Noninvasive measuring: Detections of materials and quantities on eddy current testing

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Abstract: We made a simplified eddy-current-tester, and observed some materials for the ingredients and mass and locations. The tester detects the current as frequency shifts of a LC-resonance circuit, which are caused by the eddy currents. Using air-wick coil and a multi-piled ceramic capacitor, we made a resonance system whose frequency was 100KHz. The shift quantity is few; so, to detect it, we used a frequency counter, and counted the shift. We can detect 10Hz order's shift.

Keywords: eddy current, neural networks, non-destruction examination, leaning algorithm, material prediction.

1. INTRODUCTION

1.1 Non-destruction examination

Noninvasive measuring is required for many fields. Nowadays the electronics is advanced, and it makes the measuring be practicable on plural approaches. Many electrical measurements are found; there is an interesting one, "eddy current testing" [1]. It is possible to measure it without damaging the sample. The electromagnetic property is different according to the metal. When the magnetic field is changed on a metal, the eddy current is arisen. The current is affected by the metal-shape and other metal properties. The fact is well known, and it is applied to tests for metal inner-scars.

We believe advantages of the eddy current test on following points:

1. High-speed automatic detections.
2. Measuring possibility for high temperature and fulmination conditions and inside of matters.
3. It is easy to obtain the signal as an electric signal, and to use the result for presumption and the size and the kind of quality controls of the defect.
4. Two or more data like the flaw detection and the material inspection, etc. is obtained at the same time.
5. Data can be preserved, and it is possible to use it for the maintenance inspection.On the other hand, the following are enumerated as a weak point in the eddy current testing.

1. The detection of a deep internal flaw is difficult from the surface.
2. It is easy to receive the influence of a lot of noise factors, vibration, the material, and the dimensional change, etc.
3. It is difficult to distinguish the kind, shape, and the size of the defect accurately.
4. Efficiency is bad for the overall inspection of the specimen of the complex configuration.

The measuring instrument is sold already but expensive. We wished to reduce the principle and to make simplified eddy current testers.

1.2 Functions of multi-layer neural networks

Techniques of artificial neural networks are remarkably developed; and now, the networks are used for various application fields. Multi-layer neural networks have a function to classify observation data. The function is obtained by a process of learning automatically. After the learning process is completed, the networks have also a function that interprets non-linear relations between observations and the consequences [2].

2 EDDY CURRENT MEASURING DEVICE

2.1 Outline

The eddy current measuring device detects frequency-changes of an oscillation circuit and outputs them. When alternative currents are going around a coil, the coil emits variable magnetic-flux to targets. The flux causes the eddy currents on the surfaces of the targets. The currents are affected by scars and shapes of the targets. They are variable on the temperatures also. The inductance of the coil changes by changing of the eddy current. In a word, the situation of the metal could understand by changing of the inductance of the coil. This equipment is LC circuit. The oscillation frequency changing of the circuit is used to indicate the changing of the inductance of the coil.

2.2 Measurement details of eddy current measuring device

The principle of our instrument is followings:
A circuit constructed of a coil and condenser makes a resonator. It has proper frequency and the coil makes magnetic field. If there were a metal nearby the coil, the eddy current would be arisen in it. The current affects impedance of the coil, and the frequency is shifted slightly. The shift shows properties in the metal. Making of a resonator is not so difficult. We adopted the oscillating frequency be 100kHz. To measure the small change surely, we make the frequency waves to binary on use of Schmitt-trigger circuits, and count up the binary waves by PIC-micro-computer. At the start timing, a counter in the PIC is reset, and the binary wave numbers are accumulated on the counter during unit observation term. The term is set as 2 seconds. The counter value of the first observation is stored on a register as the reference. Counter values of next and later observations are compared with the register value, and the difference is converted by DA-converter of 8 bits, and the analogue voltage output is recorded. The eddy current testing is done at a point and timing. It is insufficient to detect materials, shapes, and scars of subjects. We call them "subject properties". To get sufficient information for estimations of the properties, we moved the subjects on a rotation board, and stored the output voltages in a data-logger. The voltages relate to intensity of the eddy currents. It includes information of the subject properties.

3 EQUIPMENTS AND NEURAL NETWORKS

3.1 Experiment device

We used following experiment devices.

1. An eddy current measuring device (Fig.1).
2. An equatorial telescope, GP-E (aluminum casting), and the controller, Sky-Sensor 2000PC that are produced by VIXEN CO.Ltd (Fig.3). The equatorial telescope has two motors that are controlled by the controller. The controller is driven via RS-232C by a personal computer. The speed around the latitude is set as 0.145 [deg./s].
3. Sensing coil: outside diameter is 50[mm], inside diameter is 35[mm], and thickness is 5[mm] (Fig.2). The specification of the coil is that: rolled 200 times, line diameter 0.3mm, and it's inductance 2.5[mH].
4. Voltage data logger, VR-71, produced by T and D CO. Ltd (Fig.2).
5. Measurement objects are three kinds of metal washers. Their materials are stainless, electric galvanizing iron with high/low chemical composition ratio of chromic acid chromium. The diameter of the washer is 20[mm], and the thickness is 1 [mm], and the aperture 4.3[mm]. These washers are sticked on a disk of the polyvinyl chloride, whose thickness is 1[mm], and the diameter is 280[mm].

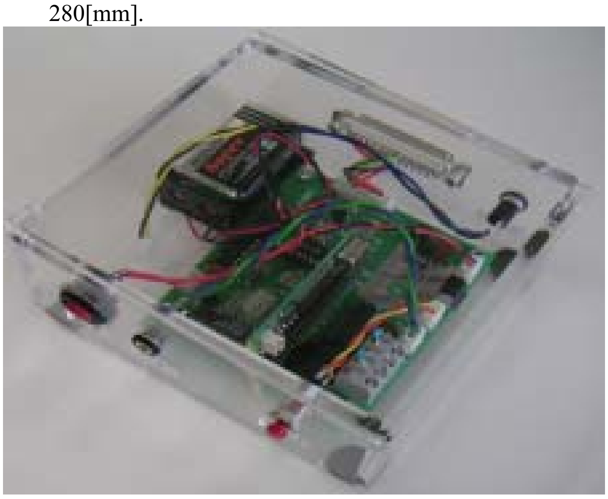

Fig.1 Eddy current tester

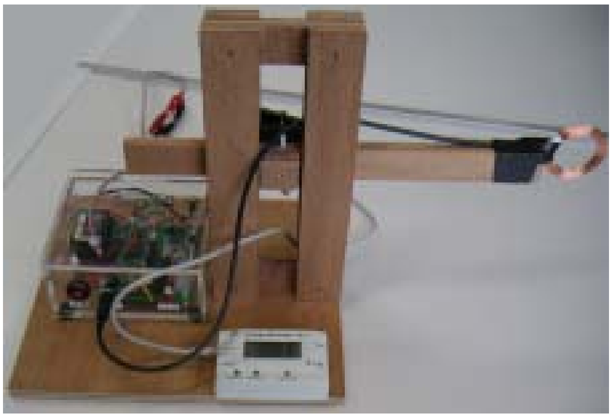

Fig.2 Stand of emission coil, and a voltage data-logger to detect amplitude of the eddy current.

Fig.3 A rotator, remodeling of an equatorial telescope: The rotation speed is controlled by PC. The transparent plastic disk is rolled around the equatorial axis, where samples are set on the disk.

3.2 Neural network structures

Our used neural network structures are followings.

1. Three-layers network, and the number of neurons: 8, 4, 1 for input-, hidden-, and output-layers. One neuron on input-layer is the bias-neuron. Other two neurons on the layer correspond to two detectors. Two neurons on output-layer indicate x-and y-coordinates.
2. Operation functions of neurons on the hidden-layer are all sigmoid functions, $f(x)=1/\{1+\exp(-x)\}$, and those of the output-layer are linear-functions. This type is often called “analogue type neural network.” The characters are rapid learning and suitable to analogue outputs.
3. The learning coefficients of the BP-learning are 0.15 and 0.1 for the hidden- and output-layers, which are determined empirically. The numbers of BP-learnings are 50, 100, 200K iterations.
4. It is a very difficult problem how to examine the prediction functions of learned neural networks. In case of small data set, “leave-one-out” method for the examination is known. The method was derived in the multi-regression approach; however, it is expanded to predictions on the neural network. We used it and calculated the standard deviations between exact values and results from the leave-one-out method.

Fig.4 Whole measurement equipments.

4. EXPERIMENTS

4.1 Estimations of materials and distance of metal chips.

In this experiment, the difference by the measurement distance and the difference by the kind of the sample are examined. We experimented from 10 to 55mm. The measurement interval is 5mm. We measured three kinds of metals. We used stainless, electric galvanizing iron with high/low chemical composition ratio of chromic acid chromium.

1. The sample is set on the disk.
2. The device is set in the measurement distance.
3. The eddy current measuring device is reset. When the eddy current measuring device is reset, it becomes a reference voltage. The reference voltage is decided depending on the frequency when the eddy current measuring device is reset.
4. Bigins the measurment after setting up the voltage data logger. The voltage data logger writes down a datum every second of data register. The disk where the sample was put is turned by the equatorial telescope. The equatorial telescope has the control computer. The equatorial telescope control computer is controled by PC to send the control command. PC and the equatorial telescope control computer are connected by RS-232C. We used RS-232C communication program “MOTHER2” [3].
5. When the disk turns to the place in which it scheduled it, the rotation of the data logger and the disk is stopped. In this experiment, data within the range of about 90° is collected. It experimented so that the sample might come to the center.

The above-mentioned 1.-5 is a flow of the experiment. We changed the kind of the sample and the distance of the measurement coil and the sample, and repeated the above-mentioned 1-5. In this experiment, operation of the sample's approaching the coil and parting is taken. In rough data, the center is growing shape. It seemed that the data to 40mm-55mm exceeded the measuring limit of the eddy current measuring device. Therefore, the data to 10mm-35mm was used for the following analyses. We made an integral value, a half breadth, and the maximum value from the data of this experiment. The integral value took the integration for 140 samples at both ends by centering on the maximum voltage. The half breadth is a number of samples to take half the value of the maximum value and minimum value. The maximum value is a difference between the reference voltage and the maximum voltage. Three of these are input to the neural network program.

4.2 Experiment method: Detections of samples locations

In this experiment, the voltage change by a positional change of the measurement sample put between standard samples is measured. This standard sample and measurement sample used the same one. The material of the metal used is electric galvanizing iron with low chemical composition ratio of chromic acid chromium. The distance of the coil and the disk is 1.5cm. About the arrangement of a standard sample. A standard sample is put at the measurement starting point and the measurement end point. It arranged it from the center of the disk onto the circumference of 120mm. The central angle degree of a standard sample is 60°. We made a right edge of the measurement coil a measurement beginning point come to the left end of a left authentic sample. We made the left end of the measurement coil a measurement end point come to a right edge of a right authentic sample. Put the sample of determining on the mid point with half the arcs of basic sample. We define it as the 1(Fig.5). 1’ places of 10mm in interval above 1. 1” places of 10mm in interval above 1. What applied to the left end of a right authentic sample is assumed to be 3 on the same circumference as a standard sample. 3’ places of 10mm in interval above 3. 3” places of 10mm in interval above 3. The one between 1 and 2 was assumed to be 2. 2’ places of 10mm in interval above 2. 2” places of 10mm in interval above 2. The flow of the experiment is almost the same as experiment 4.1. Difference between experiment 4.1;

1. The measurement distance fixes to 15mm.
2. Measurement beginning point and measurement end point.

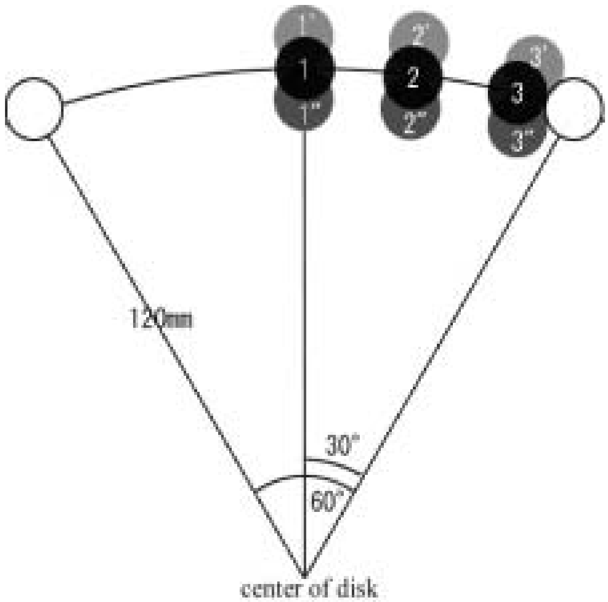

Fig.5 Configurations of samples (washers).

4.3 Examinations of prediction ability of neural networks

The number of observations is rather small, which is not sufficient to make statistical processing. In such a case, as an examination of predictor, leave-1-out method is proposed. Principle of leave-1-out method is simple; that is followings.

1. One datum is left from the examination assemble.
2. The remains are learned by a network.
3. The exclude datum is inputted to the network, and the difference between the output and excluded observation is calculated.
4. The above scheme is repeated on every numbers of data.We used the leave-1-out method, calculated standard

deviations of the differences, and made them an index of the judgment.

5 EXPERIMENTS RESULTS

5.1 Estimations of distance of metal chips.

We show the output voltage of each distance that uses three kinds of metals below (Fig.6~8).

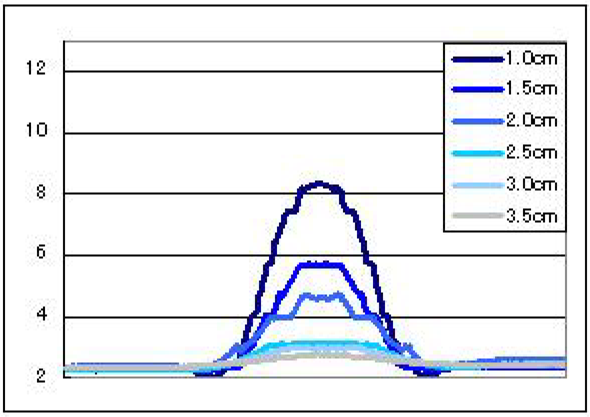

Fig.6 Measurements of an eddy current tester; for detections of distances from objects: The unit of vertical axis is voltage [V], the unit of horizontal axis is numbers of data, and the objects are electric galvanizing iron with low chemical composition ratio of chromic acid chromium.

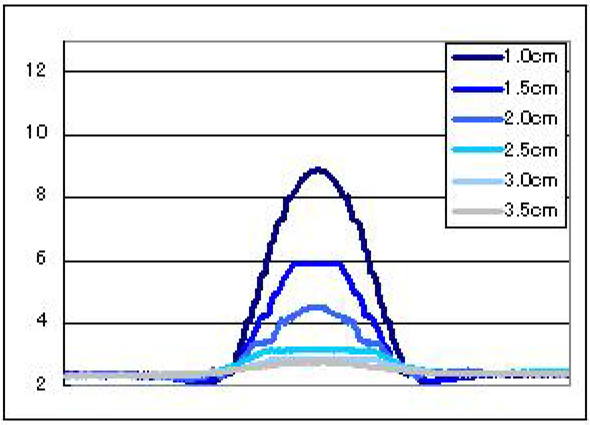

Fig.7 Measurements of an eddy current tester; for detections of distances from objects: The unit of vertical axis is voltage [V], the unit of horizontal axis is numbers of data, and the objects are electric galvanizing iron with high chemical composition ratio of chromic acid chromium.

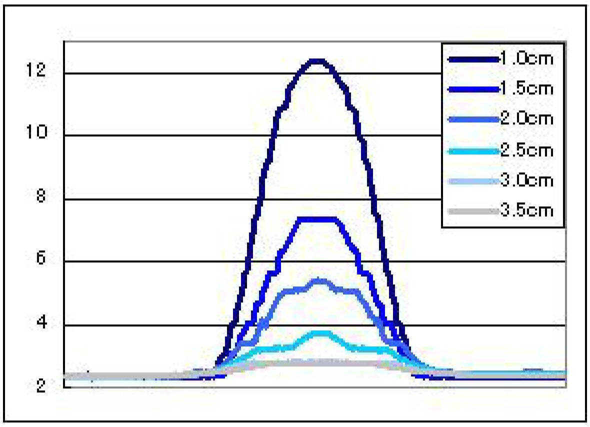

Fig.8 Measurements of an eddy current tester; for detections of distances from objects: The unit of vertical axis is voltage [V], the unit of horizontal axis is numbers of data, and the objects are stainless steel.

It is understood that there is a difference in the output voltage according to the difference of the material and the difference of the distance. Next, we calculated the integral value, a half breadth, and the maximum value from the data of this experiment, and studied by the neural network. The study result is shown below.

Table 1 Predictions of the leave-one-out method for multi-layer neural networks: The column means the number of input data, the datum is left out of NN learning. The row indicates the number of BP-iterations for the NN.

	50k	100k	150k	200k
1	0.050897	0.023844	0.008192	0.001394
2	0.045903	0.017595	0.007642	0.005324
3	0.243165	0.15841	0.052014	0.040818
4	0.0139	0.003012	0.030038	0.041349
5	0.025211	0.028287	0.022358	0.021148
6	0.137282	0.156117	0.176855	0.186754
7	0.103317	0.048061	0.004635	0.011647
8	0.045732	0.057368	0.045075	0.041692
9	0.089951	0.105479	0.135783	0.177266
10	0.135498	0.086479	0.023964	0.03768
11	0.124976	0.188202	0.197698	0.197225
12	0.006311	0.010672	0.011053	0.022838
13	0.0745	0.066742	0.06599	0.070945
14	0.097124	0.087694	0.086915	0.088147
15	0.058223	0.069652	0.094988	0.125453
16	0.068702	0.041179	0.009676	0.016525
17	0.110372	0.103408	0.094051	0.085942
18	0.28951	0.238221	0.244164	0.248911

The prediction error ratio were 7% (averaged), which was got from 150K learning-iterations. On the predictions, we are sure that the NN forecasts distances of objects.

5.2 Estimations of materials

Now, we are analyzing them.

5.3 Detections of samples locations

We analyzed 4.2 experiment results. We used the first data of experiment 4.2.We tried to detect the locations of a sample. By an eddy current tester, the locations were observed as the difference from two references. About distance L. This distance L is a number of experimental data. The experimental data is taken every second. Moreover, the disk where the sample was put rotates at a constant speed. Therefore, the number of experimental data can be treated as distance L.

The references are washers same as the sample, and their interval is set as L=470. The sample's locations are set as L=235, 315, 395, where the three tests are written as C1, C2, C3. Our objective is to detect the sample's locations in C1-3 tests. Amplitudes of the eddy current are shown in Fig. 9.

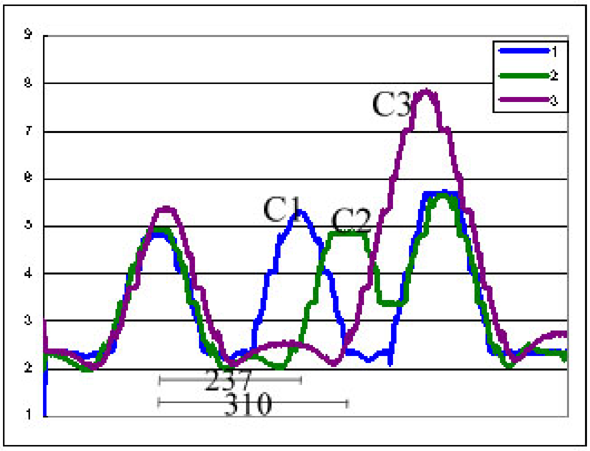

Fig.9 Measurements of an eddy current tester; for detections of samples locations: The unit of vertical axis is voltage [V], the unit of horizontal axis is numbers of data, and the arrangement methods of samples are 1, 2 and 3. (Fig.5)

C1, 2, 3 are test names. The both side's peaks are that of references, and a center peak is the sample's peak. Sample's locations can be detected by the peaks. The error are +2,-5 those are rather small and are acceptable. However, in case of the C3 test, the sample's and reference are merged. To separate the merged peak, we make reference's peak graph, that is in figure 10.

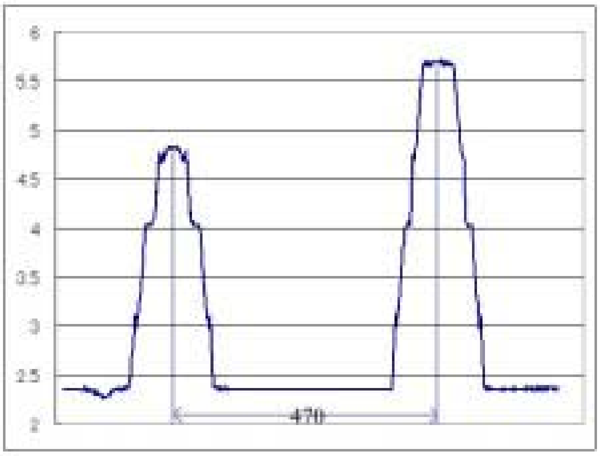

Fig. 10 The reference's peak curve. The unit of vertical axis is voltage [V] and the unit of horizontal axis is numbers of data.

This is calculated from C1 test.
So, we subtract the second peak of reference curve from C3, and get Fig. 11.

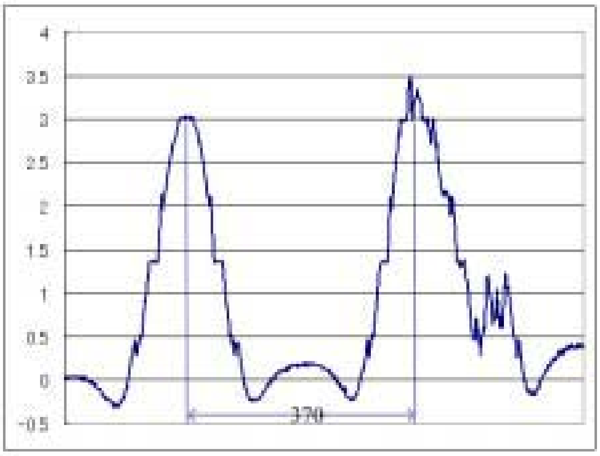

Fig. 11 Separated curve of sample. The unit of vertical axis is voltage [V] and the unit of horizontal axis is numbers of data.

From the separated peak, we get the location as 370 whose error difference is –25 from the expectation. 1 counts in distance L means 0.1276[deg]. 1[deg] means 2[mm] on circumference. So 1 count means 0.2552[mm] on circumference. In C1 result, +2 count error means 0.5104[mm] error on circumference. It is 0.4% error. In C2 result,–5 count error means 1.276[mm] error on circumference. It is 1% error. In C3 result, –25 count error means 6.38[mm] error circumference. It is 5% error.

The measurement result of the remainder is shown below (Fig.12~13).

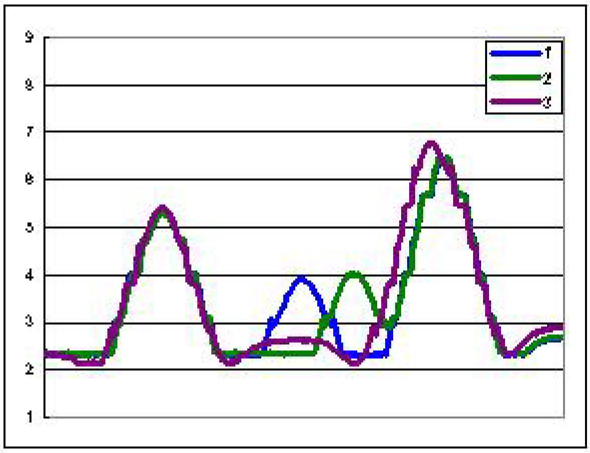

Fig.12 Measurements of an eddy current tester; for detections of samples locations: The unit of vertical axis is voltage [V], the unit of horizontal axis is numbers of data, and the arrangement methods of samples are 1', 2' and 3'. (Fig.5)

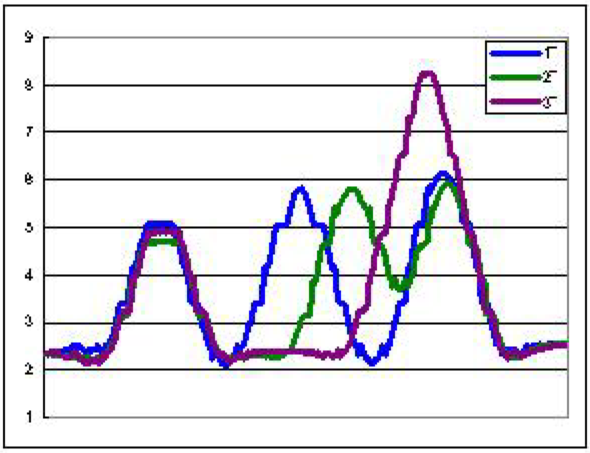

Fig.13 Measurements of an eddy current tester; for detections of samples locations: The unit of vertical axis is voltage [V], the unit of horizontal axis is numbers of data, and the arrangement methods of samples are 1", 2" and 3". (Fig.5)

We similarly analyzed the data of the remainder of experiment 4.2 (Table 2).

Table 2 Results of detections of samples locations

	C1	C2	C3
First experiment 4-2	0.4%	1.0%	5.0%
Second experiment 4-2	2.0%	0.9%	1.0%
Third experiment 4-2	0.6%	1.5%	1.5%

6 CONCLUSIONS

We made a simplified eddy-current tester as a noninvasive measuring, which is constructed of a magnetic-flux-emission coil, a resonance circuit, a frequency shift counter, a converter between the count and voltages. Detection sensitivity of frequency shifts of the tester is 10Hz/100KHz, and the sensing distance of the coil is 3.5cm. It is not so sensitive, but we satisfy the ability as a tester made by ourselves. Next, we made equipment for automatic noninvasive measuring, which were voltage-data-logger and controllable rotator that was remodeling of an equatorial telescope. We used PC-RS232C interface for the rotation controls. Then, we observed distances or locations of objects that were made by iron or stainless. The detection error averages were about 7% or 2% for the distance and locations.

We can show a simplified noninvasive measuring, by using an eddy current tester. We believe two possibilities for detections of materials or more precision location determinations.

So, we are revising the equipment.

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