DESIGN OF AN INTEGRATED CAM MECHANISMS WITH REAL-TIME DISPLAY SYSTEM

THIẾT KẾ CƠ CẤU CAM TÍCH HỢP VỚI HỆ THỐNG HIỂN THỊ THỜI GIAN THỰC

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ABSTRACT

This research proposes an integrated cam system with real-time electronic display. Electronic devices are used as tools for control and data collection, after which this information is presented on an electronic screen through a central controller. The data is used to create real-time displacement graphs of the cam mechanism. This electronic display system visually represents both the nature and the current status of the cam mechanism, providing support for engineers and researchers in analyzing and optimizing control mechanisms that utilize this structure. Experimental fabrication demonstrates that this is a reliable solution for capturing and monitoring the cam mechanism, leading to efficiency and increased accuracy in the design, machining, and operation of mechanical systems.

Keywords: *Cam mechanism; Display; Control; Sensor; Real-time.*

TÓM TẮT

Nghiên cứu này đề xuất một hệ thống cam tích hợp với màn hình điện tử thời gian thực. Các thiết bị điện tử được sử dụng làm công cụ điều khiển và thu thập dữ liệu, sau đó thông tin này được hiển thị trên màn hình điện tử thông qua bộ điều khiển trung tâm. Dữ liệu được sử dụng để tạo biểu đồ chuyển vị thời gian thực của cơ cấu cam. Hệ thống hiển thị điện tử này thể hiện trực quan cả bản chất và trạng thái hiện tại của cơ cấu cam, hỗ trợ các kỹ sư và nhà nghiên cứu trong việc phân tích và tối ưu hóa các cơ cấu điều khiển sử dụng cấu trúc này. Chế tạo thử nghiệm chứng minh rằng, đây là giải pháp đáng tin cậy trong việc nắm bắt và giám sát cơ cấu cam, dẫn đến hiệu quả và tăng độ chính xác trong thiết kế, gia công và vận hành các hệ thống cơ khí.

Từ khóa: *Cơ cấu cam; Hiển thị; Điều khiển; Cảm biến; Thời gian thực.*

1. INTRODUCTION

In the realm of mechanical engineering, the study of cam (Camshaft) mechanisms holds significant importance. The use of cams and camshafts can be traced back to ancient civilizations, where they were employed in a variety of devices, including water clocks, automata, and looms. In modern mechanical engineering, cam mechanisms are integral components in numerous applications. These mechanisms serve as fundamental components in a wide range of applications, from automotive engines to industrial machinery, where precise ☞

control of motion is paramount [1]. For example, in automotive engines, cam mechanisms play a critical role in controlling the opening and closing of valves in internal combustion engines, dictating the engine's performance and efficiency [2, 3]. In manufacturing machinery, cam-driven machines are used in manufacturing processes such as metal stamping, textile weaving, and paper processing, enabling precise and repeatable motion, thus enhancing product quality and production efficiency [4, 5]. In robotics, cam mechanisms control the movement of robotic arms, grippers, and other components, facilitating precise and programmable motion [6]. In aerospace, cam mechanisms are employed in aircraft landing gear systems and wing flaps, contributing to safe and controlled flight operations [7]. Understanding the behavior and performance of cam mechanisms is essential for optimizing applications, improving reliability, minimizing wear and tear, and enhancing efficiency, especially in precision engineering and control engineering and automation applications. Research and development in this field continue to drive innovation, enabling technological advancements across various industries.

Recently, the development of innovative tools and systems for real-time data visualization and analysis has become a key area of interest among researchers and engineers. Cam mechanisms can be tricky because they make complex and not-so-straightforward movements. It's a challenge because these movements happen quickly and in different directions. In the past, scientists mainly used computer models and math to predict how cam mechanisms would behave [8]. However, these methodologies possess inherent constraints, often failing to provide a comprehensive view of real-world occurrences when factors such as friction, wear, and various other forces come into play [9]. Additionally, turning all this complicated data into clear pictures that make sense to engineers and researchers is no easy task. Consequently, the big challenge here is finding a way to show these complicated cam movements in real-time and make it easy to understand for people who work with machines and mechanical systems [10].

To overcome this challenge, real-time data acquisition for cam mechanisms have been developed [11]. Through high-precision sensors and advanced data capture technology, real-time displacement data can be obtained with exceptional accuracy, providing engineers and researchers with dynamic insights into cam behavior. The combination of real-time data acquisition and GUIs empowers users to comprehend and analyze the complex motion patterns of cam mechanisms, facilitating quicker optimization, enhanced reliability, and informed decision-making in mechanical engineering applications. Following this practical approach, this study presents an application: the design of an integrated cam system with a real-time display tailored explicitly for visualizing displacement graphs within cam mechanisms. This system included optical sensors and Arduino-based control, to capture real-time displacement data and present it graphically on an OLED LCD display.

2. SYSTEM DESIGN

2.1. Mechanical system design

In designing the cam mechanism system, various models were considered, ranging from those used in internal combustion engines to specialized educational models. This study aims to showcase the efficiency of an electronic display system using a versatile mechanical model with a cylindrical cam and roller follower. The choice of this model is based on its practicality for student use, accommodating various cam movements and presenting results in different formats. While some universities have replicated actual cam structures, these lacked real-time information. The preferred solution involves integrating an electronic display system to complement existing models, allowing for better comparisons and conclusive observations. Detailed mechanical design instructions is show in Figure 1.

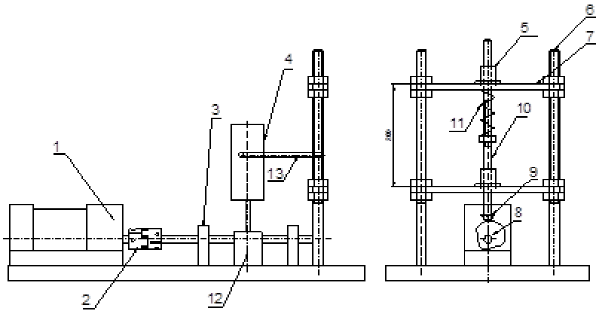

Figure 1. Mechanical design of cam system
1 - Engine; 2 - Coupling; 3 - Pillow Block; 4 - Paper Winding Drum; 5 - Sliding Pillow Block; 6 - M20 Threaded Shaft; 7 - Sliding Pillow Block Frame; 8 - Cam; 9 - Roller; 10 - Slide Shaft; 11 - Spring; 12 - Lead Screw Transmission; 13 – Pointer

For the structure of the model, the gear reduction motor (1) is connected to the cam drive system through coupling (2). The transmission shaft is mounted on pillow block (3), driving the shaft of the lead screw transmission - worm gear (12). The transmission shaft also engages with the paper winding drum (4) and simultaneously drives the rotation of cam (8), pushing roller (9) to move, exerting force on slide shaft (10).The slide shaft (10) moves due to being mounted on sliding pillow block (5) and spring (11). In terms of the operating principle, motion is transferred from motor (1) to the lead screw transmission (12) through coupling (2). This motion is then transmitted to the drive cam (8), causing roller (9) to move the slide shaft (10) linearly up and down between the two pillow blocks (5). A pointer (13) is attached to the slide shaft (10) and moves along the scale on the paper winding drum (4) to mechanically represent the displacement of the cam profile. The paper winding drum is designed for comparison and cross-checking with the electrical display, which will be designed atop the model later.

2.2. Cam profile

Assume a predefined cam profile with displacement dependent on the rotation angle, as shown in Table 1.

Table 1. Predefined CAM profile

φ^o	0^o	30^o	60^o	90^o	120^o	150^o	180^o	210^o	240^o	270^o	300^o	330^o
S(mm)	0	6	10	14	14	14	14	14	14	14	10	6
	Near	Go Far		Far							Come Near	

To design the cam profile, Autodesk Inventor software is used. In the Assembly environment, select the Disc Cam function in the Design tab and input the required setup parameters. In the Motion Function section, choose the parabolic profile and enter the displacement values corresponding to the four phases: Near, Go Far, Far, Come Near. Switch to the Calculation tab and input the required calculation parameters. Other parameters should be left as default settings. The parameters, the calculation results in the ☞

software and the profile of cam are presented in the Table 2 and Figure 2.

Table 2. Parameters of cam profile

Basic radius	12 mm
Cam width	20 mm
Roller radius	20 mm
Roller width	8 mm
Eccentricity	0
Speed	10 rpm
Force on Roller	60 N
A. Weight	1 kg

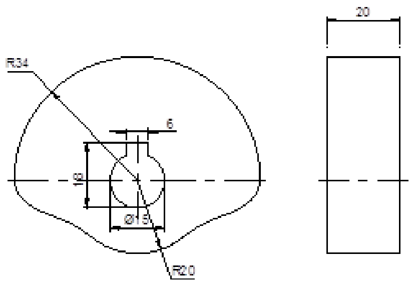

Figure 2. The profile of cam

2.3. Electronic system design

Angular velocity and revolution count are crucial in cam mechanisms, guiding understanding and control. Real-time display allows immediate adjustments for stable operation and swift issue detection, enhancing overall performance. To showcase these parameters, the cam system employs a motor (2) with a speed control unit (1) for power transmission. An encoder (4) measures rotational speed, sending signals to the controller board (1), which calculates and displays the information on the LCD screen (10).

Another important insight is visualizing the displacement diagram of the cam mechanism. Visualizing the displacement diagram is vital for real-time insight into motion, aiding troubleshooting and optimization. To represent the displacement diagram of the cam mechanism in real-time, an optical sensor (7) is utilized to measure the displacement of the slide shaft and roller (6) due to cam (5) and movement. The signal is then transmitted to the controller board (8) and displayed in real-time on the OLED screen (9) in the form of a graph.

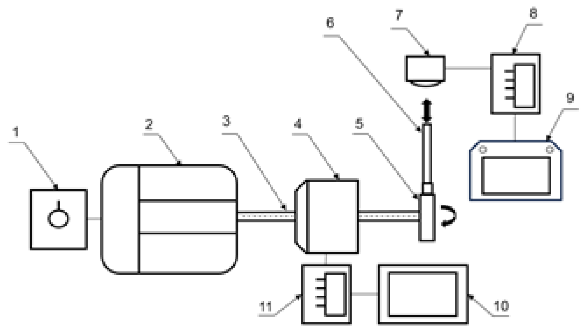

Figure 3. Block diagram of display system
1 – Speed control unit; 2 – Motor; 3 – Motor shaft; 4 – Encoder; 5 – Cam; 6 – Roller and Slide shaft; 7 – Optimal Sensor; 8,11 – Controller board; 9 – OLED screen; 10 – LCD screen

2.4. Determining the mechanical and electronic components

With a required mass of 1 kg for the follower, combined a value of approximately 60 N on roller with the frictional force at the roller bearings, a motor with a gearbox and a following parameters is chosen: P_{dc}=90W, n_{nc}=150rpm. For mechanical display, it requires drawing multiple graphs on one scroll of paper. The number of graphs that can be drawn depends on the transmission ratio of the worm gear set. To get a compact gear set with no tooth truncation, the worm gear set with a transmission ratio of u = 26 is selected.

For electronic components, the Arduino board is chosen for its user-friendly nature and cost-effectiveness in electronic components. Utilizing the HD44780 driver and a 16x2 LCD screen module simplifies I2C communication, reducing wiring complexity. Signal inputs from the encoder allow the Arduino board to calculate parameters like angular speed, angular acceleration, and main axis revolutions, displayed on the LCD screen. In order to effectively display the displacement graph, the ILI9486 model of a 3.5-inch OLED TFT board is preferred over an LCD. The GY-530 VL53L0X ToF optical sensor captures operational data, promptly processed by the Arduino board for real-time display on the OLED screen. Powered by a 12V electrical source through an AC-DC power adapter, additional electronic components can be added if needed. This combination offers a responsive GUI, presenting definitive observations and facilitating intuitive visual analysis and refinement of cam mechanisms.

2.5. Menufacturing and assembling

Overall, the mechanical system comprises an engine linked to a worm gear reducer via a coupling. The worm gear reducer's output shaft will feature a paper scroll for drawing, while the gearbox's input shaft will connect to the camshaft, equipped with a timing belt drive for the encoder. This system should be mounted on two vertical slide bearings on the machine frame, with a compression spring and ball bearing on the push rod. The mechanical display, including paper wind drums and a pointer, is designed to remain centrally positioned for easy operation and maintenance. The optical sensor and OLED screen are directly attached to the holding jig, while an LCD screen is housed in a plastic outer box for front-view display and improved aesthetics. All housing parts and jigs are manufactured using either mica material or plastics with 3D printing technologies (Figure 4).

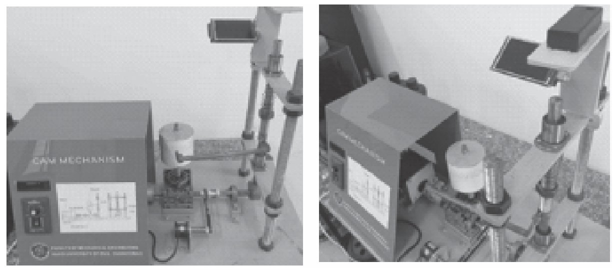

Figure 4. Cam system after manufacturing and assembly

3. RESULT AND DISCUSSION

When conducting the experimental run with predefine parameter RPM = 10 (table 1), the cam display systems produces the result as shown in Figure 5.

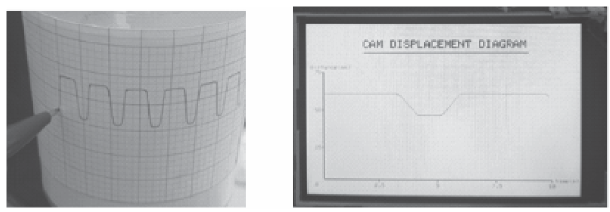

Figure 5. Results on Paper winding drum (left) and OLED screen (right), RPM = 10

Based on the graphical representation, the cam mechanism demonstrates a profile that perfectly aligns with the displacement parameters as designed on software for the cam (Table 1), consisting of four phases as defined: Extending Phase; Standoff Phase; Approaching Phase; Close-in Phase. Moreover, the OLED display shows that the cycle time is 6 seconds, which aligns with the setting of 10 RPM, and the lifting distance around 14mm matches the designed cam profiles. Both the OLED display and the mechanical display (paper winding drum) share the same geometrical profiles; the only difference is the time interval chosen for display on the OLED. ☞

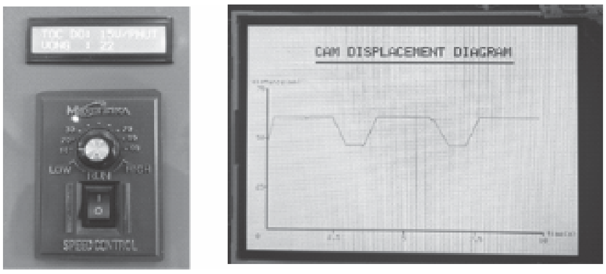

Figure 6. LCD screen and OLED screen when setting the RPM to 15

When selecting a different time interval, such as setting the RPM to 15, it implies that each cycle lasts 4 seconds, as accurately displayed on the OLED screen (Figure 6). Notably, when comparing the information on the LCD screen to that on the OLED screen, details about the time per cycle (4 seconds) and the maximum lift distance (14mm) are aligned and easy to visualize. While gradually adjusting the RPM, the graph's shape remains consistent, only the cycle of the pushing displacement changes. Therefore, the fundamental parameters of the cam mechanism, including displacement, velocity, and acceleration, still adhere to a predetermined pattern. The experimental results are shown in Table 3, revealing that the manufacturing error is less than 1%. For instance, the lift distance is 14.1 mm, compared to the designed profile of 14 mm, and the displacement velocity is 2.31 mm/s and 3.48 mm/s, compared to the designed profile of 2.33 mm/s and 3.5 mm/s, indicating a successful manufacturing system.

Table 3. Experimental results of cam parameters:

	Angular velocity (RPM)	**Lifting distance (mm)**	**Displacement velocity (mm/s)**	**Displacement acceleration (mm/s^2)**
Defined profile	10	14	2,33	0
Results	10	14,1	2,31	0
Defined profile	15	14	3,5	0
Results	15	14.1	3,48	0

When the graph, it shows both repeated and unrepeated disturbances. Unrepeated disturbances may result from noise during digital signal processing, challenging to eliminate entirely in real-time. Addressing this involves integrating noise filtering algorithms or using better equipment. Repeated disturbances suggest deflection in the cam's geometry, influenced by manufacturing variations, friction, wear, and gradual environmental factors. The graph clearly depicts these deflections, aiding in easy identification and adjustment. This visualization enhances understanding of cam mechanisms, improving reliability, efficiency, and providing guidance on system maintenance.

4. CONCLUSION

The implementation of the electronic display system for the cam mechanism is a notable success, showcasing seamless integration. This ensures prompt transmission of accurate data to the controller board, enabling an elegant and minimal-delay display on both the paper drum and OLED screen. The visually appealing and user-friendly interface enhances understanding and serves as a valuable GUI system. However, it's essential to note that, there may be occasional issues arising from noise generated by the optical sensor. To address this challenge, various potential solutions are under consideration. These include the possibility of upgrading to a more advanced optical sensor or exploring a redesigned mechanical structure that minimizes the likelihood of noise interference, thus further enhancing the system's overall performance. Aside from that, this display system offers potential benefits in enhancing complex cam systems by providing real-time insights for industrial applications, optimizing performance, and ensuring reliability. Its user-friendly interface serves as an invaluable educational tool, simplifying the learning process.

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