CAM DYNAMICS AND VIBRATION CONTROL BY DETECTING JUMP

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ABSTRACT

Typical industrial cam-follower systems include a force closed cam joint and a follower train containing both substantial mass and stiffness. Providing the cam and follower remain in contact, this is a one degree-of freedom (DOF) system. It becomes a two-DOF system once the cam and follower separate or jump, creating two new natural frequencies. A study was conducted to determine whether imperfections in the cam surface, while the contact force is on the brink of incipient separation, may cause a spontaneous switch to the two-DOF mode and begin vibrations at resonance. A force-closed translating cam-follower train was designed for the investigation. The system is designed to be on the cusp of incipient separation when run. One of the many potential problems with unwanted vibrations in high-speed machinery is the possible introduction of follower jump in a cam-follower mechanism. Jump is a situation where the cam and follower physically separate. When they come back together the impact introduces large forces and thus large stresses, which can cause both vibrations and early failure of the mechanism. This paper will suggest different methods to detect the jump practically with the accuracy. The illustrative experimentation with results will be discussed in this paper.

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1. INTRODUCTION:

Many of the journal articles that have been researched focus on a jump phenomena, vibration control, and natural frequencies of cam-follower systems. In a cam follower system, the follower is kept pressed against the cam surface by means of a retaining spring. Due to inertia of the follower, beyond a particular speed, during a part of cam rotation, the follower may loose contact with the cam. This phenomenon is known as cam jump or bounce, which is a type of vibration. This is a transient condition that occurs only with high speed, highly flexible cam follower system. With jump, the cam and the follower separate owing to excessively unbalanced forces exceeding the spring force during the period of negative acceleration. This is undesirable since the fundamental function of the cam follower system, is to constrain and control the follower motion. Also, the life of cam flank surface reduces due to hammering action of follower on cam, hammering noise is also generated. which further results in vibrations of the system. [3, 4, 5]

2. SOLUTIONS FOR ENSURING CONTACT:

When the cam contact force goes to zero, the cam and follower will separate. Separation occurs at very large negative accelerations of the follower. If there is not a large enough spring force, which is contributed by both the spring constant and the preload, the follower will have the ability to jump from the cam. A large enough spring force and preload must be applied to the cam follower joint at all times to keep them in contact throughout the entire rotation. This large spring force also has the ability to cause problems in a cam follower system. If the spring force is too large, this will increase the contact force, which will induce higher stresses possibly leading to early surface failure of the parts. The motor driving the system will also have to work harder to push the followers through their motions.

The determination of jump characteristics requires that the conventional cam follower system be idealized as a single-degree-of-freedom model, or, for more accurate results, a multi-degree-of-freedom model. In order to detect jump, the acceleration and thus the inertia force of the follower on the closure spring must be calculated. Jump will occur when this inertia force is larger than the spring force. When these two forces are equal then the system is basically on the cusp, balanced and ready for jump to initiate. The contact between the cam and follower can be ensured in two ways: by shape or by force. In the first case, some solutions can be used: cam with channel (groove), cam and counter-cam or cam with slot/notch. These cams ensure the permanent contact between the cam and the cam follower with the help of the cam profiles, but they also lead to design complication and implicitly to manufacturing costs increase, because of the high execution precision implied. In the second case, in order to ensure the contact between the cam and the cam follower, forces or exterior moments can be used, generated with help of spiral or helical springs by gravitation or through additional masses acting over the cam follower, through hydro-pneumatic forces or through centrifugal forces at mechanisms running at high angular velocity. [6, 7, 8]

3. NATURAL FREQUENCIES AND RESONANCE:

The natural frequency of the follower system is very important to the dynamic behavior of the system. If the operating speed of the machinery in question is close to or is at the natural frequency of the system then that system will go into resonance. Resonance is a form of free vibration in which the system will vibrate violently, and is extremely harmful to a high-speed machine. Cam mechanisms are driven by the displacement curve or profile of the existing cam; thus the follower motion can be described by a dynamic model or spring mass system under translation-based excitation. Translation based excitation means that the forcing function for the differential equations is the cam displacement function not force acting on the follower. The main rules for the design of high-speed machinery are to use lightweight, strong materials of high modulus of elasticity, to increase the second moment of area and to reduce the length of the links. In effect, their recommendation can be interpreted as wanting to increase the natural frequencies of the mechanism. [5, 7]

4. SOURCES OF VIBRATIONS:

(a) Vibration due to the shape of the follower acceleration curve. An infinite slope or pulse ($da/dt = \infty$) will be seen to be undesirable. With the compression spring loaded follower, this is called “jump”.

(b) Vibrations that are a result of separation of the cam and the follower. In positive drive cams with backslash, impact of the roller on the cam is produced, and is called cross over shock. With the spring loaded follower it is due to the “jump” condition.

(c) Vibrations due to surface irregularities, of which they are of many kinds.

(d) Vibrations due to the rate of application of the external load.

(e) Miscellaneous sources as due to cam unbalance. Intelligent practical design of the cam structure and the body to reduce the offset mass will keep these vibrations to a minimum. Vibrations may be transmitted to the cam surface from the driving mechanism through the frame from such sources as electrical motors, gears and chains.

To reduce the vibrations in the cam follower system, it is suggested that the member from the driver to the follower end be made as rigid as possible.

The conclusion that we can offer for any cam curve at moderate to high speed operation are:

(i) The acceleration maximum value should be kept as small as possible.

(ii) A finite pulse should be maintained at all time, never exceeding the maximum of the cycloidal curve.

(iii) The cycloidal curve is reasonable choice in most cases, giving lower peak forces, vibratory amplitudes, noise and stresses and in general, smoother performance.

The accuracy with which the cam is cut will influence the vibration effects. Play or backlash should be kept to a minimum. Vibration, together with noise and wear, will occur in the dynamical system if it is operated at the speed of its natural frequency. The forces and stresses from vibration are usually superposed on those resulting from normal operation. The operation is affected by the flexibility or elastic deformation of the parts of the system. The parts of the system act as springs of various stiffnesses. The moving parts should be both as rigid and as light as possible. Faulty operation can occur from the difference between the movement at the end of the mechanical chain and the initial movement imposed by the cam. The polydyne cam permits the design of the cam shape to be such that the desired motion will occur at the end of the follower chain. An increase in the pressure angle usually means an increase in the forces, which must be provided for. The guide for a translating follower may reduce the pressure angle during that portion of the cycle where the forces are the greatest. The mathematical calculations, however, are more involved. A pivoted oscillating follower will reduce the side thrust and permit a smaller cam to be used. The spring of a compression system must be strong enough to keep the follower in contact with the cam at all times. This is important in flexible high-speed systems. The follower must not be allowed to jump or leave the cam surface. Sometimes a ramp or small precam is located at the start of the main part of the cam to remove the play and elastic deformation from the system so that the end of the chain will start to move as soon as the main part of the cam begins to act. For light loads and slow speeds, a cam can be composed of sections of circular arcs. Such cams are relatively easy to manufacture and check dimensionally. The acceleration curve, however, has abrupt changes in value. The research that has been presented in this literature review exactly addresses the topic of incipient jump. There has been a significant amount of research conducted on vibration control and dynamic modeling of cam-follower systems. All this information is critical to better understand the problem and to get some idea of how the problem at hand could be addressed. [9, 15]

5. EXPERIMENTAL SETUP SPECIFICATIONS:

In this experiment the setup consists of an eccentric cam and a roller follower with a follower spring whose preload can be adjusted. If during the motion at any time the contact force becomes zero then the follower will loose contact with the cam and move independently till the contact is established. This phenomenon is called Jump-off speed. Jump-off speed depends on cam profile, type of follower, spring stiffness and preload, follower mass etc.

The three methods to be introduced for jump detection accurately are

i) Infrared transmitter and receiver circuit

ii) Vibration measurement at bearing housing by FFT Analyzer

iii) Sound level measurement

5.1 SPECIFICATIONS FOR INFRARED TRANSMITTER AND RECEIVER:

Transmitter Section:

Here the IC 555 is the timer IC wired in astable mode. Thus it gives continuous square wave at its pin no.3 whose frequency can be varied by varying the value of resistance. The output is given to the infra-red led which generates IR-light to be transmitted.

Receiver Section:

In this section the 9v supply is converted in to 5v using regulated power supply IC 7805 to drive the IR Receiver module (TSOP-1738) .The IR Rays transmitted is received by the receiver module. This signal is amplified by the power amplifier stage comprising transistors. A reference voltage of 5.1v developed across zener diode, connected to the inverting input. When the voltage level increases beyond the reference voltage, output goes high and this is indicated by glowing the Red LED, as shown in Fig.1.

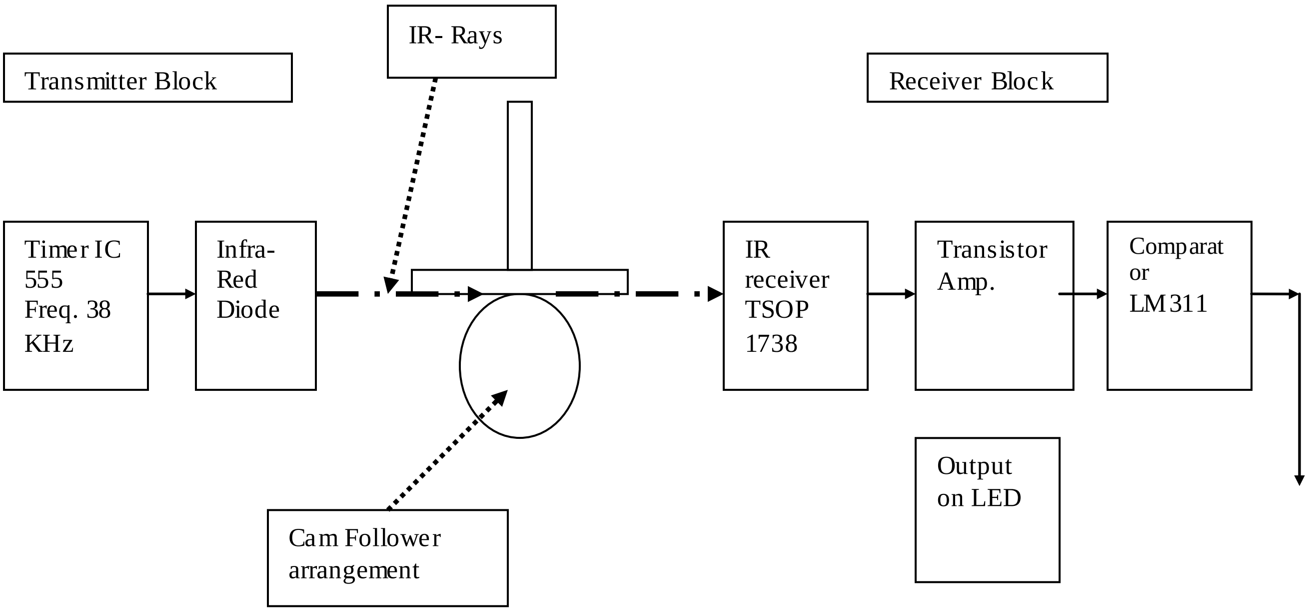

Fig.1: Block diagram of infrared module

5.2 SPECIFICATIONS FOR FFT ANALYZER:

Temperature: 5^oC - 50^oC

Humidity < 85%

Without strong electric-magnetic field & strong impact

Table 1: Maximum measurement range / frequency range

Parameter	Maximum Measurement Range	Maximum Resolution	Frequency Range
Displacement Peak-Peak value	2 mm	1 micrometer	10 - 500Hz
Velocity RMS value	200mm/s	0.1 mm/s	10 – 1kHz
Acceleration Peak value	$250m/s^2$	$0.1\ m/s^2$	20 – 10kHz
High Frequency Acceleration Envelope RMS value	20unit	0.1unit	5-1kHz, Demodulated from15-40kHz acceleration

Accuracy:

Frequency response accuracy: ±5%, ±10% for ACC 4.5 kHz - 10 kHz

Non-linearity: ±5%

Type of sensors: Piezoelectric accelerometer.

5.3 SPECIFICATIONS FOR SOUND LEVEL METER:

Frequency Weighting Network- A & C weighting.

Microphone: Electric Condenser Microphone.

Size of Microphone: 1/2 inch standard size.

Operating temperature: 0^oC to 50^oC.

6. RESULTS:

PROCEDURE: Start rotating the cam and gradually increase the speed till the jump gets detected by any of the methods which could be introduced first of all. Results to be produced are nothing but introducing following methods with remarks and comparisons of these with accuracy.

The preload will be adjusted to maximum and minimum values and the readings can be taken at these conditions.

But for the three methods to be introduced the preload value should not be changed so that the different methods would be accurately assessed and compared.

The Infrared Transmitter and Receiver Circuit will made on and we will measure the sound by sound level meter and vibrations (velocity) by FFT analyzer ,then we get the following sets of readings when jump occurs.

Table 2: **Results with three different methods for jump detection:**

Sr.No.	Method of Jump Detection	Readings				Remarks
1	**Jump Detection by Infrared Transmitter and Receiver Circuit**	Preload Levels	RPM at which Jump Occurs		Observations	
		1	640	before the jump occurs	LED off	Preload levels 1 Maximum 2 Minimum
		1	658	after the jump occurs	LED on	
		2	545	before the jump occurs	LED off	
		2	552	after the	LED on	

				jump occurs			
2	**Jump Detection by Vibration Measurement (Velocity) at Bearing Housing by FFT Analyzer**				Position	Velocity (mm/s)	ISO 2372 Class –I(Less than 15kW) machine A= 0 to0.71 mm/s B =0.71 to 1.8 mm/s C=1.8 to 4.5 mm/s Preload levels 1 Maximum 2 Minimum
		1	642	Before the jump occurs	X-axis Y-axis Z-axis	0 .56/0.71 0.71/0.84/1.8 0.71/0.93/1.8	
		1	660	After the jump occurs	X-axis Y-axis Z-axis	1.8/2.66/4.5 1.8/3.67/4.5 1.8/2.45/4.5	
		2	542	Before the jump occurs	X-axis Y-axis Z-axis	0.68/0.71 0.71/1.2/1.8 0.71/1.3/1.8	
		2	553	After the jump occurs	X-axis Y-axis Z-axis	Greater than 4.5 mm/s (Not acceptable)	
3	**Jump Detection by Sound Level Measurement**	1	650	When the jump occurs	85 dB		noise for max hold C –weighting
		2	550	When the jump occurs	90 dB		Preload levels 1 Maximum 2 Minimum

7. CONCLUSION WITH DISCUSSION:

Jump will occur when the system is basically on the cusp, balanced and ready for jump to initiate.

Methodologically the Infrared transmitter and receiver circuit provides the visual output but practically it may not be possible always because of space constraints and the kinds of assemblies we would be having.

Vibration measurement at the bearing housings will be more prominent and the results to be seen with permissible range of vibrations and ultimately the jump detection. Finally, to measure the sound level due to jump is also an effective way of detection; only it should be measured at the cusp of separation with the maximum hold position.

The methods are showing significantly the similar range of readings for the speeds at which jump occurs.

We, also should remember the range of vibration levels at the point of jump occurrence and therefore one can not predict the speeds of jump unless and until the levels are set .From vibration readings it is already seen that beyond 4.5 mm/s we should consider there are serious concerns about the vibrations and ultimately total system is in the mode of vibration which indicates the jump occurrence in a system. Our concerns therefore should not be towards speed enhancement which could be possible by selecting proper stiffness and rigidity to the system, but in any circumstances to measure the speed at which jump could get occurred. We hope this paper put enough highlight on the methods of follower jump detections which could be incorporated with respect to any kind of system configurations.

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