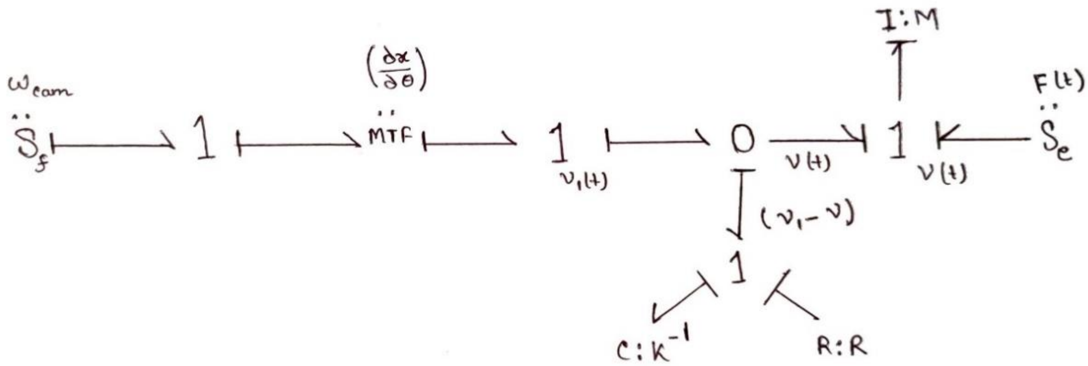

Figure 1: LFT Model of The cam follower System

When dealing with an angled slope, we cannot use a conventional T(F) but instead, we need a modulated transformer that can change based on another variable. Thus, we can establish a relationship between the angular velocity of the cam and the linear velocity of the follower.

$$v_1(t) = \left(\frac{\partial x}{\delta \theta}\right) \times \omega_{cam}$$

The linear velocity (v(t)) is equal to the transformer modulus operating on the angular velocity of the cam. Once we have determined the linear velocity of the follower - which we have already discussed - we can calculate the relative motion between the cam and the follower. The relative velocity (v1-v) is calculated using a 0 junction as we need to subtract the two velocities. We use a flow summing junction for the algebraic summation of these velocities.

5. Conclusion

In conclusion, the utilization of bond graph methodology for detecting single faults in cam-follower systems presents a comprehensive and structured approach to fault detection and maintenance. By creating a detailed model of the system's dynamic behavior and thoroughly analyzing the resulting system equation, potential single faults such as broken springs or worn-out surfaces can be accurately pinpointed. This enables proactive and precise fault detection and maintenance strategies to be implemented. This study underscores the significance of bond graph methodology as a non-invasive and highly effective approach for fault detection, creating opportunities for further exploration in real-time fault detection and monitoring systems. Overall, the systematic approach outlined in this study serves as a valuable and robust tool for diagnosing and maintaining cam-follower systems, thereby significantly enhancing operational efficiency and system reliability.

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