During the production of high quality sheet metal, tiny variations in the strip thickness can cause unevenness of the finished coil. Variations in the base material or coating thickness can cause this quality problem. The TopCoS system was developed to measure this problem and alert the operator for corrective action.

IN-LINE COIL SHAPE MEASUREMENT AT THE WINDUP

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During the production of high quality sheet metal, variations in the strip thickness across the strip will be reflected in unevenness of the finished coil at the windup. Variations in the thickness of the metal itself or variations in coating thickness can cause this problem. These small variations in thickness are not normally visible during production. Very small strip thickness variations on the order of micrometers will cause significant unevenness of the coil, and as a result the quality of the finished coil is reduced. In many cases, the coil cannot be sold at the desired high quality level but must be downgraded to a lesser quality and sold at a reduced cost. It is very desirable to detect coil unevenness as soon as possible and correct the process problem or possibly cut the coil short before the unevenness is too large and the coil has to be downgraded. The TopCoS measurement system was developed to detect coil unevenness very early as the coil is being wound.

System Design

Based upon customer requests and our experience with measurement systems for steel process lines, the following requirements were developed:

- unevenness resolution of 0.1 mm (.004 inches) or better
- detect unevenness occurring at any crosswise location of the coil
- detect coil unevenness as soon as possible
- reliable minimum bulge height detection of 0.5 mm (0.020 inches)
- Non-contact measurement
- measurement width variable up to a maximum of 2m (80 inch wide coils)
- the measurement should be done right in the process line (In-line measurement) so the operator can be alerted to a problem
- line speeds up to 20m per second (3,600ft per second)

This design is based on the concept of 2D Triangulation. The system setup is shown in figure 1. Shown in figure 2 is a reference coordinate system.

Fig. 1 - 2D Triangulation

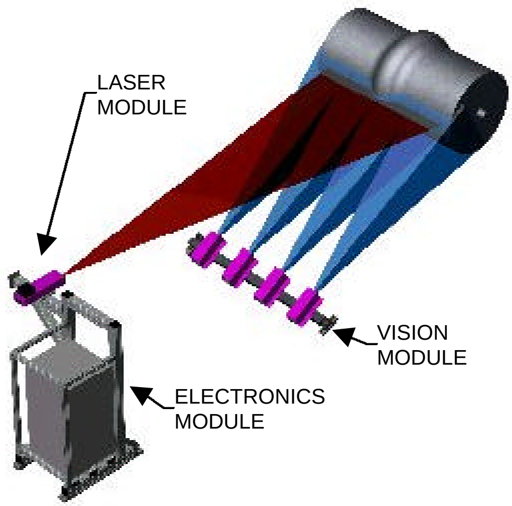
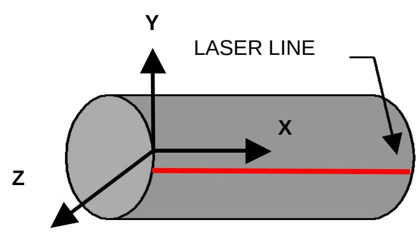


Fig. 2 - Reference Coordinate System



The x position of the laser line is the cross coil location. The y-axis is perpendicular to the x-axis and is tangent to the coil at the laser line location. The z-axis is perpendicular to x and y and also normal to the coil surface at the laser line location.

> A simple experiment will illustrate the concept of 2D Triangulation. Take a piece of string and pull the string so it is under tension and lower it straight onto a flat surface. View the string at an angle off the normal to the surface. The string should look straight. Now, place a pencil on the surface with the pencil pointing away from you. Again, lower the string to the surface and across the pencil. View the string from approximately the same angle as before. Now, you will notice that the string is not straight but is bent as it goes over the pencil. The distance the string is bent is related to the diameter of the pencil

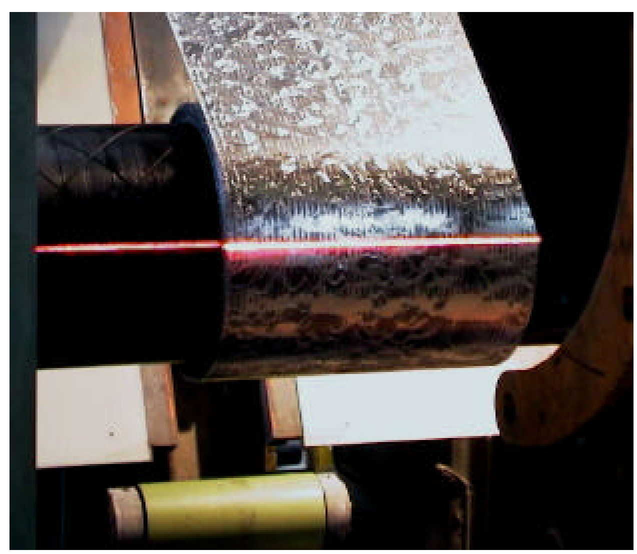
The application is basically to determine the z position of the coil surface at each x data point and process this data to detect and measure any surface unevenness or bulges. The coil profile is then displayed (figure 5) for the operator. In many cases the operator can take corrective action before the coil has to be downgraded.

The unevenness occurs mostly at the coil edges but can also occur at the interior of the coil. Small variations in strip thickness will add up over the many wraps of a coil at the windup. For example, a 5µm strip thickness variation builds up to 5mm bulge for a coil with 1,000 wraps.

Laser Module

The laser module projects a line of laser light across the coil. If the surface of the coil illuminated by the laser line has any high spots or low spots the laser line will not be straight as it crosses over the high or low spot but instead will be bent slightly as viewed from the location of the vision module. The magnitude of the displacement of the laser line is related to the size of the high or low spot. The laser line is produced by using a 500mw laser and optics that are designed to project a line. The angle between the laser and the cameras is 30 degrees. Figure 3 shows the laser line on a windup core and a galvanized coil.

Fig. 3 - Laser Line



The line is as wide as needed to cover the complete width of the widest coil that may be made on that process line. The line generating optics were chosen so that a 2m wide line is generated at a standoff distance of 6m from the coil. However, this distance is flexible depending on the actual installation space available. The line is 5mm in height (y). The laser light intensity is uniform in the width (x) direction and is gaussian distributed in height (y).

Figure 1 shows a very large bulge only to illustrate the concept of 2d triangulation; in reality, the levels of bulges that must be detected are very small, much less than one millimeter. Someone looking at the coil, in most cases, cannot see the bulge even if they knew where to look. It is the system's task to be able to detect this tiny bulge in the presence of dust, oil spray, vibration variable ambient light, shinny and dull coils and other difficult conditions.

Vision Module

The array of intelligent cameras images the laser line. The software in the camera analyzes the image and determines the coordinates of the line. Each camera then transmits the coordinates to the Electronics Module. By analyzing these data points over a short period of time the occurrence of a very small bulge can be determined and its height (z) measured.

A charge coupled device (ccd)-area machine vision intelligent camera is used as the sensor. The camera used is shown in figure 4.

Fig. 4 – Intelligent Camera

The number of cameras depends on the width of the process line. For example, 4 cameras are used for a 2m wide line. A standard camera lens is used which avoids expensive special lenses. Based upon the system geometry and the camera field of view the result is an optical resolution of approximately 1mm in the vertical (y) and 0.5mm in the horizontal (x).

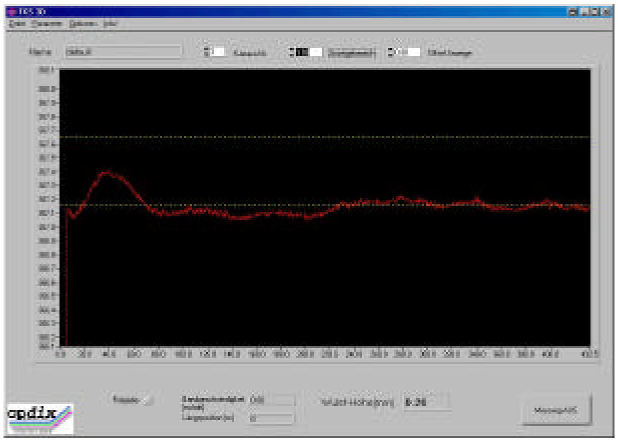
As the coil is being wound the cameras snap images of the laser line. The image processing software in the camera then computes the line coordinates. The coordinates of the line are the cross strip position (x) and the location of the center position of the line (y). Since the bulge information is contained in the distortion of the laser line in the y direction it is very important that the center position of the laser line be calculated accurately and reliably. The software algorithm in the camera image processor that accomplishes this makes use of the fact that the laser light intensity is gaussian distributed in the y direction.

The Vision Module uses cameras with video memory and an image processor. They integrate a high-resolution CCD sensor with a fast image-processing signal processor. A dynamic RAM is used to store data and video images. Interfaces allow communication with the outside world. These cameras are built for industrial applications where a rugged EMI insensitive sensor is needed. Only a DC supply voltage is required to operate the cameras (usually 12 volts). An image processing system or a PC with a frame grabber board is not necessary. The model used in this application is a progressive scan with a resolution of 1280X1024 pixels. The DRAM size is 8Mbyte. It has a SVGA video output and a processor performance of 200MIPS

Electronics Module

The Industrial PC computer in the Electronics Module receives and processes the coordinate information from the cameras and then displays the x and z coil profile for the operator. Each second approximately 10 coil profiles are evaluated. Monitors for display of the coil profile may be located at convenient locations for the operators. These locations can be a large distance from the Electronics Module. Figure 5 shows the operator display showing a bulge with a height of 0.3mm. Also displayed are lines indicating the average coil surface height and an operator adjustable bulge height threshold. There can be as many monitors as are required.

Fig. 5 – Operator Display



The cameras output information via a high-speed serial port. An interface converts the serial information to TCP/IP format for transmittal via an Ethernet connection to the PC computer in the Electronics Module. The Electronics Module can be located at a large distance from the Vision Module The software In the PC computer also makes corrections and adjustments to the coordinate data from the Vision Module:

- adjusts the profile data from the individual cameras to one profile line
- corrects for any distortions in the optics
- adjusts for any movement of the coil
- adjusts for any light intensity changes in the laser light line
- adjusts for any optical changes in the strip surface

Height deviations from the normal coil surface are candidates for possible bulges. The software makes use of knowledge of how the bulge occurs in the process:

- a bulge stays in the same place relative to the coil edge
- a bulge is continuous over the length of the coil
- the height of the bulge changes slowly as the coil is being wound
- the diameter of the coil increases continuously as the coil is being wound

The system uses techniques from stochastic signal processing to accomplish a measurement of much higher resolution and precision than the sensor normally could make (sub-pixel processing). The bulge height processing algorithms also make use of the fact that as the coil is wound the laser line images move in the camera y direction. Utilizing this fact improves the signal to noise ratio. Figure 6 and 7 illustrates how this affects the measurement results. Figure 6 shows the measurement taken with the coil being wound and figure 7 shows the same measurement with a stationary coil. The difference in the resolution is very clear. The resolution with the measurement done on a stationary coil is approximately 200µm whereas the same measurement done on a coil that is being wound is less than 50µm

Fig. 6 – Measurement from a Coil Being Wound

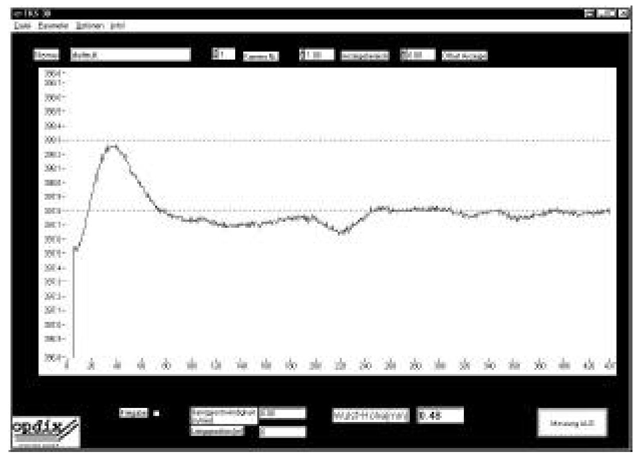
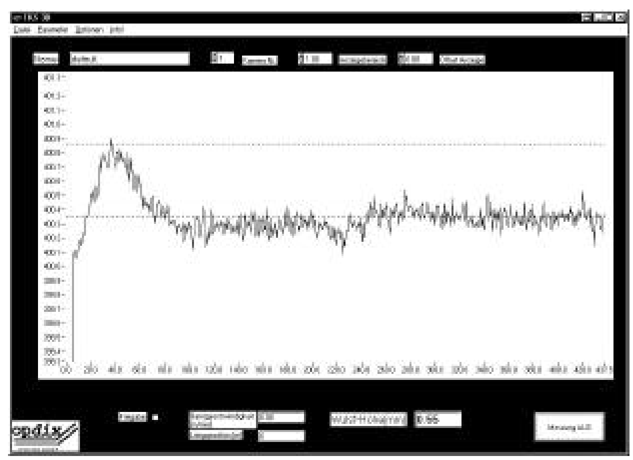


Fig. 7 Measurement from a Stationary Coil



This sub-pixel resolution allows the use of a lower cost camera as compared to the much higher cost of a high-resolution camera. By processing 100 pictures and a pixel resolution of approximately 0.5 mm the system can reach a system resolution of 30um. This is a system resolution that is more than 10 times better than the pixel resolution of the camera.

Summary

Shown in figure 8 is an actual installation at the Thyssen Krupp Steel Company. The Electronics Module is shown in the foreground.

Fig. 8 - Installation

The system can detect bulges greater than 0.1mm at a resolution of 50µm. Additional system advantages are:

- modular design
- inspects coil widths from small to very large (2m)
- handles different products
- fits in very small space
- no moving parts
- use of standard components
- large standoff distance from the coil

It is very important to note that the system can be maintained without shutting down the line. All the system components are located outside of the windup area. The large standoff distance also reduces the risk of component damage due to a process problem. Component failure due to wear is minimal since the system has no moving parts. The use of standard components provides lower replacement cost and reduced time to repair should any component fail. The modular design of the system allows installation of the system on any line and special customer requests can be easily handled.