AC 2012-3597: FRAME-BY-FRAME ANALYSIS AND DIAGNOSIS OF A HIGH-SPEED PACKAGING SYSTEM USING FASTEC INLINE NETWORK-READY CAMERA VISION EQUIPMENT

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Frame by Frame Analysis and Diagnosis of a High Speed Packaging System Using Fastec InLine Network-Ready Camera Vision Equipment

Abstract

High speed camera vision system is a vital tool in the modern industry. The industry now-a-days are known for their high speed manufacturing processes. A delayed downtime may cost a company millions. Similarly an inaccurate operation of certain machinery parts of a packaging machine may cost highly. Therefore, the quickest possible method to resolve a fault or even tuning is most advisable. This is where a high speed camera system comes into use.

High speed imaging is a technique used for specific motion analysis and troubleshooting purposes. This may include applications in fast operating industry machinery, crash impact testing for automobiles and so on. It is when photography is conducted in a very high rate ranging from 250 frames per second and higher. This may range up to as high as several thousand frames per second depending on the application and budget. For example, if a motion sequence at 600 frames per second is captured and played back at 30 frames per second, a smooth continuous motion or a frame by frame playback of that event can be viewed. It can be studied for improvement, tuning or solving a malfunction which cannot be done with the naked human eye or standard video framing (approximately 25-30 fps). Availability of such a tool can greatly reduce machinery downtime in a fast moving packaging system.

This paper will talk about troubleshooting a problem of a certain cam profile between two screw conveyors in series. The two screw conveyors are required to function in a certain cam profile which will transfer a fixed number of bottles to the next machine in a process. This transfer process often works properly at low speed (e.g. ten containers per minute) but at high speed (e.g. 300 containers per minute) its functionality deviates from the desired pattern. In such a case, to observe and analyze the problem, a high speed imaging tool reduces troubleshooting time significantly. Such problems between two servomotors can be found in machines such as orienters, transfer screw conveyors, stackers, palletizers, high speed cutter and so on.

Introduction

High speed imaging is a technique used for specific motion analysis applications. This may include applications in fast operating industry machinery, crash impact testing for automobiles and so on. It is when photography is conducted in a very high rate ranging from 250 frames per second and higher. This may range up to as high as several thousand frames per second depending on the application and budget. For example, if a motion sequence at 600 frames per second is captured and played back at 40 frames per second, a smooth continuous motion of that event can be viewed. It can be studied for improvement, tuning or solving a malfunction which cannot be done with the naked human eye or standard video framing (approximately 25-30 fps). The mechanism uses a charge-coupled device (CCD) or a CMOS active pixel sensor for recording the high speed imagery into DRAMs.

For the purpose of diagnosis, a single second event can be stretched into frame by frame playback of several minutes or so. This playback can be analyzed for a deviation from the expected behavior. Thus a solution may be suggested. Availability of such a tool can greatly reduce machinery downtime in a fast moving packaging system.

Let us consider a packaging situation with two screw conveyors. These two screw conveyors are placed one after the other in series. This setup is placed in the packaging line right after a machine which gives output of the products at random rates. But the next machine in the packaging line requires the products to be in fixed groups, for examples batches of six at a time. Thus such a screw conveyor setup is required between these two machines which will accumulate the products and transfer them in fixed batches to the later machine. The conveyor setup seems to operate fine at slow speed, which is observable by the naked eye, while testing. But when it is run at high speed, the bottles / containers are not able to pass, rather they get stuck or shatter. With the naked human eye or standard video framing, the specific cause of the problem cannot be detected as the machine operates at a very high rate. In such an instance, using a high speed camera vision system will allow capturing of 1000 frames per second of the conveyor motions. Later frame-by-frame analysis of the operation will guide us to suggest a solution to the inaccuracy. This paper will discuss the process of diagnosis using a Fastec InLine Network -Ready High Speed Camera vision equipment.

Problem Description

In our problem, one conveyor continuously runs (identified as master), driven by a 3-phase ac induction motor, with an encoder attached to the drive shaft. The other screw conveyor (identified as slave, placed before the master screw in the packaging line) is to collect perfume bottles (easily breakable glass) from a machine before it in the packaging line. The slave screw is driven by an ac servomotor. It waits and collects a set of 6 bottles. When six bottles are collected, it feeds the set of bottles to the master screw conveyor at once. The master screw continuously runs at a high speed (RPM of the motor = 240 RPM). If the pocket which is created at the junction of these two screws is not perfect during handing over, the bottles cannot pass and may be crushed or shattered. The scenario is portrayed by Fig.1 below.

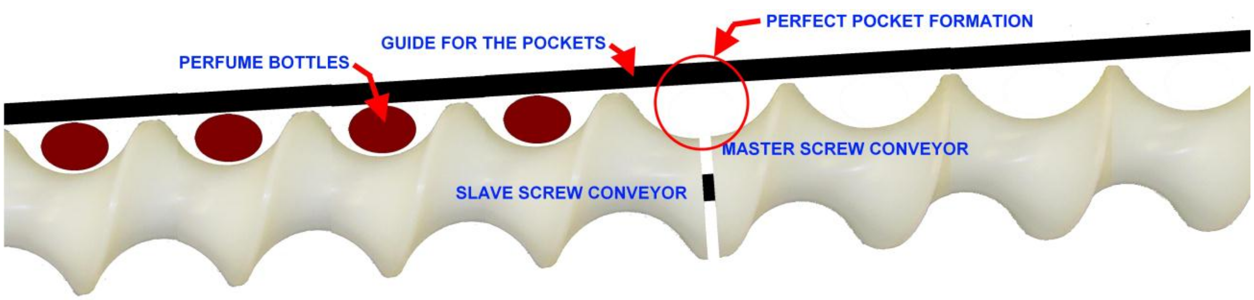


Fig.1: A perfect pocket formation at the junction of the two screw conveyors

The screw conveyor on the left hand side is the slave screw and the screw conveyor on the right hand side is the master screw. The slave collects the bottles before feeding it to the master screw. In the above figure, at the junction of the two screws, a perfect pocket is formed. The slave will move to a 1:1 gear lock when this pocket is formed and will maintain the pocket throughout the process as the bottles pass through. As they will be in a 1:1 gear lock, it can be said that the two screws are basically functioning as one single unit and passing through the bottles.

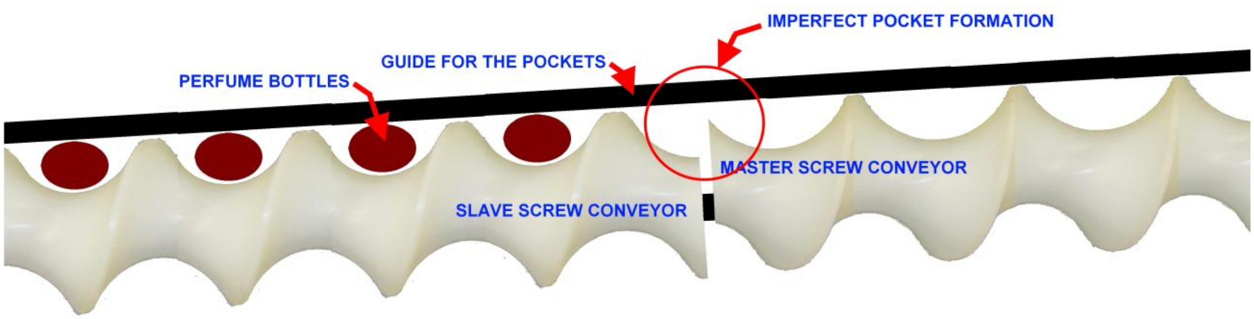


Fig.2: An imperfect pocket formation at the junction of the two screw conveyors

Fig.2 demonstrates the situation if the slave screw fails to lock on to the master screw at a point where an imperfect pocket is formed. If such a situation occurs, the deformed pocket will be maintained throughout the process. So when the bottles try to pass on, the will shatter as they are easily breakable glass. Needless to say, this is a very undesirable situation on the industry floor. If hard glass bottles were the products needed to be passed on, then this would cause jamming of the machine. So a failure locking on to a perfect pocket results in failure of the transfer process.

The whole operation is done in a three step cam profile between the motors of the two screw conveyors.

Cam profile 1 – initiation cam: The slave servomotor catches the master servomotor at the immediate next point of range as instructed by the cam table in the ladder logic codes in the PLC. The perfect pocket is created. The servomotor running the slave screw will execute the complete cam table once and will move to cam profile 2.

Cam profile 2 - run cam: This is analogous to a one-to-one gear lock between slave and master motor. The perfect pocket created in cam profile 1, is maintained. The slave starts to pass the set of six bottles to the master screw conveyor. This will continue for a few cycles until all six of them are passed on.

Cam profile 3 - stop cam: Once the bottles are passed on, the slave servomotor will move to the stop cam and stop at the immediate next point instructed by the cam table. Then the slave will wait for the next collection of six bottles and repeat these three steps all over again to transfer the bottles.

As mentioned earlier, failure of the slave screw conveyor to lock on to the master screw conveyor at the right moment will result in formation of a deformed pocket. When the screws are paused in the middle of the execution and observed, a perfect pocket formation is noted. When they are run at a slow speed, which can be observed with the naked eye, also a perfect (pocket) execution was observed. This kind of imperfection of the pocket between the screws that holds the bottles and transfers them, only occurs at high speed. If there is such an imperfection as mentioned above, at high speed, such as 240 RPM, the pocket will not be as synchronized as observed at slow speed with the naked eye. We will demonstrate with the following laboratory experiment that a high speed camera is necessary for detecting such a problem and how troubleshooting time reduces significantly by using such a tool.

Simulation of the problem and frame-by-frame analysis:

Experiment 1:

The two master-slave screw conveyors' operations mentioned above are analogous to two servomotors placed side by side with arrows on their shafts to indicate the current phase / positions of their shafts as shown in Fig.3.

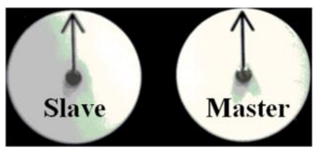


Fig.3: Two servomotors with arrows indicating the current phase of their shafts

In our laboratory simulation experiment, we configured the servomotor on the right as the master servomotor and the servomotor on the left as its slave. This is analogous to the two motors running the two screw conveyors as mentioned earlier. In our experiment, the master servomotor continuously runs at 240 RPM. Then the slave servomotor is instructed to start the three step cam process. The cam operation is run for 21 cycles. This is captured by the high speed camera with the following settings,

Camera Capture Frame Rate: 1000 fps

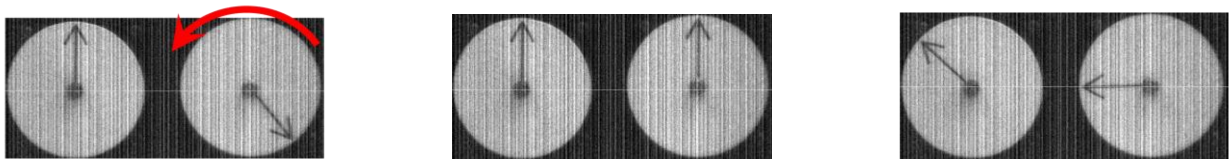
Playback rate: 20 fps

Resolution: 320x240

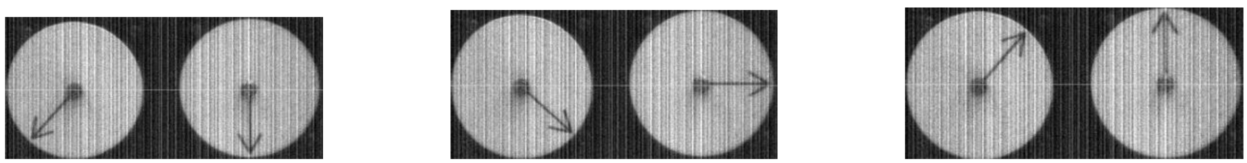
Shutter speed: 1/5000 seconds (200 microseconds)

(All the degrees are mentioned in anti-clockwise direction in the following figures)

The captured images are given below,



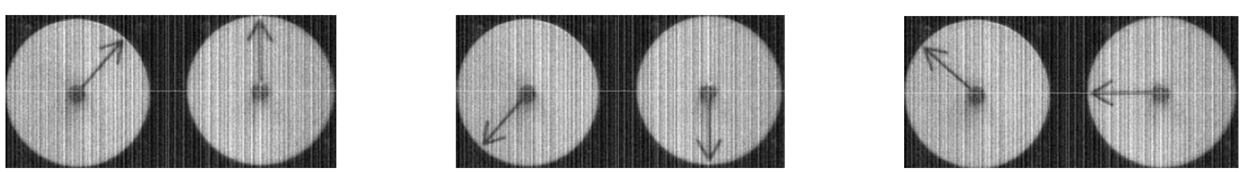
a) Before initiating cam b) cam initiated c) cycle 1: 90 deg



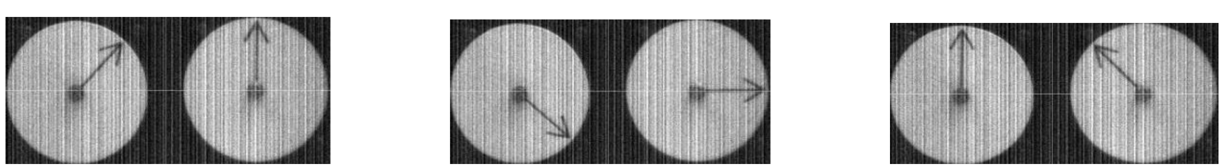
d) cycle 1: 180 deg e) cycle 1: 270 deg f) cycle 2: 0 deg

Fig.4: Initiating cam operation

In Fig.4a, the slave servomotor is idle and the master servomotor continuously runs at 240 RPM in anticlockwise direction. At this point, the cam is initiated for the slave servomotor. According to the cam table in the ladder logic codes, the slave will catch and lock on to the motion the master at the immediate next moment when the master crosses its “0” degree point (shown in Fig.4b). As we can see in Fig.4c, the slave has failed to catch the master at the exact point as instructed by the cam table. There is an undesired phase difference between the motor shafts shown in the figure measured to be approximately “43” degrees. If this would occur in the real scenario with the two screw conveyors, this would result in failure of formation of a perfect pocket at the junction of the two screws. Instead the formed pocket would be significantly deformed.



a) Cycle 3: 0 deg b) Cycle 5: 180 deg c) Cycle 10: 90 deg



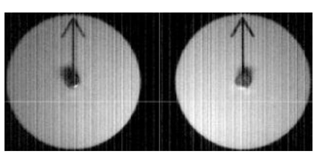
d) Cycle 15: 0 deg e) Cycle 20: 270 deg f) Cycle 21: 360 deg (cam stopped)

Fig.5: The fault is carried on throughout the process

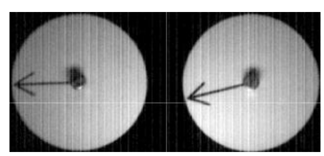
In the middle of cycle 20, the stop cam (cam profile 3) was initiated and at completion of the last cycle, cycle 21 is shown in Fig.5f. It is clear that the “43” degree lag has been constant throughout the steps of the cam operation. This implies, in the case of actual screws, the pocket is locked in a deformed condition and will cause failure of transferring the bottles to the master screw from the slave screw. To be noted that when this operation was conducted at a slow speed, no phase difference was noticed between the motor shafts. The lag became visible only when the motors were run at high speed.

Experiment 2:

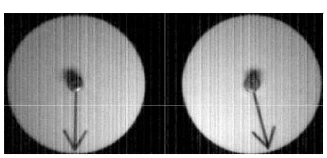
In this experiment, both the servomotor motions will be initiated from an idle condition. The servomotors have been programmed to be on a 1:1 gear lock while in operation. The servos will be accelerated to 240 RPM from the idle condition and the phases will be monitored. Ideally, there should be no phase difference or whatsoever between the shafts for a flawless execution. At slow speed the motors seemed to work as expected when observed by the naked eye, with no phase difference. In addition, when the motors are in a stopped condition, they show no phase difference between themselves. Then they are accelerated from zero speed to 240 rpm and the high speed camera is used to observe its rotations and phase difference. The same camera settings have been used for the following captures,



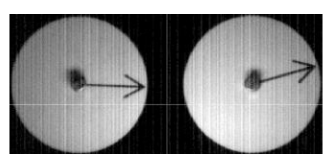
a) Cycle 1: 0 degrees (<u>LAG: 0.00 deg</u>)



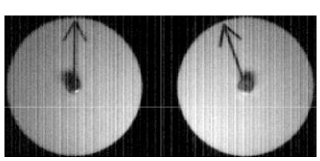
b) Cycle 1: 90 degrees (<u>LAG: 15.00 deg</u>)



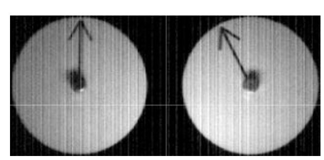
c) Cycle 1: 180 degrees (<u>LAG: 15.93 deg</u>)



d) Cycle 1: 270 degrees (<u>LAG: 18.31 deg</u>)



e) Cycle 2: 0 degrees (<u>LAG: 20.71 deg</u>)

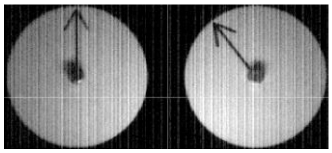


f) Cycle 3: 0 degrees (<u>LAG: 27.74 deg</u>)

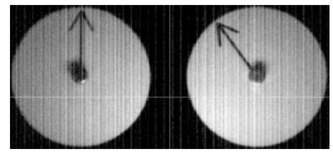
Fig. 6: Initiation of the one-to-one gear lock motion

The motors are idle in Fig.6a. The acceleration to 240 RPM is initiated here.

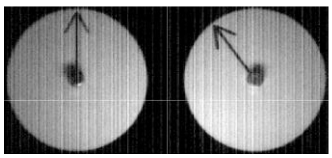
At idle condition there seems to be no phase difference between the shafts. This is cycle 1: 0 degree rotation. At cycle 1: 90 degree rotation, it is visible that a phase difference of 15 degrees has accumulated. And this lag keeps on increasing as the motors keep on accelerating (fig 6a-f).



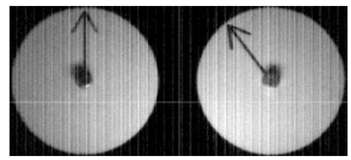
a) Cycle 5: 0 degrees (<u>LAG: 37.68 deg</u>)



b) Cycle 10: 0 degrees (<u>LAG: 37.68 deg</u>)



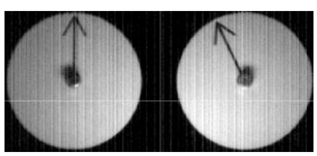
c) Cycle 15: 0 degrees (<u>LAG: 37.68 deg</u>)



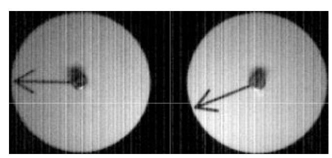
d) Cycle 20: 0 degrees (<u>LAG: 37.68 deg</u>)

Fig. 7: The phase difference is constant at constant speed

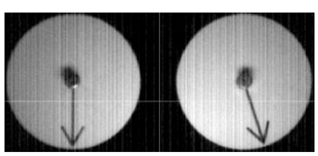
As the motors reach full speed (240 RPM) and stops accelerating and maintains a constant speed, the phase difference also remains constant at 37.68 degrees (Fig.7a-d). The phase difference remains constant as long as the speed remains constant. Then it starts to reduce as the motors are started to be decelerated (Fig.8a-e).



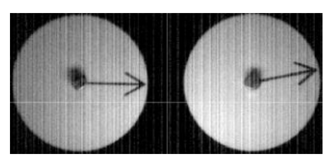
a) Cycle 21: 0 degrees (<u>LAG: 27.82 deg</u>)



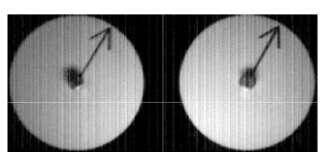
b) Cycle 21: 90 degrees (<u>LAG: 21.88 deg</u>)



c) Cycle 21: 180 degrees (<u>LAG: 18.05 deg</u>)



d) Cycle 21: 270 degrees (<u>LAG: 10.98 deg</u>)



e) Cycle 21: stopped (**<u>LAG: 0.00 deg</u>**)

Fig.8: Deceleration commenced

The deceleration is commenced in the middle of cycle 20. Fig.8a-e shows that during the last cycle, the phase difference between the shafts of the motors start to decrease and completely diminishes at stopped condition. To be noted, the phase difference is constant at constant speed of the servomotors and varies proportionally with the speed of the motors. The fault is insignificant at slow speed and only becomes prominent in high RPM.

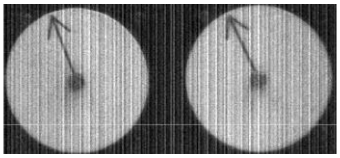
Diagnosis and solution of the problem

In a stopped condition, the pocket between the screws conveyors will always seem perfect as well as in slow speed when observed by the naked eye. But it may still malfunction at high RPMs and as a result, the bottles may be shattered. To find the root of the problem a high speed camera should be used.

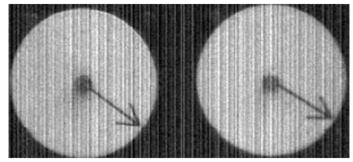
Using the camera we can narrow down the cause of the above problem. Judging the pattern of the phase difference between the motor shafts and how it acted at different speeds, we can narrow down the troubleshooting and comment that the problem must be due to tuning of the motors. The problem cannot be due to a fault in the cam tables because the phase difference is varies along with speed of the servomotors (Experiment 2).

The servomotors are controlled by proportional-integral-derivative controllers (PID Controllers). This is a generic control loop feedback mechanism (controller). It calculates an "error" value as the difference between a measured process variable and a desired target value. A PID controller attempts to minimize the error by adjusting the process control inputs. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change [1]. To be noted the use of a PID algorithm for control does not guarantee optimal control of the system or system stability. The optimum values of the P, I and D constants, specific to applications are often required to be manually adjusted. In our experiment, the slave servomotor was failing to reach the target points at the correct instances due to the inaccurate tuning in the proportional values (P constants) of the Position and Velocity Gain parameters.

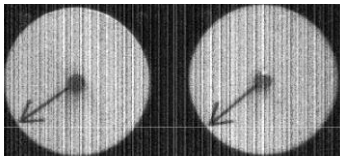
The cause was not the mechanical design of the screws, mechanical defect of the motors or the ladder logics of the PLC codes. The proportional parameters of the position and velocity gains were re-adjusted and the problem was fixed (see Fig.9-10).



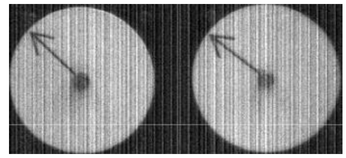
Cycle 1: Commencement (Perfect synch)



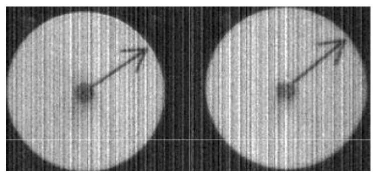
Cycle 5: 225 degrees



Cycle 10: 135 degrees



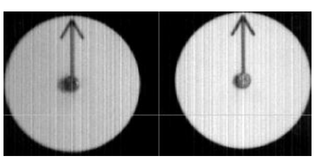
Cycle 15: 45 degrees



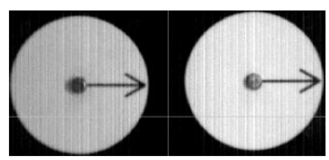
Cycle 20: 315 degrees

Fig. 9: Experiment 1 - inaccuracy corrected

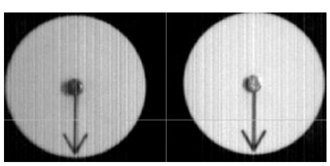
As seen in Fig.9, the slave servomotor successfully locked on to the master servomotor at the right instance and executed the three step cam profile perfectly throughout the 21 cycles of execution.



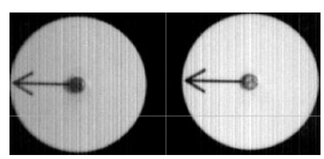
Cycle 1: Commencement (Perfect synch)



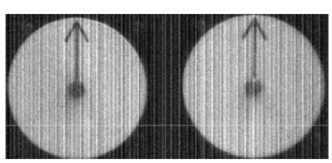
Cycle 5: 270 degrees



Cycle 10: 180 degrees



Cycle 15: 90 degrees



Cycle 20: 0 degrees

Fig. 10: Experiment 2 - inaccuracy corrected

Fig. 10 shows that there is no phase difference between the shafts of the two servomotors at any speed throughout the acceleration or deceleration process.

Outcome for Student Learning and Educational Value

One of the main intentions of this paper is to provide a guideline for using high speed cameras for troubleshooting problems which only become prominent at high speeds and they are not diagnosable by the naked eye. The methods explained in the experiments and the ideas for diagnosing the problem expected to help Mechatronics students to prepare themselves for the real world environment when they will face such extraordinary problem. The student readers of this paper are expected to be capable of solving the issue when they are also dealing with actual problems rather than only in a laboratory environment. As mentioned earlier, such methodology is applicable to a large variety of situations. Also, such method is quite helpful for a situation where the problem become more crucial to the manager or the business owner in the industry floors due to a harsh deadline.

Conclusion

A downtime of a machine is undesirable on an industry floor and is a major concern for the manager. This downtime needs to be reduced and the machine should be put into action as quickly as possible. Problems which occur only at high speed are very common in the packaging machinery industry. They may occur with orienter machines, flipper machines, rotation unions, infeed of a filler, fast robots (arms, packaging robots etc) etc. Tasks such as ensuring the proper setup of a seamer or diagnosing a faulty case packer that jams every two hours is nearly impossible at speeds such as 1500+ units per minute. High speed video enables maintenance personnel to slow down operations without slowing production. Machine tools degrade over time and their performance gets affected. Operators can perform a frame-by-frame analysis to observe how the tool is performing. For manufacturing PET bottles, cans or cartons, a small inaccuracy such as a slight delay on a glue nozzle can be the difference between a profitable day or lost money. Industries characterized by stringent requirements and high per-unit cost such as pharmaceutical manufacturing can make use of such troubleshooting tools to remove variations. High speed imaging can also be applied in reduction of noise or undesired vibrations, performing alignments between machines and so on. These kinds of issues in the packaging industry could be resolved quickly through use of a high speed imaging system.

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