INEXPENSIVE MULTIPOINT ROLLER SPEED MEASUREMENT SYSTEM

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ABSTRACT

Machines that manufacture photographic web products use rollers to convey the web. Product imperfections, like scratches and scuff marks, are caused by loss of traction between these rollers and the web. Loss of traction is due to a variety of well-known conditions and always has the characteristic that the roller surface speed is not identical to the web speed. In typical photographic manufacturing processes, imperfections like these cannot be seen until the product is completely through the machine, and then only by well-trained operators in lighted areas and/or expensive automated scanning equipment.

The existence of the imperfection means the product must be scrapped; the machine time used to make the product is "lost". Additional machine time is necessary to search for the responsible roller(s). The search compromises operator safety in that in order to take many of the measurements necessary to locate the responsible roller, using handheld contact and non-contact tachometers, and prony brakes, the operator is placed in dangerous proximity to the moving web.

To address these machine and operational problems, many have suggested installing roller speed sensors on the rollers. This would allow operations personnel to identify responsible rollers more quickly and safely. However, the high cost of installing traditional single-point roller speed measurement systems has, until now, kept us from monitoring every roller. One recent single-point roller speed installation cost nearly $25K and these rollers number in the thousands in a typical machine. The goal of this development effort was to design an inexpensive multipoint roller speed monitoring system for photographic product manufacturing machines.

The method we used is composed of (1) single magnets affixed to each roller, (2) magnetic field sensors, (3) custom printed circuit boards (PCB's) for multiplexing a multitude of sensor signals from the field to a remote location for processing, (4) high-speed counter/timer electronics, and (5) digital output electronics. The design of the field sensors and electronics satisfies low-power electrical code requirements, which reduces the cost of conduit usually required to protect field cables.

The final costs were roughly $100K for an installation of about 450 sensors ($220/point) after initial development and design. That cost did not include the control computer or programming.

NOMENCLATURE

OD	Outer diameter of roller, cm
P	Period of roller rotation, sec
P_w	Pulse width, sec
R	Roller radius, cm
t	Web thickness, cm
V_R	Velocity of roller surface, cm/sec
V_W	Velocity of web calculated from roller period, cm/sec

PROJECT REQUIREMENTS

The environmental conditions to which the sensors and field electronics were designed were for a temperature up to 180 °F, and a non-condensing humidity. There were no mechanical vibration concerns. Sensors and cables would have to be mounted out of the way so that machine cleaning, and personnel travel through the machine while it's blacked out would not be hindered.

Because there are no solvents present, the method would not have to be designed to satisfy hazardous area electrical codes. The distance from the computer to nearest sensor is about 100 ft, and to farthest sensor about 200 ft. Since web conveyance drive motors would be in proximity to the sensors, cables, and field electronics, some thought would need to be given to the strength and nature of the electrical signals, and means of protecting that signal.

DISCARDED SENSORS AND METHODS

There were several sensors and methods we considered, but did not pursue. These were:

- a tachometer on each roller shaft (expensive to purchase and install; increased drag on roller due to encoder bearing; measurement/analysis more complicated)
- multiple targets on shaft (more triggers per revolution mean more complex analysis and extra cost)
- using existing tachometer tapes on roller and an optical sensor (tape could not be manufactured and installed to within 1% accuracy)
- custom sensor, networked using one of the sensor protocols being sold in the sensors market

DESIRABLE SENSOR/TARGET CHARACTERISTICS

There are some characteristics of the sensor and target combinations that are desirable for any effective system. These are:

- a wide detection range (offset and misalignment)
- fast enough for the chosen method
- cheap (sensor features that can add significant cost are threaded metal bodies, custom brackets, liquid-tight bodies and connectors, and attached cables)
- non-contact (does not contribute drag to current rollers)

For the specific method we chose, we also needed a sensor and target combination that produced a precise pulse train. That is, where the observed roller period was minimally influenced by the sensor and target. We also needed one with low power consumption. For example, a magnetic sensor might consume about 0.05 W, whereas a photoelectric sensor might consume about 0.84 W.

METHOD INVESTIGATION

One of the first steps was to determine the influence of different sources of variation. The sources of variation that would compromise the desired results would have to be measured, known, or used in the method calibration.

We started out with the basic equations for roller surface velocity:

$$V_R = 2\pi R/P \tag{1}$$

$$V_W = 2\pi(R+t/2)/P \tag{2}$$

P is the primary variable that will be measured. However, R and t are two other variables that must be known before velocities can be calculated. Can R and t be assumed constant, or must some sort of calibration or measurement on them be performed? If the latter, how often must this be done? These are questions that need to be answered.

Influence Of Roller Radius Variation

Measurements from several "identical" rollers indicated that there was a distribution of roller OD's present in the machine. When these values are used in the equation (1), the variation in indicated web speed was significantly greater than the accuracy the client requested. From this analysis, we concluded that the roller radius would have to be accounted for by some combination of measurement, calibration, or analysis method.

Influence Of Web Thickness Variation

The web thicknesses presently run on this machine are not always the same nominal value. We divided the known methods of analysis and calculations into 3 groups — those that used the actual nominal web thickness in the method, those that assumed an average value, and those the lumped the thickness variation in with roller variation. For the first group of methods, web thickness variation is the variation within the block of 'identical' support being run. From equation (2) we determined that the maximum influence of web thickness variation on these methods was negligible. For the second group of methods, we determined the maximum influence was on the order of 1/10th of the accuracy the client requested. For the third group of methods, the maximum influence was on the order of 1/2 of the accuracy the client requested. From this analysis, we concluded that the web thickness would not have to be accounted for if a method from one of the first 2 groups was chosen.

Influence Of Natural Speed Variation

The normal roller speed deviation was measured with prototype equipment on the production machine, and the 6σ value was found to be better than 1/4 of the accuracy the client requested. From this piece of data we concluded that the natural machine speed variation would not have to be accounted for.

METHOD DETAILS

The method we chose was to attach a magnet to each roller shaft, and mount a magnetic field sensor at each roller. The individual sensor signal pulse streams are multiplexed back to a central point for period measurement. We use electronics to measure the period of rotation by timing the interval between two consecutive rising edges of the sensor signal. This method has the advantages of high accuracy, "fast" data retrieval rate, and "fast" continuous collection rate. However, it does have the disadvantage of non-simultaneous data collection.

Sensor/Target

For the sensor, we chose a digital output magnetic field sensor from Honeywell (P/N SS21PE). We embedded it into a plastic body. The primary features of the unit are its (1) extremely low power consumption (< 0.05W), (2) high speed of response (>100 KHz), (3) robustness (that is, it's still sensitive even with large sensor/target offset and misalignment), and (4) ease of fabrication and installation.

For the target, we chose a single small magnet embedded in one of two halves of a plastic split collar that was attached to each roller shaft. The primary features of the unit are its (1) design (using a low weight plastic which does not measurably affect roller's dynamic balance and is easy to install, remove, and re-use), (2) materials (a durable plastic that's easy to machine), (3) a captured magnet.

Field Electronics and System

Each PCB multiplexes 32 sensor signals from the field. Enough PCB's are connected in series to monitor every roller location desired. The sensor signals are transmitted to a remote location for processing. Up to 9 PCB's can be connected together to operate as one system multiplexing up to 320 sensors. However, for our application, we found it more convenient to use 8 PCB's per system which would allow us to monitor 256 sensors per system.

Data pulse streams from each of the sensors are selected for measurement using the state of 8 digital inputs. Each PCB has a unique number from the others in the same system which is set by a jumper on the PCB. 3 of the digital inputs select the PCB and the other 5 select the sensor #. If a PCB is not selected, it simply retransmits the signal being received from the PCB behind it. If a PCB is selected, it transmits the signal from the sensor # indicated by the state of the other 5 digital inputs. This PCB is able to fit in a 12" x 16" metal electronics enclosure.

The sensors and electronics were designed to satisfy low-power electrical code requirements. The reason for designing for low-power consumption is that conduit is not required for protecting sensor or connecting cables. Conduit adds significantly to the total cost of the installation. Low-power electrical code requirements are addressed under UL1310 (also called Class 2). The code specifies a maximum allowed power through the AC transformer primary of 100 W. In practice, this means there's less than 50 DC Watts available at the power supply output to run all the electronics in the whole system - multiplexer boards, sensors, and computer I/O. In this project, each power supply (at 42 W, 12 V DC output) can power 2 complete roller speed monitoring systems comprised of 512 sensors, 16 PCBs, 2 high-speed counter cards, and 1 16-bit digital output card. 12 V DC power is provided to each PCB and regulated down to 5 V DC to operate the sensors, and electronics.

Since the data pulse stream is transmitted all the way to the computer room, the opportunity exists for debugging "problem" sensors from a lighted convenient location away from the process. With a scope, a maintenance person can determine the quality of the pulse signal getting to the computer.

Signal Analysis

To determine the roller period at the computer, the pulse stream from the sensor is fed into a high-speed pulse counter card configured to measure the time of one rising signal edge to the next rising signal edge, that is, one roller period. This method is independant of magnetic signal strength (sensor/target alignment and offset), and critical mounting of the 2 halves of the split collar. The high-speed counter card has an on-board 100 KHz master clock. The sensors rising signal edges "gate" the 100 KHz clock signal, and the card counts the number of 100 KHz pulses collected. The roller period resolution therefore is 10 nsec.

Data Analysis And Alarming

The data analysis method may be one or a combination of the following:

Option 1: Each roller's OD is determined at some point in time by (1) running the machine at constant speed with support of known thickness, (2) measuring each roller's average period, and (3) "back" calculating the roller radius using equation (2). These values of roller radius are stored in the computer and used in subsequent calculations of web velocity. Alarm on speed deviations in measured web velocity as a percentage of machine web speed.

Option 2: Bring machine to stable web speed at beginning of run of "identical" support. Assure non-slip conditions. Measure and store actual period of each roller. Alarm on period deviations as a percentage of this initial period measurement. (The web thickness does not have to be known with this option.)

MAIN RESULTS

We achieved a web velocity measurement resolution better than requested by the client. The resolution is dictated by the high-speed pulse input card, machine speed, and roller OD. We achieved a web velocity measurement accuracy better than requested by the client. The accuracy is dictated by the high-speed pulse input card, machine speed, and analysis method. We achieved a measurement collection rate sufficient for the client. The collection rate is dictated by the nature of computer, the program, the high-speed pulse input card, machine speed, and roller OD. The minimum cycle time (fastest rate) for the method we chose is from 1 to 2 roller periods.

We achieved a final cost of roughly $100K for an installation of about 450 sensors ($220/point) after the development and component design was complete. That final cost included fabrication and installation of (1) 16 custom PCBs, electrical enclosures and mounting frames, (2) 450 sensors, sensor mounts, and collars, and (3) connecting wiring and conduit (where needed). That final cost does not include the computer or programming.

Unit Cost Breakdown

ITEM	UNIT COST
Sensor assembly	$35
Collar assembly	$20
Mount assembly	$30
Printed circuit board, enclosure, and contents	$65
Power supplies, cable, conduit and entire installation labor	$70
TOTAL	$220

Limitations

Due to the fact that this method integrates the speed over an entire revolution of the roller, it may be incapable of detecting problems during web and roller acceleration and deceleration. Also, this method cannot obtain roller speed data simultaneously from 2 or more sensors in the same system.

RECOMMENDATIONS

These are some areas where further development would be desirable:

- More robust sensor/target combinations - ones that can accommodate farther offset and misalignment distances.
- An assessment of the capability of determining sensor/target robustness from P_W/P ratio.
- Intelligent sensors (in conjunction with an intelligent master controller) that can ...
  - ⇒ ... Output maximum raw signal strength on command, so one can optimize sensor/ target spatial mounting, and remotely debug sensor/target from computer room),
  - ⇒ ... Average several pulses (N from 2 to 10),
  - ⇒ ... Perform pulse error checking/ data filtering so the sensor filters out nonsensical data,
  - ⇒ ... Be commanded to sleep and awaken to save power,
  - ⇒ ... Directly output roller velocity. This capability would require a timer internal to the sensor that was stable, or a system-wide sensor timer synchronization and/or calibration method, and also require the sensor to store the roller OD internally.

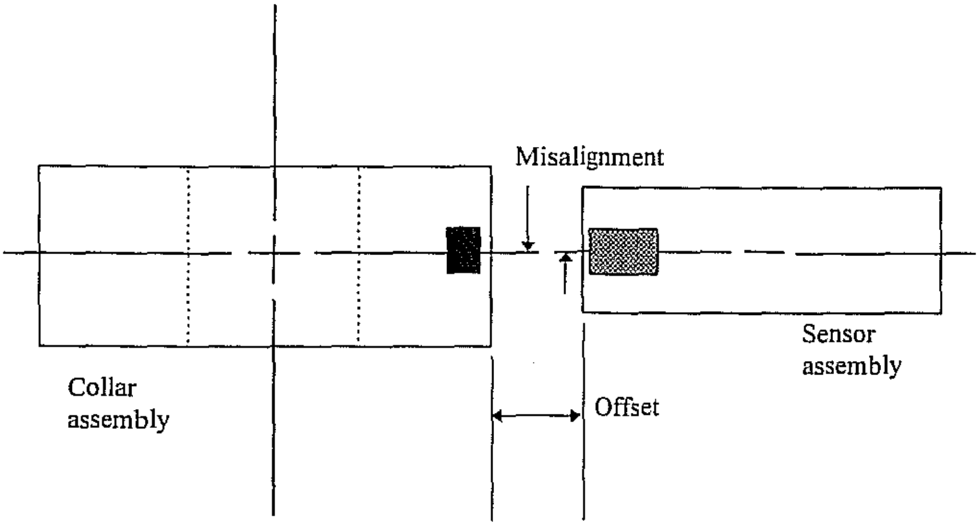

Fig. 1 Sensor and collar diagram

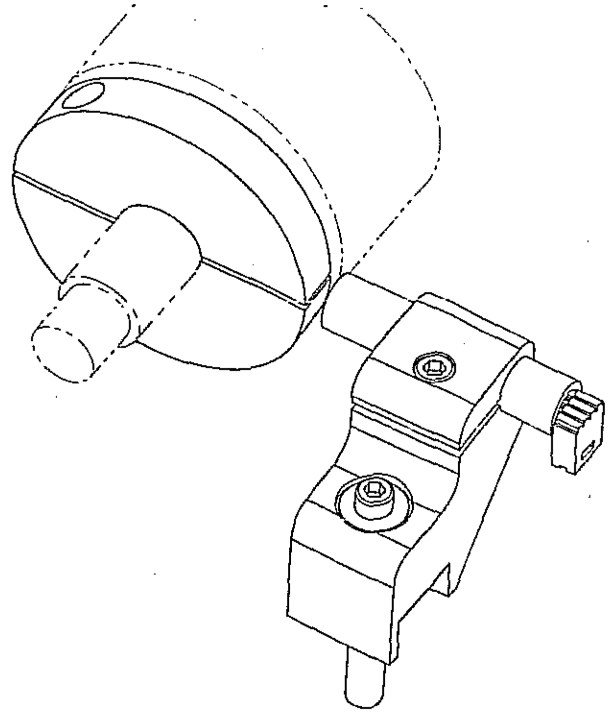

Fig. 2 Sensor and collar pictorial

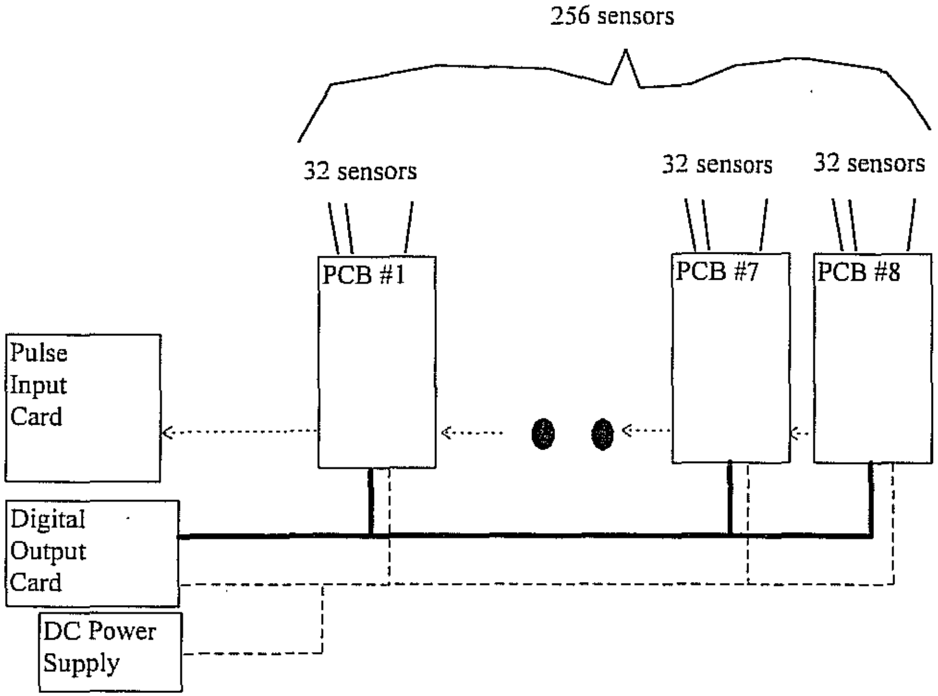

Fig. 3 System electrical connection diagram

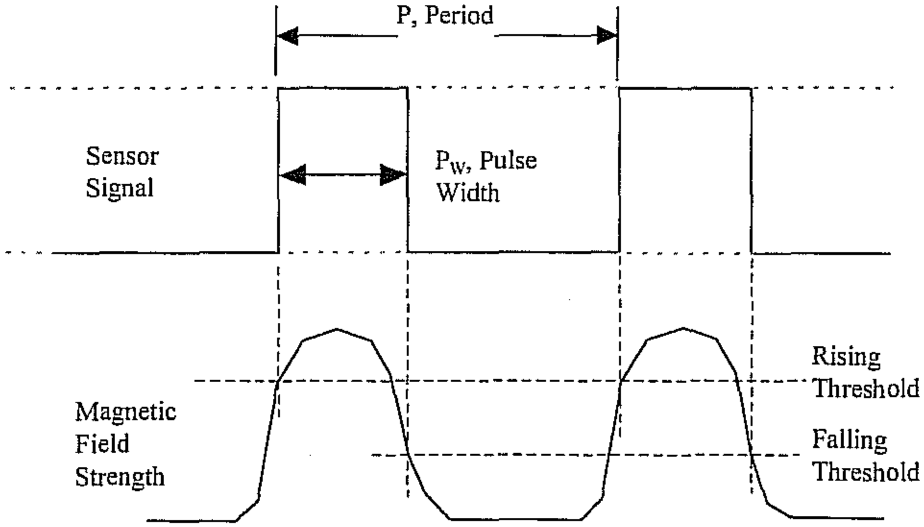

Fig. 4 Sensor Electrical Pulse Signals

Question - Do you use your system to stop the production line, as a maintenance help, on start up? Does the maintenance crew run the line at a change over?

Answer - That is the intended result for operators to use the stop, to use the speed value coming off the system.

Question - Do you have an idea what the total cost per point is when you factor in the (up front) design and total engineering?

Answer - That is really hard to tell, cause we went through a lot of scenarios that didn't work. Roughly $100,000 - with a big allowance on both sides.

Question - Did that include the hardware and installation with labor, or total project if we start from scratch to design and build first time?

Answer - It depends on first time cost or recurring cost.

Question - Do you know if the capital investment has been justified from this installation?

Answer - Too early to tell.