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CFM에서 하강 에지 정렬과 파라미터 에러 평가에 의한 크림프 시그널 분석 성능 향상

Improving Performance of Crimp Signal Analysis by Falling Edge Alignment and Parameter Error Estimation in CFM

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Abstract: A Crimp Force Monitor (CFM) is equipment for detecting crimp errors by analyzing crimp signals obtained from force and strain sensors. The analysis is commonly performed by aligning a measured crimp signal with a reference signal and comparing their difference. Current analysis methods often suffer from wrong alignments that result in false negative detections. This paper presents a new crimp signal analysis method in CFM. First, a falling edge alignment is proposed that matches falling edges of the measured and the reference signals by minimizing the absolute difference summation. Second, a signal parameter error is introduced to evaluate the crimp quality difference between the measured signal and the reference. For calculating the signal parameter error, part of a signal is identified and divided into several regions to maximize the signal parameter errors. Experiments showed that the proposed method can improve the signal alignment and accurately detect bad crimps especially with the strain sensor.

Keywords: crimp force monitor, crimping, signal alignment

I. INTRODUCTION

Crimping is the most commonly used method for terminating electrical wire with metal crimp terminals [1,2]. It is a process of joining a stripped wire that is often stranded and a crimp terminal by pressing the terminal to hold the wire and make an electrical connection. Fig. 1 shows a crimped wire. The insulation crimp holds the rubber insulation of the wire for a mechanical binding and the conductor crimp holds the wire strands for an electrical connection. For a good conductor crimping, the wire strands that is also called conductor brush, should be long enough to pass through the conductor crimp. Compared to the traditional screwing and soldering, the crimping provides fast and simple installation as well as good electrical and mechanical connection. This makes the crimping the most efficient termination method for high volume production such as wire harnesses in automotive systems.

Quality assurance becomes more important as the crimp quality requirements are getting tighter. While automatic crimping machines are normally used for high productivity and they provide better and more consistent crimp quality than manual crimping, there are still uncontrollable factors that cause defects in crimping such as faults in wires and terminals, and errors even in the crimping process. For example, crimping an improperly stripped wire can make its wire strand electrically unconnected to the metal connector. Wire position on the anvil, the alignment of a wire and a connector, and the strength and the press distance of the crimping hammer also affect the mechanical strength of the binding [3]. Thus, it is necessary to monitor the quality of a crimped connection and determine whether it is good or not.

There are several methods to determine crimp quality by directly measuring attributes of the finished crimp, such as crimp height measurement, micrograph inspection, and pull force testing [4]. Crimp height can be measured directly using a micrometer or calculated by measuring the hammer displacement during crimp process [5,6]. Micrograph inspection analyzes the photo of a crimped terminal cross-section taken by a microscope. The pull force testing directly evaluates the mechanical strength of the crimped terminal by pulling the terminal. Because direct measurements are slow and costly, and some of them are destructive, they are normally performed offline on random sample base. However, there is a non-negligible false detection

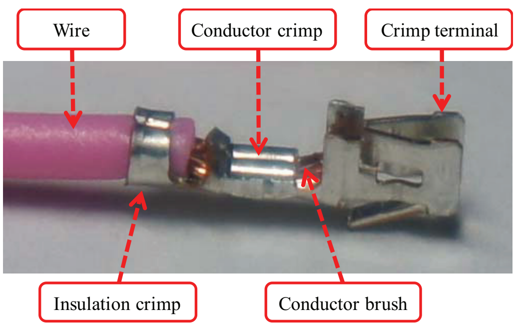

그림 1. 크림핑된 전선.
Fig. 1. Crimped wire.

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rate for the sample based testing. To meet the tight requirements of crimp quality, it is required to check all the crimp results in real-time.

The quality of crimp termination can be determined immediately by monitoring the signal produced during the crimping process. Crimp Force Monitor (CFM) is an equipment to monitor the crimp signal. It measures the crimp signal such as force, strain, and acceleration from sensors installed to the crimping machines and analyzes the signal to determine the crimp quality. Comparing the peak signal is one of the simplest methods for analyzing the crimp signal. However, comparing the specific point value is usually not enough to determine the crimp quality, but the whole signal should be inspected. The commonly used method in CFM is to analyze crimp signals measured from force and strain sensors [7,8]. In this method, the measured signal is aligned to the reference signal that is obtained from good quality crimps and then their difference is calculated with some metric. The difference should be within allowable tolerance range for the crimp to meet the quality requirements. There are several signal alignment methods such as peak alignment and point alignment. However, the alignment methods based on certain point values can result in wrong alignments when there are many movements in crimp signal curves. For example, it is difficult to find the actual peak value for a signal with two similar local peak values. For comparing the measured signal and the reference, the crimp signal is divided into one or multiple zones and the area covered by the signal in each zone or every single data value is compared with the reference. Some of analysis methods require additional sensors to obtain others data such as hammer movement to align the signal. They include measuring incremental value and/or total work performed during crimping process [9], combining crimp signal and displacement of the ram or force and stroke relation [10,11], and comparing crimp signal with crimp terminal deformation [12].

In this paper, a new crimp signal analysis method is proposed. It utilizes the crimp signal measured from force and strain sensors. The proposed analysis works in two steps. Firstly, the measured signal is aligned to the reference signal using an absolute differences summation for the falling edge part of the crimp signal. The signal alignment is important because a crimp signal difference is very small and a bad alignment may result in overestimating the difference. The proposed signal alignment utilizes the signal characteristic that the falling part is similar in every crimp signals because it corresponds to the press release phase of the crimping. Secondly, signal parameters of the measured signal are determined by dividing the signal into regions and calculating the area of each region. The ratio of the signal parameters of the measured signal to the reference is used for the metric in determining the crimp quality. The boundaries of regions are chosen by experiments to maximize the difference between a defective signal to the reference. The proposed CFM has been implemented using a microcontroller and a signal measurement circuit. Experiments were performed to show the effectiveness of the proposed CFM with a commercial crimping machine. For the experiments, normal wires and defective wires are used. The defective wires were intentionally made by cutting one of their wire strands. It is observed that aligning falling edge parts using the absolute difference summation produce better signal alignment compared to the peak or point alignment. The experimental results also show that defective wire crimps have relatively larger signal parameter ratio than normal wire crimps especially with the strain sensor.

The rest of the paper is organized as follows. In Section II, the CFM hardware configuration and the signal measurement circuit design is presented. Then, Section III describes the proposed analysis method for the signal alignment and the signal parameter calculation. Section IV provides experimental results. Finally, Section V states the conclusion.

II. CFM HARDWARE

Fig. 2 shows a crimping machine used in this paper. While a specific model JYP-P700 is used for the implementation and the experiment of CFM, the proposed method can be generally applied to other automatic or semi-automatic crimping machines.

There are two sensors installed on the crimping machine – a force sensor FTW20 and a frame strain sensor PSS50. The force sensor is located at the bottom of anvil to detect the force from hammer and the frame strain sensor is located at the middle part of the crimp machine body to detect the strain present during crimp process.

Fig. 3 shows a signal flow diagram from the force sensor to a microcontroller. The signal is conditioned by a buffer and filters before it is read by an analog-to-digital converter (ADC) and sent to the microcontroller. There are several major improvements compared to the previous design [13]. The signal measurement circuit has ADC with 1 MHz sampling rate which was 100 KHz previously. The higher sampling rate allows more accurate signal information in calculating the crimp parameters. The circuit has both a high pass filter (HPF) and a low pass filter (LPF). The low pass filter has 1.2 kHz cutoff frequency and reduces high frequency noises. The high pass filter has around 1 Hz cutoff frequency and removes constant high DC voltage from the force sensor. Thus, only AC signal will be amplified.

III. SIGNAL ANALYSIS METHOD

In this section, details of the proposed signal analysis method

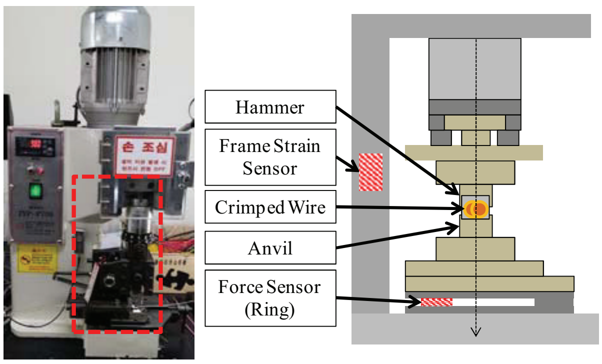

그림 2. 크림핑 장치.

Fig. 2. Crimping machine.

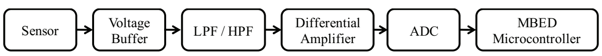

그림 3. 시그널 흐름도.

Fig. 3. Signal flow diagram.

are described. First, a signal alignment using the absolute difference summation for the falling edge is presented. Second, the parameter error is calculated by dividing the aligned signal into several regions. Then, teach mode is described to determine the reference signal.

1. Signal alignment

Before a measured and a reference crimp signal are compared, they have to be aligned because their start times are different. A bad alignment may result in an incorrect comparison of the signal difference. A signal alignment method has to find common segments or points of signals and match them so that only quality dependent parts are compared.

The most commonly used method to align signals is shifting the signal peak or the highest value into the same position in the reference or a designated position. This method is quite simple and fast in calculation. However, the highest value alignment is effective only for good signal curves to obtain good alignments. Fig. 4 shows a result of the highest value alignment which is not aligned as intended due to the difference of peak location. The signal has two local peaks one of which is slightly smaller than the other. In normal crimping condition, the right peak has higher value than the left, but error or small variation in wire condition or crimping process may produce higher left peak. The peak alignment is also inefficient when shapes of signals are different from the reference or the peak value is slightly smaller than the reference peak value. In these cases, signal differences are spread across the entire signal curve which causes the error to be harder to inspect.

Point alignment provides more general way of setting points used for alignment [11]. It is an alignment method by shifting a measured signal to be matched with the reference at a point with a specified value. Contrary to the peak alignment, the alignment point can be chosen from any part of a signal ranging from the beginning of the rising edge part to the end of the falling edge part. In addition, the alignment point can be set at an absolute level or at a percentage level of the highest value. The advantage of point alignment is that it took less process and almost as fast as peak alignment. The point alignment result becomes more reliable when more alignment points are used. However, the alignment result still depends on the choice of alignment points.

In this paper, a new alignment method is introduced to solve the problem occurred in the peak alignment and further improve the point alignment result. The main idea is using an absolute differences summation to determine the similarity of the falling part of signals for the alignment [13,14]. The falling parts of signals corresponds to the press release phase of the crimping process and has a stable curve that is not much affected by wires and crimp terminals condition. These parts can be chosen as a signal's representative to the alignment. The signal is considered having good alignment when both reference and measured signal's falling parts are aligned correctly.

The absolute differences summation determines similarity between two signals by summing the absolute difference between the measured signal and reference signal over a certain interval. The absolute difference summation $d(l)$ is given as

$$d(l) = \sum_{n=s}^{s+r} \left| x_r(n) - x_m(n-l) \right|$$

where

$x_r(n)$: reference signal
$x_m(n)$: measured signal
l : time shift of the measured signal
r : range of summation
s : alignment starting time index of the reference signal

The time shift l that minimizes the absolute difference summation $d(l)$ is the time needed to shift the measured signal for alignment. However, it takes long search time to find the time shift that minimizes the absolute difference summation because the measured signal should be slid from the beginning to the end of the falling part of the reference signal. To reduce the search time, the proposed alignment method works in two steps. First, a pre-alignment is performed using the point alignment at the 50% level of the maximum value on the falling edge. This ensures that the measured signal is shifted close to the correct alignment position and enables searching only nearby ranges. Second, the absolute difference summation alignment is performed for the fine alignment. This method shifts the measure signal to the position that minimizes the absolute difference summation with the reference signal. Fig. 5 shows the result of the falling edge alignment using absolute difference summation. It can be observed that the falling edge part is perfectly aligned.

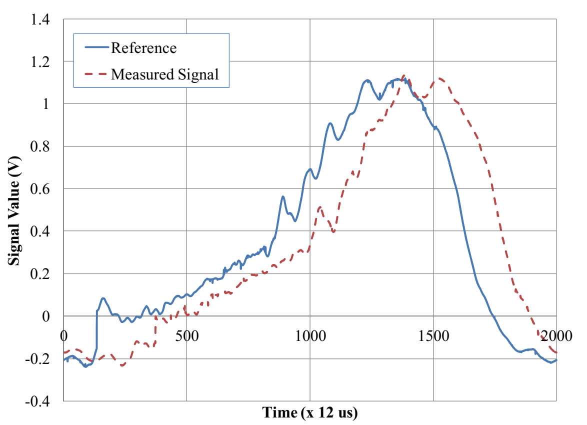

그림 4. 최고점 정렬 오류.

Fig. 4. Bad peak alignment.

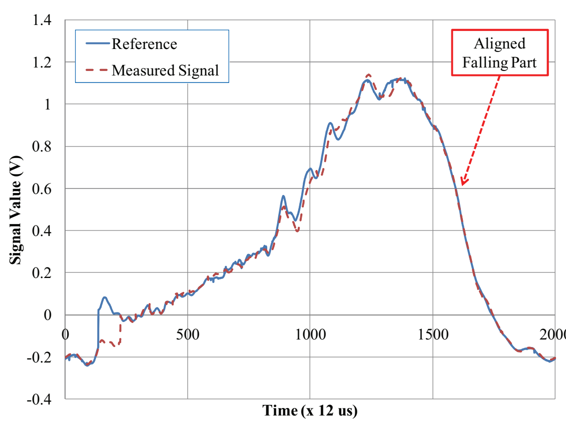

그림 5. 하강 에지 정렬.

Fig. 5. Falling edge alignment.

2. Threshold lines positions and signal parameters

After alignment, the crimp signal is analyzed by dividing it into several regions by boundary lines and calculating each region's area that is called a signal parameter. The signal parameter $P(T)$ of a region T for a signal $x(t)$ is calculated as

$$P(T) = \sum_{t \in T} x(t)$$

The parameter error $e(T)$ of a region T is defined by the difference between the measured and the reference signal parameters divided by the reference signal parameter as

$$e(T) = \frac{P_m(T) - P_r(T)}{P_r(T)}$$

where $P_m(T)$ and $P_r(T)$ are the signal parameter of the measures signal and the reference signal respectively.

The threshold line positions can be determined simply by time indices of the reference signal with specified values that is normally percentages of the highest value [8]. It can also be divided based on the crimp cycle - hammer stroke, press, and release. In this paper, a new approach is proposed that selects regions that show large difference from the reference according to crimp conditions. Threshold lines for regions are determined by comparing many aligned signals. In Fig. 6, several crimp signals from the force sensor are shown together after alignment. It can be observed that the region circled by the dashed line has large variation which is unique for each signal. This is chosen as a region and divided further into smaller regions depending on the curve characteristic. The lowest threshold line is around the starting point of the rising part where the signals start to diverge. The highest threshold is located near the starting of the aligned falling part where signals converge. One large region is defined using these two threshold lines. This region can be divided further into two or more sub-regions to inspect it more detail.

Threshold lines for sub-regions are determined according to the characteristics of signals. Different type of wire, terminal, and sensor might produce different curve pattern which required different threshold line positions. For the force sensor, the region is simply divided into two equal width regions of the rising part and the peak part because signals from the force sensor have small variation. For the strain sensor, more threshold lines are defined to divide the region. However, the width of each region should not be too small for the calculation of area difference, at least 150 signal data in this paper.

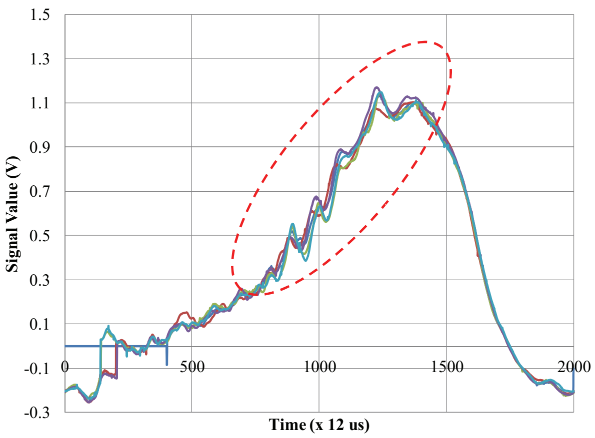

그림 6. 힘 센서에 대한 크림프 시그널의 특성 영역.

Fig. 6. Characteristic region of crimp signals from the force sensor.

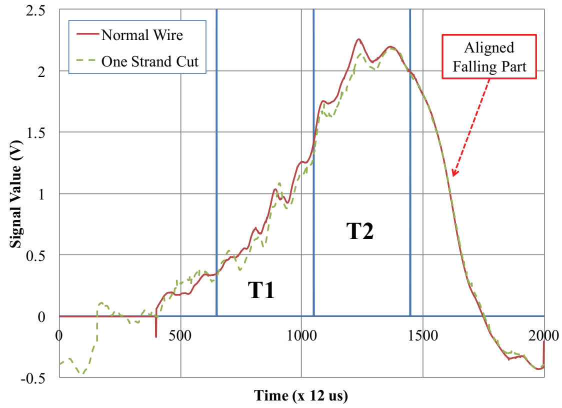

그림 7. 힘 센서 시그널에 대한 시그널 파라미터.

Fig. 7. Signal parameter for the force sensor signal.

The force sensor produces quite a simple signal with relatively little variations as shown in Fig. 7. In this paper, the threshold line positions are set at time index 650, 1050, and 1450 as indicate by vertical lines. The areas bounded by these lines are signal parameters, T1 and T2, and TT is defined as the sum of T1 and T2 that represents the whole area.

The strain sensor on the frame of the crimp machine produces signal with more variations during the crimping process compared to the force sensor. In addition, the difference between normal and defective wire with one strand is cut is relatively larger compared to the force sensor signal. In this paper, the threshold line positions are set at time index 725, 926, 1075, and 1450 as indicate by vertical lines in Fig. 8. These positions are chosen experimentally with many good and bad crimp samples. Initial threshold positions are located at local maximums or local minimums of the reference signal and they are adjusted to maximize the separation of parameter errors between good and bad crimps. The areas bounded by these lines are signal parameters, TN, T1, and T2, where TN is an area of the beginning of the signal that has large variations and TT is defined as the sum of TN, T1, and T2. Any

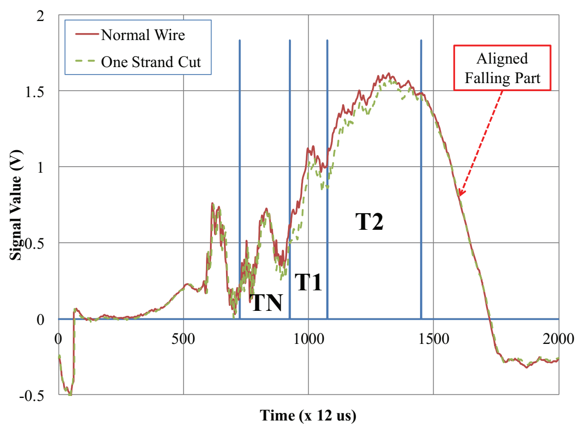

그림 8. 변형 센서 시그널에 대한 시그널 파라미터.

Fig. 8. Signal parameter for the strain sensor signal.

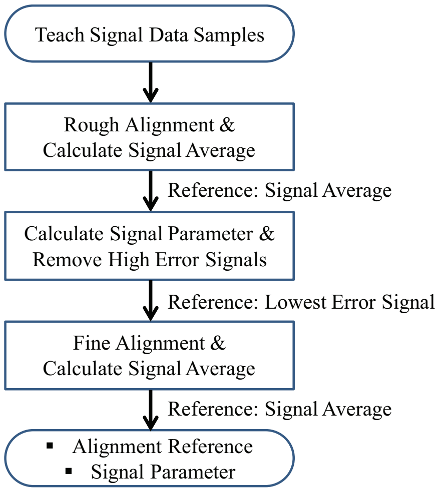

그림 9. 학습모드 흐름도.

Fig. 9. Teach mode diagram.

measured signal must be aligned correctly to avoid incorrect calculation of signal parameters because threshold lines are fixed for any signals.

The reference signal parameters are obtained in the teach mode described in the next section. Current selected threshold line positions are valid only for similar types of wires used in the paper. For different types of wires, they can be adjusted according to the signal curve characteristic and user preference.

3. Teach mode

Teaching is a process of determining the reference signal and its parameters. The reference signal must be determined carefully for better crimp quality assessment. Only good quality crimps are used in the teach mode. Fig. 9 shows the diagram of the teach mode process. While five samples are used for determining the reference in this paper due to the memory limitation, more samples can be used in general. Sample signals are aligned by using the pre-alignment and saved temporarily. After all sample signals are obtained, their average is calculated to be used as a reference. Then, the signal parameters of each sample are compared with the average signal parameters and sample signals with the parameter error over certain tolerance are removed. The remaining sample signals are realigned by the falling edge alignment using the sample signal with the lowest parameter error as a reference.

They are realigned once more using their average by the falling edge alignment. Finally, their average becomes the reference signal. Its parameters are also calculated and saved in memory to avoid unnecessary recalculation of the reference signal parameters.

IV. EXPERIMENTS

Semi automatic crimping tool model JYP-P700 with a force sensor FTW20 and a frame strain sensor PSS50 are used in the experiment. The force sensor is located at the bottom of the anvil to detect the force from hammer and the frame strain sensor is located at the middle part of the crimp machine body to detect the strain present during crimp process. Wires with seven strands are used. They have outer diameter 1.4 mm, insulation wall thickness 0.3 mm, cross sectional area 0.37 mm^2, and core strand 7/0.26 mm. Before they are crimped, the tip of the rubber insulation is

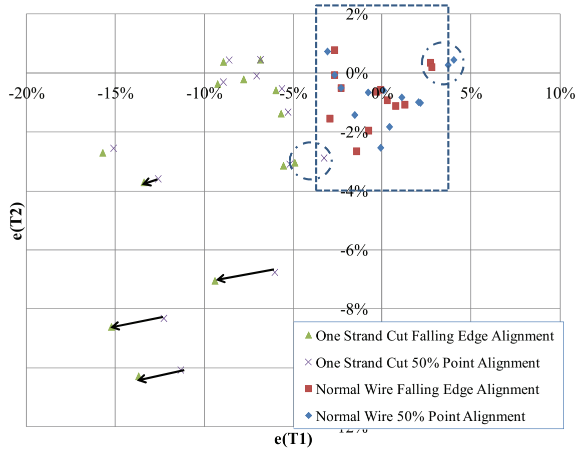

그림 10. 두 가지 다른 정렬 방법에 의한 파라미터 에러.

Fig. 10. Parameter errors after two different signal alignments.

already peeled around 2 mm automatically by a wire stripping machine. Defective wires were intentionally made by cutting one of their wire strands because they are considered one of the most difficult crimp errors to be detected by CFM. While other defect factors will also affect the crimp quality, only wire strand is considered in this paper.

1. Performance of falling edge alignment

To show the effect of the falling edge alignment, parameter errors after the pre-alignment with the point alignment at the 50% level and the fine alignment with the falling edge alignment are compared. Fig. 10 shows parameter errors after two different alignments for the same signal set. Signals are obtained using the force sensor. Square and triangle dots are parameter errors after the falling edge alignment for normal and bad wires respectively, and diamond dots and cross marks are parameter errors after the point alignment for normal and bad wires respectively. Arrows indicate the changes of parameter errors of the same signal before and after applying the falling edge alignment. It can be observed that most of the parameter errors are increasing or moving farther from zero point after applying the falling edge alignment such that the difference can be seen more clearly. Because bad wires have one less number of wire strands, their signal values are smaller than the reference overall and the parameter error is negative. While the point alignment shifts the measured signal to the right to match the 50% level, there still remains error in the falling edge part. The falling edge alignment will minimize this error and the decrease of the error will be added to the parameter error. Thus, arrows are drawn outward direction in Fig. 10. On the other hand, for normal wires, the change of the parameter error is very small.

Note that there are normal wires that are detected as bad crimps and defective wires as good crimps when the point alignment is used. They are indicated by circles on the figure. These false detections are solved when the falling edge alignment is applied. It moves points of bad crimps out of the error tolerance limit and good crimps inside of the error tolerance limit. Because the parameter changes are small, the above effect is valid for points close to the error tolerance limit.

2. Crimp quality determination using force sensor

The first experiment is conducted using the force sensor for normal and defective wires. Figs. 11 and 12 show plots of

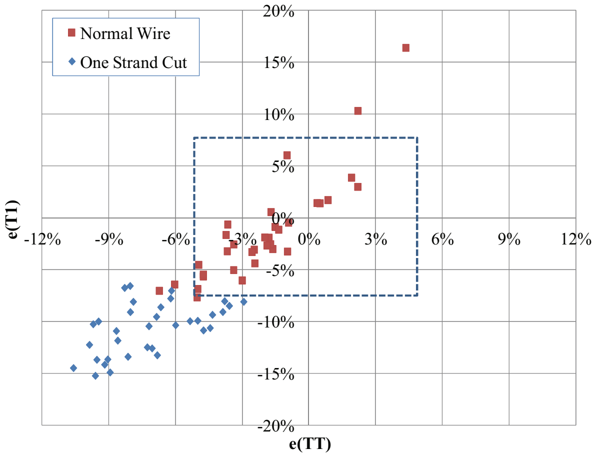

그림 11. 힘 센서에 대한 TT와 T1 영역의 파라미터 에러.

Fig. 11. Parameter errors TT and T1 with force sensor.

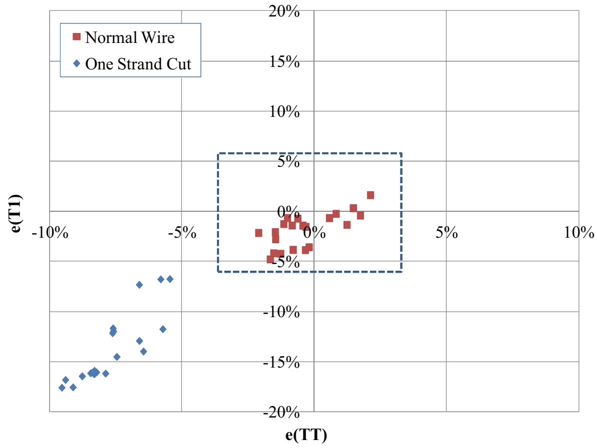

그림 13. 변형 센서에 대한 TT와 T1 영역의 파라미터 에러.

Fig. 13. Parameter errors TT and T1 with strain sensor.

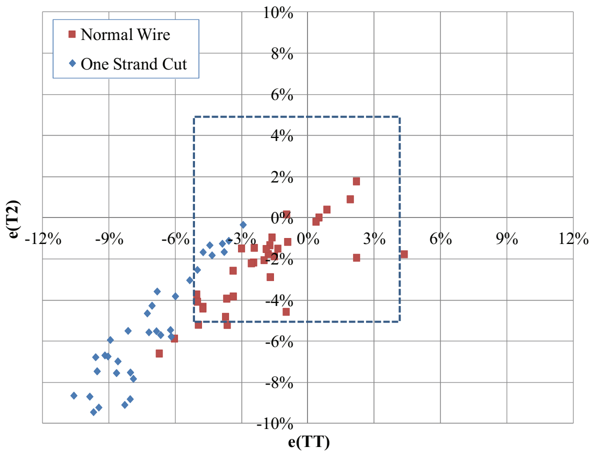

그림 12. 힘 센서에 대한 TT와 T2 영역의 파라미터 에러.

Fig. 12. Parameter errors TT and T2 with force sensor.

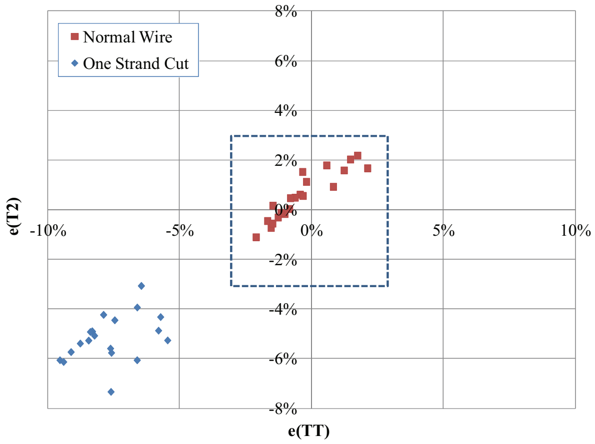

그림 14. 변형 센서에 대한 TT와 T2 영역의 파라미터 에러.

Fig. 14. Parameter errors TT and T2 with strain sensor.

parameter errors of the two wire conditions using the proposed method. To show the parameter error distribution, two different parameter errors are used for each plot - TT & T1, and TT & T2. Square dots indicate the parameter errors of normal wires and diamond dots defective wires. The error tolerance, drawn by a dashed square box, is set at ±7.5%, ±5%, and ±5% for T1, T2, and TT, respectively. As expected, majority of defective wires have larger parameter errors than normal wires. There are some normal wires whose parameter errors are outside of the error tolerance. They have other defect factors such as wrong insulation strips and crimp positions. In Fig. 11, there are two normal wire signals with very large T1 errors which are caused by the bad crimp position where the rubber insulation is crimped by the conductor crimp. Some normal wire parameters errors are outside of the negative error tolerance which indicates that the insulation crimp partially hold the insulation part of the wire. In Fig. 12, some defective wire errors are inside of the error tolerance. This happens because the insulation is slightly forward closer to conductor crimp and partially crimped by the conductor crimp. Most of the parameter errors are related to the number of wire strands, insulation position, and the crimping process.

At least one the parameter error is outside of the error tolerance for wires with bad crimp. This means that as long as all three parameters are checked, the crimp quality can be determined. Not only the wire strand error but also other crimp errors result in large parameter errors that are outside of the error tolerance and they can be determined with high accuracy.

3. Crimp quality determination using strain sensor

The second experiment is performed using the strain sensor for the same wire conditions as the first experiment. In this experiment, wires are placed on the anvil with a specific placement method to reduce the the number of defects caused by the wire position and improve the consistency and the accuracy of the experiment result. Before crimping, the tip of a wire is forced to touch the corner of the anvil such that the crimp terminal is crimped at the same location. While the crimped wire might still have slight variation in the insulation rubber positions, it is still within a good position range between the insulation and the conductor crimp.

Figs. 13 and 14 show plots of parameter errors of the two wire conditions. Because three parameters are defined for the strain sensor signal, plots are for TT & T1 and TT & T2. Square dots indicate parameter errors of normal wires and diamond dots defective wires. The error tolerance, drawn by the dashed square box, is set at ±6%, ±3%, and ±3% for T1, T2, and TT, respectively. Noticeable separation can be observed between good and defective wire for the strain sensor case compared to the force sensor signal. This allows the defective crimps to be detected more accurately.

V. CONCLUSIONS

This paper presented a new crimp signal analysis method that improves the signal alignment and crimp quality detection. First, the falling edge alignment using the absolute difference summation has been proposed. Second, the characteristic part of the aligned signal has been identified and divided into several regions. Then, the parameter error has been used to discriminate between bad and good crimps. Experiments have performed using a commercial crimping machine. It shows that the proposed alignment method helps in separating parameter errors of good and bad crimps. It also can be observed that using multiple parameter errors improves the accuracy of detecting bad crimps especially with the strain sensor.

While the accuracy can be decreased for thinner wires due to small parameter errors, combining multiple sensor signals can improve it. Also, vision-based inspection methods that are commonly used in other test systems [16,17] can be used to check crimp quality more detail.

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