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Development of diagnosis system for knife and strip cutting face in the side trimming process

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Abstract

It is very important to measure and diagnose the state of knife and strip cutting face in real time in the side trimming process due to improvement of quality of strip trimming face. In this study, a diagnosis system for knife and strip cutting face was developed. Two CCD cameras facing each other are mounted at the delivery side (the entry of the bur masher roll) of the side trimmer. This system offers the operator the diagnosis result of state of knife and strip cutting face. With the help of the developed system, the knife breakage has been detected 100% and bad quality of trimming face is significantly decreased. Using CCD cameras, an on-line diagnosis system which can determine knife breakage and bad quality of trimming face in real time is developed in trimming. A diagnosis algorithm determining the state of the strip cutting face is also developed by calculating characteristic values and image processing based on the images of the strip cutting face obtained from CCD camera.

Keywords: Diagnosis system; Side trimming; Saw ear; Knife breakage; CCD camera; Strip; Image process

1. Introduction

In POL (pickling and oiling line), CAL (continuous annealing line), RCL (recoiling line), the side trimming process is full of significance in order to meet the strip width demanded by customers. In addition, it is also required to eliminate cracks which would exist at the edge of hot rolled strips in TCM (tandem cold rolling mill) process. During the side-trimming, knife breakage frequently occurs due to inadequate setting in knife gap or lap, and abnormal trimming conditions [1-4].

If special attention to observing both sides of the strip is not paid by an inspector after coiling, local breakage of the knife can cause badness of strip cutting-face consecutively (5-7 coils), because it is not easy for an operator to recognize directly the knife conditions at the side trimmer. Recently, the occurrence rate of knife breakage has significantly increased due to high production rate of high strength steels used for automotive application, and such breakage is also greatly affecting the yield and reduction of productivity. Therefore, many steel companies in close cooperation with instrumentation companies have had special interests in development of a on-line system which measures and diagnoses knife conditions [5-8].

In this study, in order to avoid the local breakage of the knife during the trimming, a diagnosis system has been developed to guide operators with the state of the knife and the strip cutting face [9, 10]. Two CCD cameras facing each other have been installed at the entry of a bur masher roll. Images of strip cutting face obtained from the CCD cameras were analyzed through an image processing technique, and the state of the knife and strip cutting face was decided based on the analyzed results. Introduction to the developed system and results achieved from the plant applications will be presented in this paper.

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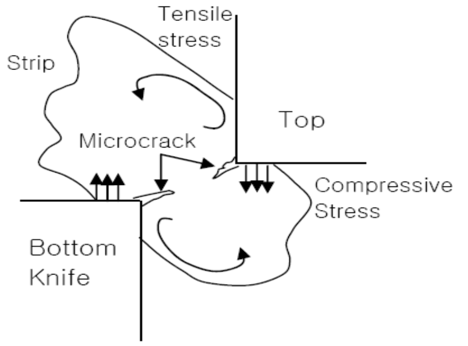

Fig. 1. Mechanism of strip cutting in the side trimming process.

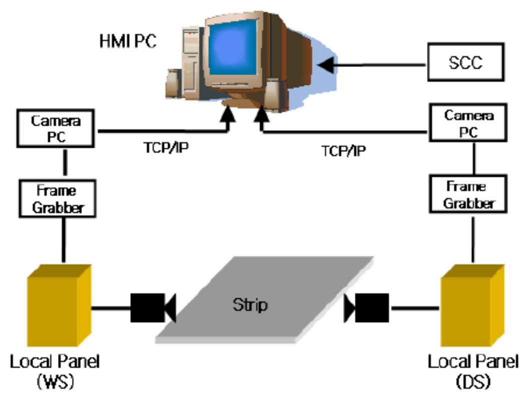

Fig. 2. Composition of the diagnosis system developed by this study.

2. Principles of the side trimming

Generally, a trimming mechanism is composed of shearing and tearing under the proper setting of the gap and the lap determined based on strip thickness and steel grade. The gap is defined as clearance between upper and lower knives, and is set about 1/8-1/10 of the strip thickness. The lap is defined as amount of overlapped distance between upper and lower knives and is set about 1/2 of the strip thickness.

As shown in Fig. 1, the trimming is a cutting mechanism whereby shear deformation is made by amount of the setting lap. And then a microcrack is formed at the knife edge due to tensile force created by the knife rotation, and the strip is finally cut by propagation of the crack. Large amount of the shearing force is applied at the region where the shearing deformation arises, and the shearing force is decreased rapidly at the tearing region. Significant factors affecting the characteristics of the strip cutting face in trimming are the amount of the gap, the lap, the knife wear, and the vibration in the strip and so on. Among these, the most critical factors are setting accuracy in the gap and the lap.

3. Diagnosis system

3.1 Hardware

The configuration of the diagnosis system is shown in Fig. 2. As can be seen, two CCD cameras facing each other are mounted at the delivery side (the entry of the burr masher roll) of the side trimmer. Images obtained from the CCD camera are inputted to the frame grabber which converts the image from analog to digital signal. Then, numerical values determining the state of knife and strip cutting face are calculated based on the level of digital image signal on the camera PC.

Fig. 3. Appearance of the light guide.

The camera PC has a special function saving raw images. An HMI (human-machine interface) PC is used to determine the state of the strip cutting face base on the values calculated on the camera PC, which is done by means of a internet protocol, namely TCP/IP communication with the camera PC. It also guides operators with the diagnosis result of the state of the knife and strip cutting face. Also, the HMI PC has a function that operators can easily monitor the trimming state by the periodically displayed images of strip cutting face on the screen.

Fig. 3 shows the light guide system. Light is generated from a light source in the control panel and transferred to the light guide installed in front of camera through the fiber optic cable.

Fig. 4 shows the CCD cameras installed at a location of 3 meters away from the delivery side of the side trimmer, that is, right before the bur masher roll which is used to decrease the magnitude of the bur created in trimming. The distance between the camera and the strip edge should always remain constant in order to obtain vivid images from the CCD camera. Even though the strip width varies, the camera position should be controlled according to the change in the strip width. To adjust the position precisely, a mechanical structure used for installation of the camera housing is attached to the structural frame on the bur masher roll, and the frame transports the bur masher roll to keep the distance constant for the change in the strip width.

The camera is covered with a steel housing to protect it from any physical impact. The camera housing is designed so that it can be pushed 150 mm backward with an angle of 30° when large impact force caused by poor welding or abnormal trimming conditions is transmitted to the housing. Light generated from the light source is coupled with the trimming speed by the trigger converter used to measure the trimming speed, and it is generated 45 times at the maximum trimming speed of 250 rpm. Since F.O.V. (field of view) of the camera is 30 mm, if one image can be grabbed with 45 frames per second, the traveled strip length is about 1350 mm. Therefore, the strip cutting face can be monitored every 1318 mm distance (knife diameter is 420mm), which is the circumference of the knife at the maximum trimming speed.

3.2 Software

Fig. 5 illustrates a screen on MMI for operator guidance. Images from the work-side (WS) and the drive-side (DS) are displayed every 100 frames. Abnormal images are also displayed at the bottom with alarm signal, when the abnormal strip trimming face is detected with the diagnosis algorithm. Once the alarm is ringing, the operator verifies the state of the strip trimming face through the screen on MMI, and takes proper measures for the state of the knife and the strip trimming faces. The abnormal images do not disappear from the screen until the next abnormal image is detected. Consequently, the counting number for occurrence of abnormal images at each coil is displayed, where it can be represented as "ABN count" on the screen. Additionally, the time that the normal images are updated is displayed on the screen so that the operator verifies the working status of the diagnosis system. The period for saving image information is about 3 months.

4. Image processing and diagnosis algorithm for the knife breakage

4.1 Image processing

Fig. 6 shows a flow chart for the image processing which calculate characteristic values. These values determine the state of the strip cutting face based on the raw image obtained from the CCD camera. First, it is essential to perform low pass filter to eliminate noise including image signals. The Gaussian filter was used as Eq. (1).

$$F(x) = f(x) \cdot \frac{1}{\sigma\sqrt{2\pi}} e^{\frac{-x^2}{2\sigma^2}} \tag{1}$$

Where, $f(x)$ is the input of the raw image signal and $F(x)$ is the filtering image. σ is a factor regulating intensity of filtering. The large σ value means the effects of high level on the low pass filter. The σ value of 4.0 is used in this study.

The next step is to detect the region of the strip cut-

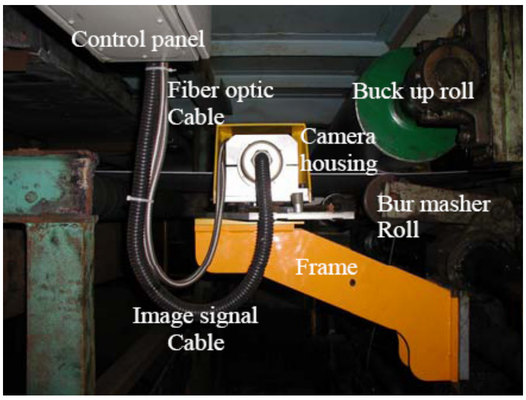

Fig. 4. Installation of CCD camera in plant.

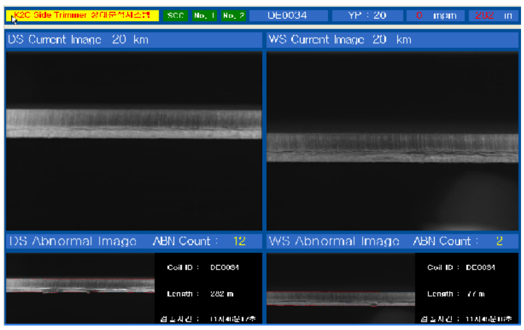

Fig. 5. Screen on MMI (man machine interface) for the operator guidance.

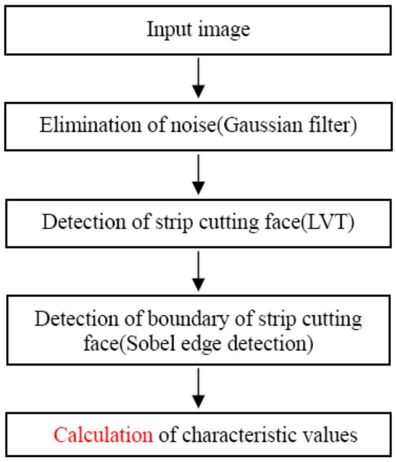

Fig. 6. Flow chart for the image processing.

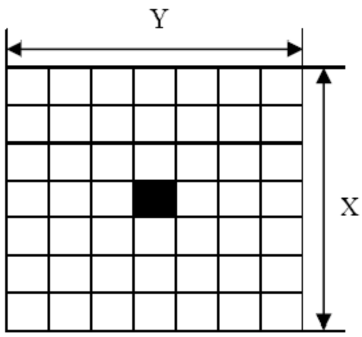

Fig. 7. Method of local variance threshold (LVT).

ting face. Local variance threshold (LVT) method is used for detection. LVT is a method of detecting objects by measuring signal variation from the local region on the image. Values in the local variance at one pixel can be determined within the image by calculating the variance of all pixels given within certain region that the pixel surrounded.

As shown in Fig. 7, the local variance of black pixels is determined by calculating the variance of pixels within (X, Y). X=7 and Y=7 have been used. After determining variance of all pixels, the images are binarized by using a threshold value. The threshold value is set to 7. The binarized image is the strip cutting face. After detection of the strip cutting face, the boundary including the strip cutting face is detected. A Sobel edge filter is used to detect the boundary. The absolute value of the filter mask gets bigger as the variation in horizontal direction within the image becomes larger. The variation arising from up to down has a large positive value, and the variation from down to up has a larger negative value.

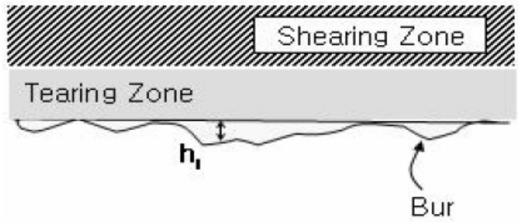

Fig. 8. A model for shape of strip cutting face

Therefore, the upper line can be precisely determined by selecting the maximum variation in the positive direction with the Sobel edge image filtering.

The bottom line can also be determined by selecting the maximum variation in the negative direction with the Sobel edge image filtering. Detection of boundary line converted from shearing part to tearing part is determined by selecting the maximum absolute value. The approximated line can be found through the linear least fitting method because both positive and negative variation appear. After the upper and the bottom lines on the obtained image are detected, the characteristic values determining the state of the strip cutting face are calculated.

4.2 Algorithm

Summation, peak and count represent characteristic values in determining the state of the strip trimming faces. Fig. 8 presents a model used to explain characteristic values. In general, the strip cutting face is composed of the shearing zone, the tearing zone and the bur. Summation represents the sum of the bur magnitude in all pixels, and the peak can be found among the burs, and the count is the pixel number in x-direction (640 pixels) over 0.5mm among the burs. Eq. (2) represents inequality criteria that determine the state of the strip cutting face including the knife breakage:

$$\begin{aligned} &Summation(h_i) \geq 1000 \\ &Peak(h_i) \geq 12 \\ &Count(h_i) \geq 20 \end{aligned} \tag{2}$$

The criterion values are found through experiments carried out at the plant, and if one of the characteristic values is greater than the criterion values, the strip cutting face is determined as the abnormal state.

5. Plant experiment and results

A plant test was performed with artificial defects made on the knife to validate the found criterion values as well as the developed diagnosis algorithm. The test conditions are given in Table 1.

The test was carried out 5 times to verify the capability of detecting the knife breakage and trimming badness such as saw ears. Fig. 9 illustrates a man-made knife defect.

Fig. 10 presents trimming badness of the strip cutting face formed by the knife defect. As shown in Fig. 10, it can be ensured that the knife defect is obviously reflected on the image of the strip cutting face obtained from the CCD camera, and the characteristic values are greater than the given criterion values, Eq. (2), when the knife breakage is caused.

Fig. 11 illustrates a test result which can be used to examine the relation between the state of the strip cutting face in trimming and defect occurrence of the saw ears after cold rolling. This figure shows an im age of the strip cutting face classified as the abnormal state by using the diagnosis system. This diagnosis result gives good agreement with the result observed with the naked eyes of a inspector after cold rolling. Defects of the saw ears are caused. Therefore, it can be verified that the knife breakage and the defect of the saw ears of the strip cutting face in trimming can be well detected with the diagnosis system made in this study.

Fig. 9. An example of the artificial knife defect.

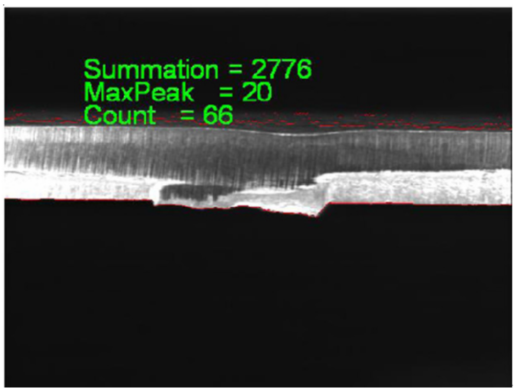

Fig. 10. Trimming badness of strip cutting face formed by the knife defect was detected.

6. Result of plant application

The diagnosis system for knife breakage and badness of the trimming such as the defect of the saw ears has been applied to the plant since February 2004. Fig. 12 represents the on-line diagnosis results by the knife breakage. Information of the strip cutting face obtained continuously is very useful in understanding the process of the knife breakage. Time taken from (a) to (c) is within 1 sec. When the knife breakage occurs, the diagnosis system rings the alarm. And then, one of operators stops operation to replace with a new knife. Therefore, the badness of trimming that may occur consecutively in 6-7 coils can be prevented.

Fig. 13 shows the on-line diagnosis result for badness of the strip cutting face. This case is associated with the defect of the saw ears after cold rolling. Recently, the knife breakage has been occurring about

Table 1. Test conditions.

	Strip thickness (mm)	Strip width (mm)	Steel grade (YP)
1	3.0	1213	27
2	3.0	1199	20
3	3.0	1199	20
4	4.0	1190	20
5	4.0	1190	20

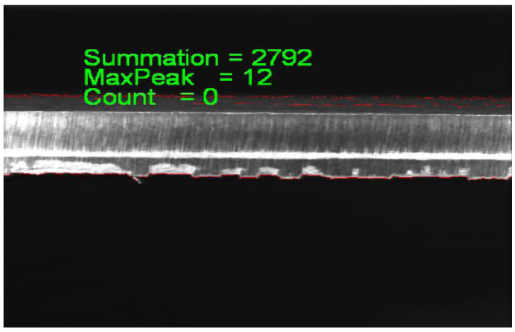

Fig. 11. An example of strip cutting face causing defect of the saw ears after cold rolling.

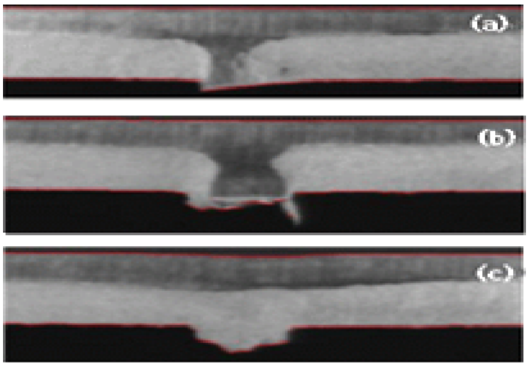

Fig. 12. On-line diagnosis results by the knife breakage.

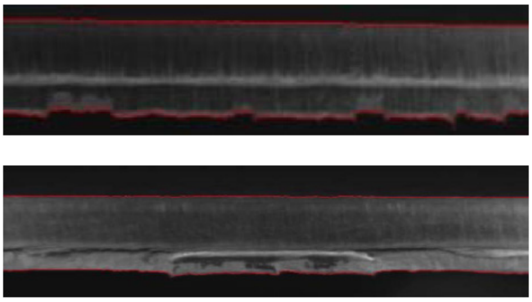

Fig. 13. On-line diagnosis results for badness of the strip cutting face.

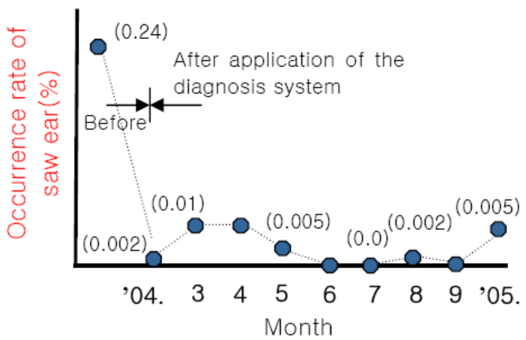

Fig. 14. Decrease of the occurrence rate for the defect of the saw ears by the diagnosis system.

10 times a month on average. With the help of the on-line diagnosis system, the knife breakage has been detected 100%, and the occurrence rate of the defect of the saw ears has decreased remarkably. Fig. 14 shows the tendency of decrease in the occurrence rate for the defect of the saw ears after the application of the diagnosis system since February 2004.

7. Conclusion

An on-line diagnosis system which can be used to measure and determine the state of the strip cutting face has been developed to increase the yield and the productivity by reducing the knife breakage rate in trimming. From the above research work, the following conclusions are made:

(1) Using CCD cameras, an on-line diagnosis system which can determine the knife breakage and bad quality of trimming face on real time is developed in trimming.
(2) A diagnosis algorithm determining the state of the strip cutting face is also developed by calculating characteristic values and image processing based on the images of the strip cutting face obtained from CCD camera.
(3) With the help of the developed on-line diagnosis system, the knife breakage has been detected 100% and bad quality of trimming face is significantly decreased in less than 1/10.

Acknowledgement

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