Development of Durability Test System for Automobile

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Abstract: In this paper, new measurement and analysis system for the durability test is introduced. Not like previous development cases, newly developed system can process both primary and secondary signals effectively to enhance the analysis performance. Developed system can be easily adopted to the industrial fields with little modifications. Compared to the commercial products, the system showed satisfactory performances.

Keywords: Durability test, Fatigue analysis, Rainflow

1. INTRODUCTION

A Durability Test System (in short, DTS) is a kind of data acquisition and analysis system that provides a method for evaluating durability and fatigue life of the target dynamic system. Most dynamic systems, driven by engines or motors, are subject to complex load and stress in the operation, and make various signals that are physically interpretable. The DTS measures strain, displacement, service load, temperature, and miscellaneous physical quantities by signals, and evaluates the durability of the measured parts of the dynamic systems.

In this paper, signals made by the dynamic system in the operation are classified into two types: the primary signal and the secondary signal.

The primary signal is defined as 'a measured signal which can be used for the fatigue analysis directly,' or 'a directly measurable signal during the operation of the dynamic system.' For example, strain, acceleration, load, and displacement measured from the dynamic system can be classified as the primary signals.

The secondary signal, on the other hand, is defined as 'a measured or computed signal which can not be used for the fatigue analysis directly but can be used for the complementary signal for the analysis,' or 'a signal which can gives some environmental or operational information of the driving condition of the dynamic system.' If the target dynamic system is an automobile, inclination angle during running uphill or downhill, RPM of the engine or the motor, velocity, internal or external temperature of the car, and geometric information such as longitude and latitude can be classified as the secondary signals. Especially, geometric information can be valuable if the target dynamic system is a kind of transportation system. It is clear that if the secondary signals are presented with the primary signals for the fatigue analysis, they will be a great help in the analysis procedures.

In General, fatigue analysis is widely used method for the durability test and analysis. One of the fatigue analysis method is 'rainflow counting method(in short, RFM),' which counts the number of cycles in each predefined stress range from a measured stress history. As this algorithm can be easily implementable by the microcomputer, the algorithm is widely used. To utilize the RFM, time history data(a kind of raw data which is continuously sampled during the operation period) of the measured signal is required. So conventional procedures, that are performed in the offline, to evaluate the rainflow counting can be summarizes as following three steps: In the first step, the user measures and collects the raw data by the measurement system as much as possible. Then the user backs up the raw data to the engineering computer in the second step. Finally, the user performs the RFM. Because much volume of the raw data gives better results of the RFM, it is necessary for the measurement system to be installed with mass storage memory device.

But in practice, installing mass storage memory device such as hard disk drive or high density compact flash memory can be hindrances if the cost and limited storage capability are considered. For example, if an experimental condition is 'collecting raw data from 8 channel with 0.512kHz sampling rate,' the size of data during one second is 512(samples) * 4(byte per sample) * 8(number of channel) = 16 Kilobyte per second or 1.35 Gigabyte per day. Due to the limitation of the storage memory device, such a huge raw data can not be handled efficiently. Therefore, if the purpose of the experiment is a kind of durability test, it is highly recommended for the measurement system to perform 'in-field analysis feature' such as online RFM result generation and conditional raw data storaging when raw data meets user-specified condition.

Previous development cases for the online RFM are as follows. Famous commercial products are 'MAS Micro-II' by Swift, Germany and 'eDaq' by Somat, USA, and etc. The online RFM system reported to the institute is 'Mini Rainflow Corder' by Kyushu university, Japan. It is remarkable that there are few measurement systems that can perform RFM in realtime except those systems.

In this paper, we introduce new measurement system. To present effective inspection during analysis procedures, the primary and the secondary signals are processed at a time. All algorithms for the fatigue analysis are evaluated in online and only results are stored, which makes the system be free from the restriction of the memory capability. The system can store short time raw data if the trigger condition is satisfied. Finally, the system is designed under the consideration of the practical use and can be applied to the industrial field with minimal modifications.

This paper consists of five sections. In section II, overall features and specifications of developed system are summarized. Evaluation algorithms for the durability test are introduced in section III, and experimental results are shown in section IV. Final conclusions are in section V.

2. OVERVIEW OF THE SYSTEM

2.1 Features

1. The system can measure, estimate, and store various primary and secondary signals. In detail, primary signals such as strain, displacement, load, acceleration, and etc. are processed. Also, RPM, velocity, inclination angle, temperature, door open/closing count, gear ratio, and GPS information, and etc. are processed as secondary signals.

2. The system performs various data processing algorithms for the purpose of the durability test. Algorithms are as follows: Online rainflow counting method, Time at level, Accumulated distance at level, location logging by the GPS information, and etc. For detail explanation, please refer section III.

3. The system offers high usabilities in the installation and the operation. Actual size of the system is 320*230*280(W*H*D) and user can locate the system in the trunk. Required power source for the system operation is easily resolved with the cigar jack(usually 12volt output). After system installation, user can perform sensor calibration and zeroing by the system before the measurement experiments.

2.2 Specifications

Hardware specifications are summarized as follows:

- Intel Pentium-MMX is used as main control processor.
- A/D converter, which measures primary and secondary signals, has 16 bit resolution and maximum 20kHz sampling rate.
- Internal memory for the operation and algorithm execution is 64Mbyte DRAM, and storage memory for logging the raw data and results of the algorithm is 256Mbyte Flash memory.
- Amplifier board supports various bridge such as quarter bridge, half bridge, and full bridge for the strain gage type sensor. Excitation voltage range is from 1 volt to 10 volt. We interfaced strain gage, loadcell, accelerometer, and etc.
- Frequency-Voltage Converter is developed to convert the frequency signal to the voltage signal. This board is applied to the measurement of RPM and velocity of the automobile.
- Counter board is developed to count the digital pulse such as open/closing count of door, measuring of the incline angle, and etc.
- Maximum eight temperatures are measured by the K-type thermocouples.
- GPS information is interfaced via RS-232c serial communication port.

Software specifications are summarized as follows:

- Algorithms for the durability test are developed: Rainflow Counting Method, Time At Level, Trigger Mode Logger, Accumulated Distance At Level, and etc.
- Microsoft Windows based programs for the operation and management of the system are developed: Sensor configuration and calibration, Data backup, Data analysis, and Report generation.
- Data post-processing program for GPS-GIS interface is developed: Tracking and visualization of the target automobile.

3. ALGORITHMS OF THE SYSTEM

3.1 Online Rainflow Counting Method

As mentioned in above, the RFM is an algorithm which counts the number of cycles in each predefined stress range from a measured stress history. The fundamental characteristics of the RFM are its simplicity in algorithm and its compatibility with the corresponding stress-strain relation when it is applied to a strain time history. Unlike another methods like level-crossing counting, peak counting, and rage counting, RFM identifies stress ranges in the variable amplitude and frequency strain histogram which are associated with closed hysteresis loops, as shown in Figure 3-1.

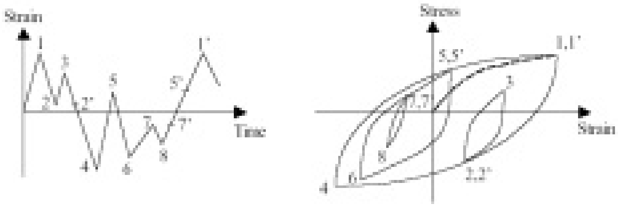

Fig. 3-1 Strain time history and corresponding stress-strain curve

Procedure of the RFM is as follows. [Ref.: "Implementation of Field Strain Measurements for Fatigue Lifetime Evaluation" by A. Huckelbridge, C. Kafali, and D. Gilmore ; Department of Civil Engineering, Case Western Reserve University, June 2002]

First the positive time axis is oriented downward, this convention facilitates the flow of data, or "rain", under the effect of gravity, along the time axis. This image is a convenient device to illustrate the method. The following rules are then applied:

1. Evenly number all positive peaks.
2. Initiate a rainflow path at the inside of each stress peak and trough.
3. Rainflow progresses along a slope and drips down to the next slope.
4. A flow can continue unless it was initiated at a minimum more negative than the minimum opposite the flow, and similarly for a flow initiated at a maximum, see Figure 3-2 path 1-8, 9-10, 2-3, 4-5 and 6-7.
5. Flow stops if it meets another flow that comes from above, see Figure 3-2 path 3-3a, 5-5a, 7-7a.
6. A flow is not initiated until the preceding flow has stopped.

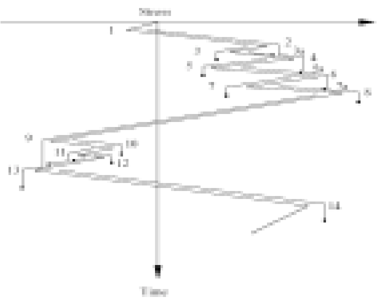

Fig. 3-2 Rainflow cycle counting illustration

For more detail information, reader can refer 'ASTM E-1049-85' published by American Society for Testing and Materials.

Following Figure 3-3, Figure 3-4, and Figure 3-5 are samples of the RFM result processed by the system. Figure 3-3 is a vertical displacement of rear tire of the experiment car. The signal is measured by the potentiometer. Figure 3-4 is a result graph of the RFM. The graph consists of 64*64 bins that divide user-defined signal range proportionally. User can estimate the count of the closed-loop hysteresis by the color of the bin. With Figure 3-5, which represents Figure 3-4 in three dimensional view, user can grasp the result at a glance.

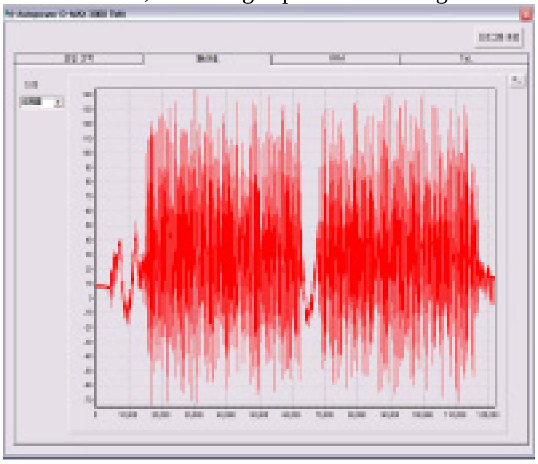

Fig. 3-3 Raw data to test RFM algorithm

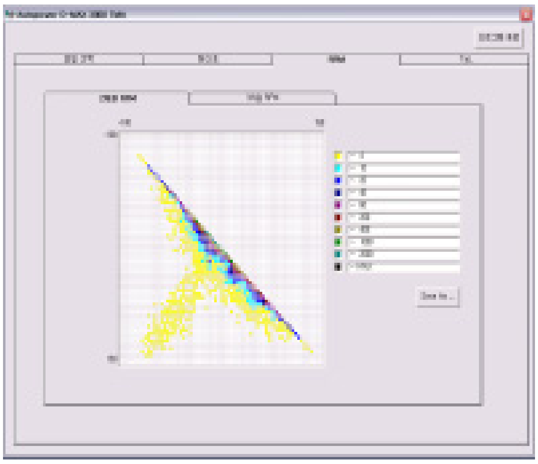

Fig. 3-4 Result of RFM: 2D graph

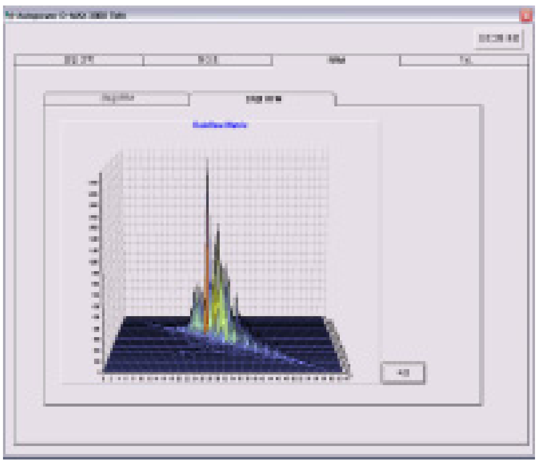

Fig. 3-5 Result of RFM: 3D graph

3.2 Time At Level

By this method, measured signal is allocated to quantized signal level. User can understand the distribution of the signal at a glance. In normal case, measured signal will shape gaussian curve(Figure 3-6). If unexpected signal is measured, the gaussian shape will be distorted and user can imagine the abnormal driving condition which caused the distortion(Figure 3-7). If the gaussian shape is not located in the center of the measuring range, user can understand that sensor calibration or zeroing is not correct(Figure 3-8).

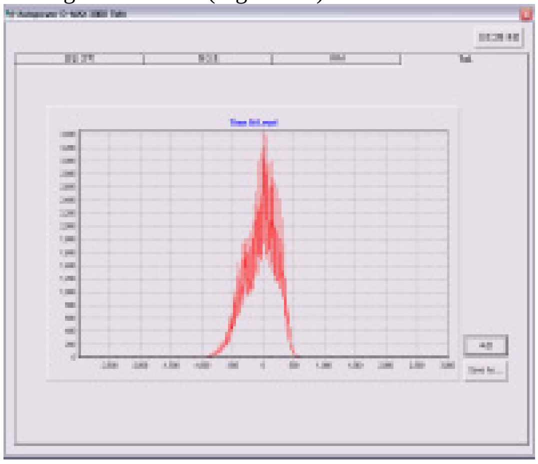

Fig. 3-6 Result of TaL: Normal case

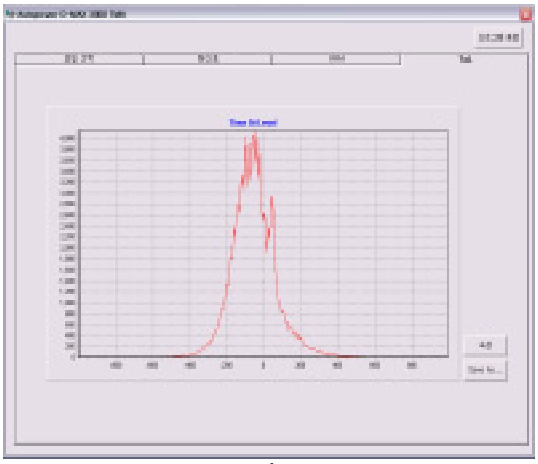

Fig. 3-7 Result of TaL: Spiked signal case

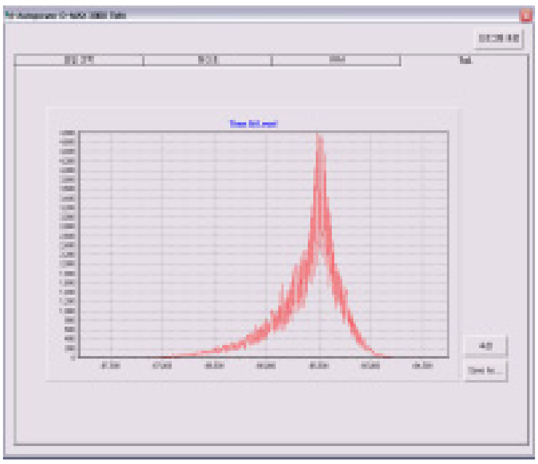

Fig. 3-8 Result of TaL: Biased signal case

3.3 Trigger Mode Logger

Major algorithm utilized in the developed system is the RFM, and the system takes the processing result of the RFM for the measured raw data as mentioned before. Therefore, if user wants to examine the situation by the raw data in accordance with time when specific event is happened, the RFM can not meet user's demand. With Trigger Mode Logger(in short, TM), the system store the raw data of pre-event and post-event for 1~4 seconds respectively if specified trigger condition is met. Results of the TM permit user to perform deepen analysis for the interested events.

Supported TM conditions are as follows:

- Trigger is fired when measured signal level is greater then user-defined trigger level.
- Trigger is fired when measured signal level is within the upper and lower bound of user-defined trigger level.
- Trigger is fired when measured signal level is out of the upper and lower bound of user-defined trigger level.

In Figure 3-9, a sample of the TM is presented. Four channels are trigger-associated and trigger is the first channel. When trigger condition is satisfied(marked as a dark circle in the figure), all raw data of trigger-associated channels are captured for 2 seconds(or 1024 samples if the sampling rate is 512Hz), which means 1 seconds(or 512 samples) for pre-trigger and post-trigger respectively. User can assign maximum trigging time as 4 seconds for pre-trigger and post-trigger respectively.

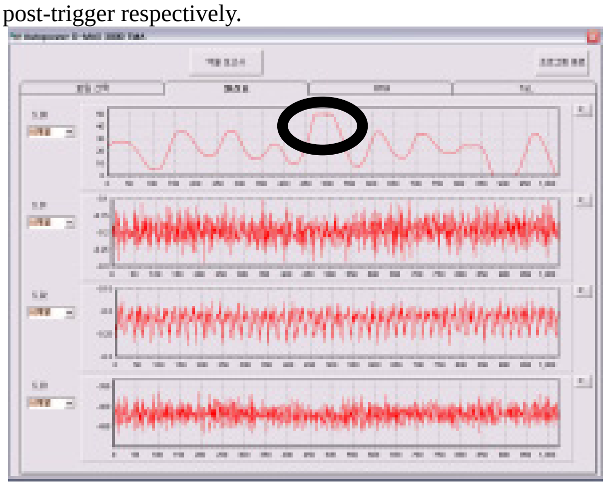

Fig. 3-9 Multiview with trigger source and trigger sourcees

3.4 Accumulated Distance At Level

Similar to Time at level, accumulated distance is allocated to quantized signal level. The result of the algorithm is n*3 matrix, where n is user-defined signal range. With the result, user can see three columns: the first column is lower bound of divided level range, the second column is upper bound of divided level range, and the third column is accumulated distance in meter. For the automobile, this algorithm is specially useful because driver's driving custom is expressed in the distance. That is, dominant signal range of PRM, velocity, inclination angle, and etc. are grisped by the result at a glance.

Secondary signals such as RPM, velocity, inclination angle, temperature, door open/closing count, and gear ratio are treated by the algorithm.

3.5 Handling of Miscellaneous Signals

The system measures temperature of eight points with 1/60 Hz sampling rate. This feature is useful when the variation of the temperature in long-term is examined. Also, the system logs when the automobile is powered on and powered off.

3.6 Association of GPS Information with GIS System

The system stores latitude, longitude, and sea level from GPS information. With the synchronization of the GPS information with measured signals from A/D converter, user can understand driving condition more detail. In Figure 3-10, GPS information such as latitude, longitude, and sea level is synchronized with RPM, velocity, and temperature of mission oil. It is easily known that the car went downhill after 300sec. During downhill, the car is run not by the engine but by the inertia because RPM is so low and the temperature is decreasing after 300sec. With GIS system, user can see the driving course(Figure 3-11). GIS system identifies that the car went and returned a mountain behind Pusan National University.

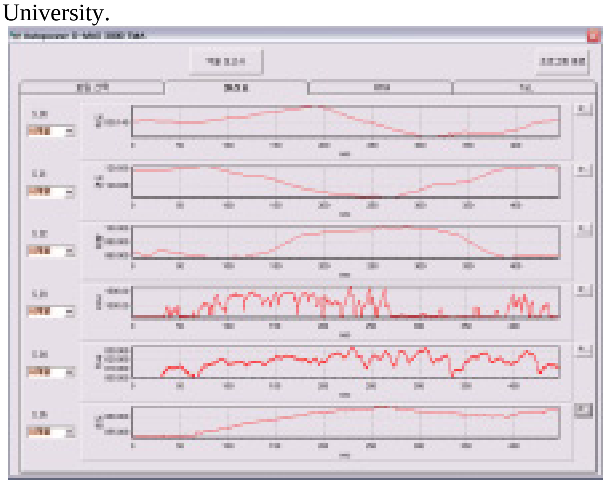

Fig. 3-10 GPS Information synchronized with A/D signals: Latitude, Longitude, Sea level, RPM, velocity, and temperature

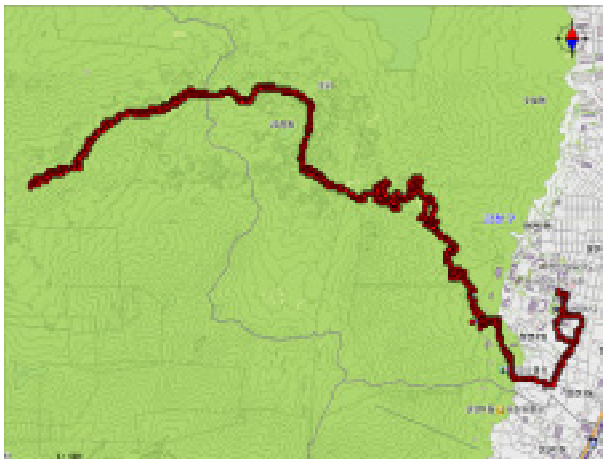

Fig. 3-11 Graphical presentation of GPS information with GIS system

4. EXPERIMENTAL RESULTS

To verify the performance of the system, data measuring and analysis experiment is performed. Hyundai Motor's Santa Fe(Figure 4-1) is selected as target dynamic system. Installed sensors are potentiometer, accelerometer, and strain gage(Figure 4-1, Figure 4-2, and Figure 4-3)

Driving course is a test belgian road in Hyundai Motor's

Ulsan Research Center, South Korea.

In Figure 4-4, system installation is shown.

Fig. 4-1 Test vehicle (Santa Fe, by Hyundai Motor, Korea)

Fig. 4-1 Sensor installation: Potentiometer

Fig. 4-2 Sensor installation: Accelerometer

4.1 Verification of hardware performance

To verify the performance of A/D s board and amplifier board, the test is performed to both developed system and Megadac by Optim Electronics. Megadac is a raw data measurement system used by Hyundai Motor Co.

Figure 4-5 shows the raw data of potentiometer measured by Megadac, and Figure 4-6 shows the raw data by developed system.

Compared Figure 4-5 to Figure 4-6, overall shape of the graph and the variation of the amplitude are almost equivalent.

Fig. 4-3 Sensor installation: Strain gage

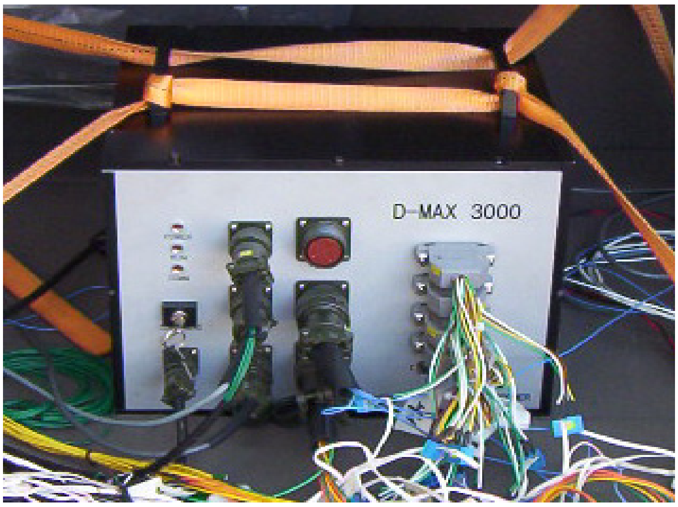

Fig. 4-4 System installation

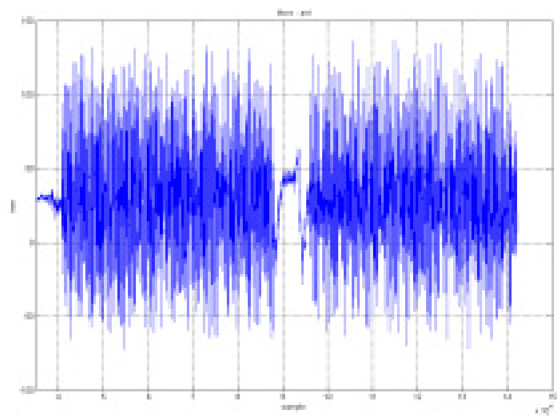

Fig 4-5 Raw data measured by Megadac®

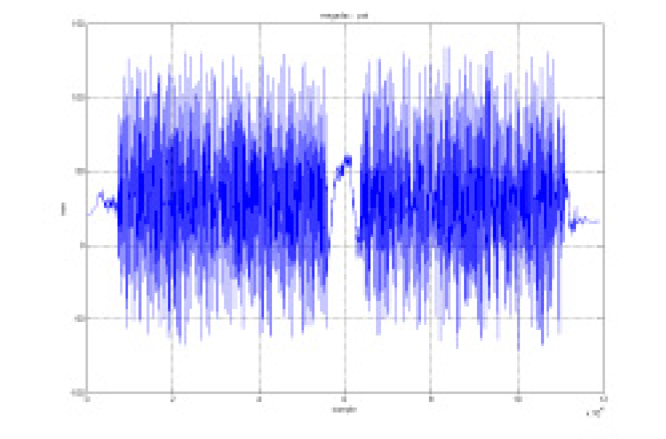

Fig 4-6 Raw data measured by developed system,

4.2 Verification of the algorithms

Compared to nCode-E, algorithms performance is tested. NCode-E is a fatigue analysis package code used by Hyundai Motor Co. As the RFM is a key algorithm, only it is compared between many other algorithms.

Figure 4-7 shows the RFM result for the raw data of potentiometer by nCode-E, and Figure 4-8 shows the RFM result by developed system in 2 dimension. Figure 4-9 is a 3 dimensional representation of Figure 4-8. Compared Figure 4-7 to Figure 4-8 and Figure 4-9, overall shape of the graph and the variation of the amplitude are same. Although nCode-E is executed in the offline and the RFM of developed system is executed in the online, it is remarkable that numerical result of two algorithms are exactly same.

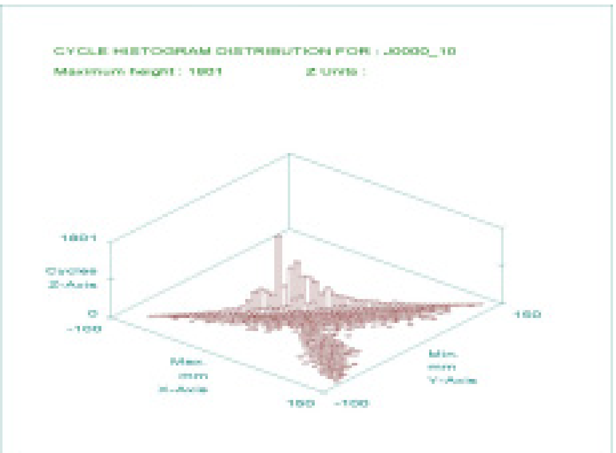

Fig 4-7 RFM result by nCODE-E®

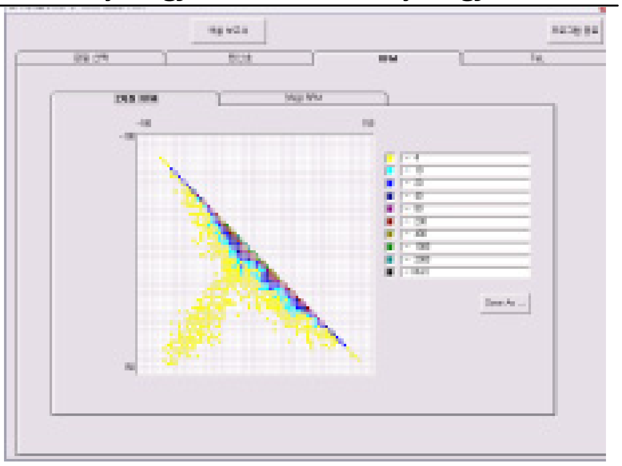

Fig 4-8 RFM result by developed system(2 dimensional)

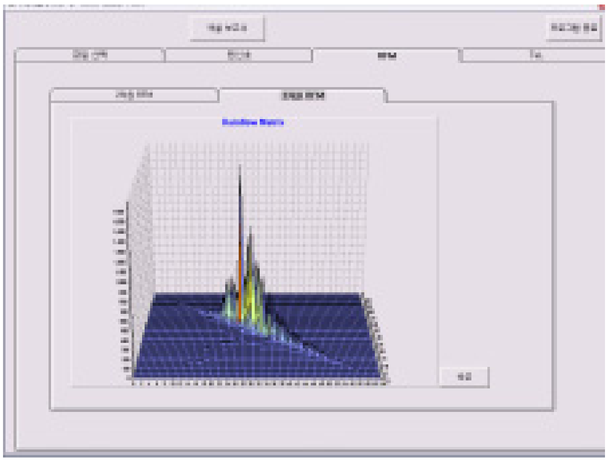

Fig 4-9 RFM result by developed system(3 dimensional)

5. CONCLUSIONS

In this paper, new measurement and analysis system for the durability test is introduced. Not like previous development cases, newly developed system can process both primary and secondary signals effectively to enhance the analysis performance. It is also remarkable that the system can be easily adopted to the industrial fields without any modifications. Compared to the commercial products, the system showed satisfactory performances.

In the further study, following two points are needed to be improved.

1) As the power circuit of the amplifier board is not precise, the system has comparably high noise levels. This problem can be solved by the using of high-precision resistors and linear regulator circuits.

2) To adjust and determine the bridge type of the sensor, user should have to open the system. This is due to the location of the interface parts, which is in the system. By using external bridge box like any other systems do, this inconvenience can be solved.