Introduction of nugget profiler

Make 10, June, 2010

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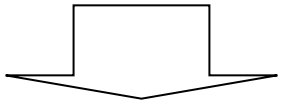
Nippon Kouatsu Electric Co., Ltd.

1 . Background

Quality control of the conventional spot welding,
-Guarantee of quality => Breaking test
- Quality identification => Driver check (DC)

The inspection method replaced with this Driver check (DC) is proposed.

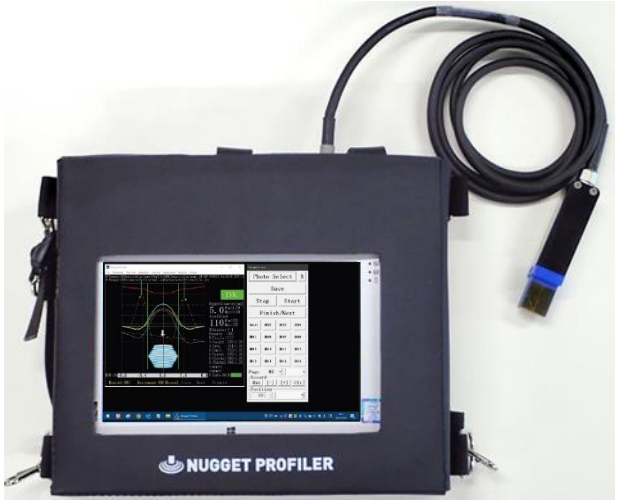


Practical application of non-destructive inspection using magnetism.

2 . What is a Nugget Profiler?

Important

A machine to inspect spot welds using magnetism.



Features:

1.A nugget can be quantified.

2.Needs no gel, water or other medium.
(Ultrasonic method requires some medium such as gel or water.)

3.Can distinguish between nugget and cold-joint (pressure weld).

4. A sensor is applied lightly and inspected.

5. The inspection speed is around 4 seconds per weld point.

6. Automatically save results to electronic file (traceability).

7. The powered is a battery.

It is an inspection machine
which can quantify the nugget of spot welding easily.

It is possible to check whether welding at the same position maintains constant quality

3 . Merit of Nugget Profiler

Important

-Performs inspection giving no external damage to the subjects.

-It can inspect even high-tensile steel.

-It has the function of quality traceability

(Automatically save results to electronic file).

<The problem of a driver check>

-usually steel (270MPa,440MPa) : A bend arises around a nugget and metal fatigue occurs.

-high-tensile steel (770MPa or more) : It cracks on a nugget or the outskirts of it. For the reason, welding intensity falls.

4. Purpose of introducing nugget profiler

Important

Common case

Conditioning
- Welding conditioning
- Tip change interval
- Welding gun teaching

→ Manufacture
- Perform welding

→ Ship

Proposed use

Build a PDCA cycle for stabilizing and improving shipping quality

Conditioning (Plan)
- Welding conditioning
- Tip change interval
- Welding gun teaching

→ Manufacture (Do)
- Perform welding

→ Inspection (Check)
- Confirm quality stability

Extraction of instability

→ Ship
- **Quality improvement**

Feedback (Action)
- Improvement of conditions

Discovering large fluctuating welding spots
⇒ Stabilize the process

5. Use (the purpose of the equipment)
5.1 .Applicable cases

This equipment quantifies (measures as numeric values) the quality of the areas formed by spot welding.
Its purpose is to confirm that the quality of the spot welding is of a sufficiently high level.
Note: The equipment is used in a comparative inspection with the breaking test.

	Cutting test		Cutting test	
		 …		 …
Common case	Item Breaking diameter measurement Standard e.g., $4\sqrt{t}$ [mm]	Item Driver check Standard No peeling off	Item Breaking diameter measurement Standard e.g., $4\sqrt{t}$ [mm]	Item DC
Proposed use	Item Breaking diameter measurement Standard e.g., $4\sqrt{t}$ [mm] + Item Measurement as numeric values with the NP	Item Measurement as numeric values with the NP Standard Comparison of the values with those of the breaking test - Unchanged: the quality is stable. - Changed: the quality fall-off is understood quantitatively by the difference of values.	Item Breaking diameter measurement Standard e.g., $4\sqrt{t}$ [mm] + Item Measurement as numeric values with the NP	Item NP

5 . 2 . Applicable cases - continuation

Plotting the inspection file described on the previous page (plot software is included in the profiler) reveals the following:.

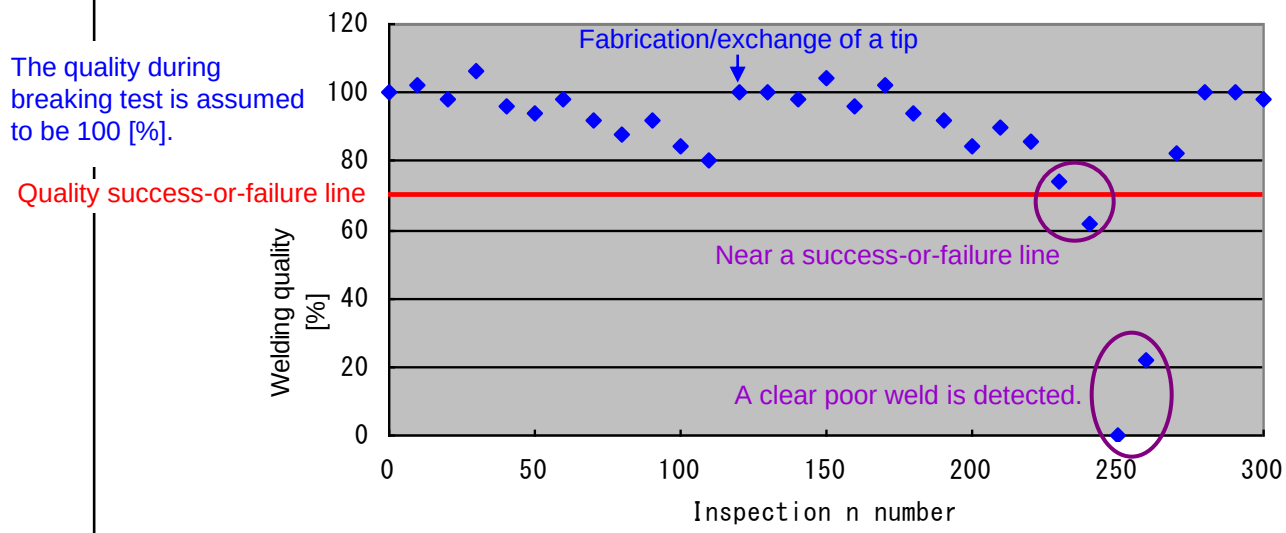
(1) If the value deteriorates: A welding defect has occurred.
(2) If the value significantly fluctuates: The process (welding condition) is unstable.
- Cause 1: The weld gun is at an angle to the steel plate
  ⇒ Improve the angle through teaching.
- Cause 2: There is a gap between steel plates.
  ⇒ Eliminate the gap by plate positioning.

- Note: The above function can be used for checking whether the process is stable in addition to detecting defectives.

(Further, it can be used as a guide for teaching operation.)

Example of applicable facility

***** The quality change to the n number of the same positions is managed.



* This equipment serves as a relative value inspection from a breaking test time.
Since it is not an absolute value inspection, the diameter of an output of equipment has differed from the diameter of an absolute size.

It is necessary to associate "The value which this equipment expressed quantitatively" and "The actual diameter of welding " at the time of a breaking test.
It is carried out by parameter setting.

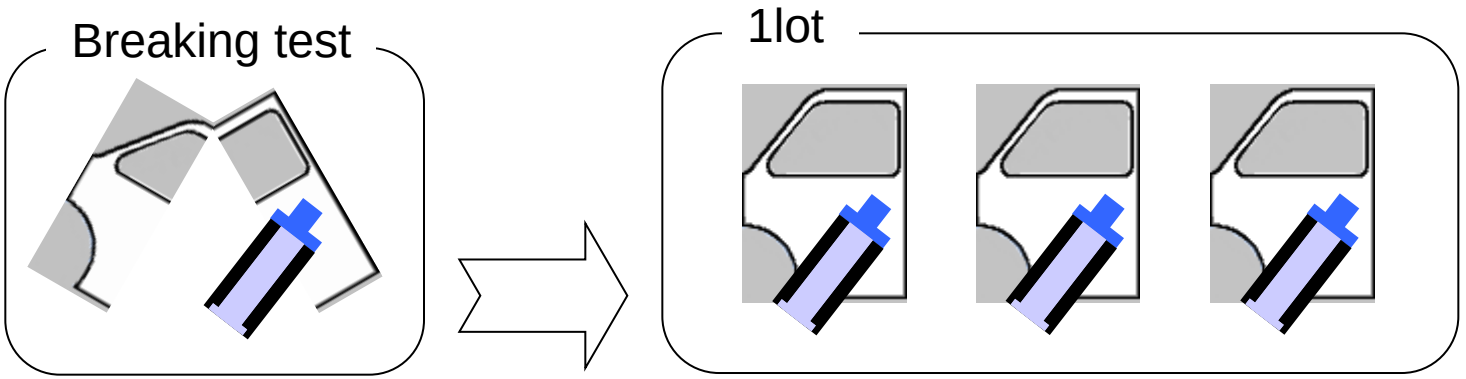
5. 3 . Applicable cases – shipping inspection

The nugget profiler can be used at parts companies.

(1) All parts in a production lot are quantified: Variations in the lot can be confirmed.

(2) Then, a single piece can be sampled out of the lot and subjected to breaking test to assure the quality.

Note: The outflow of defective parts can be prevented.
(Parts other than those subjected to breaking test can also be checked for quality.)

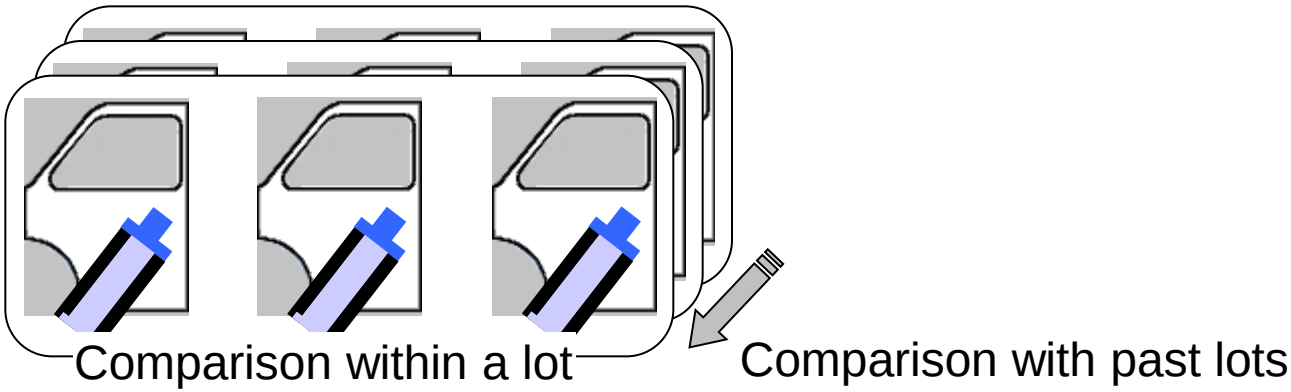


5. 4 . Applicable cases - acceptance inspection

The nugget profiler can be used at acceptance sections.

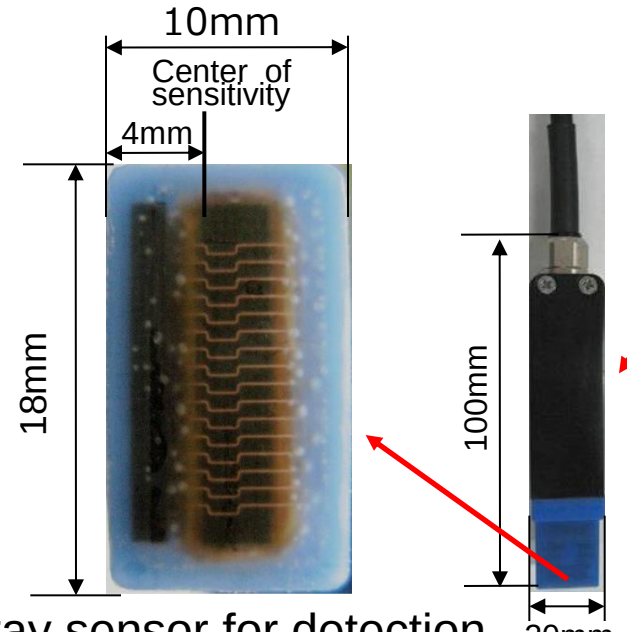
Comparison within a lot : The parts in a received lot are checked for whether they have the same quality.

Comparison with past lots : A received lot is checked for whether it has the same quality as the past lots.

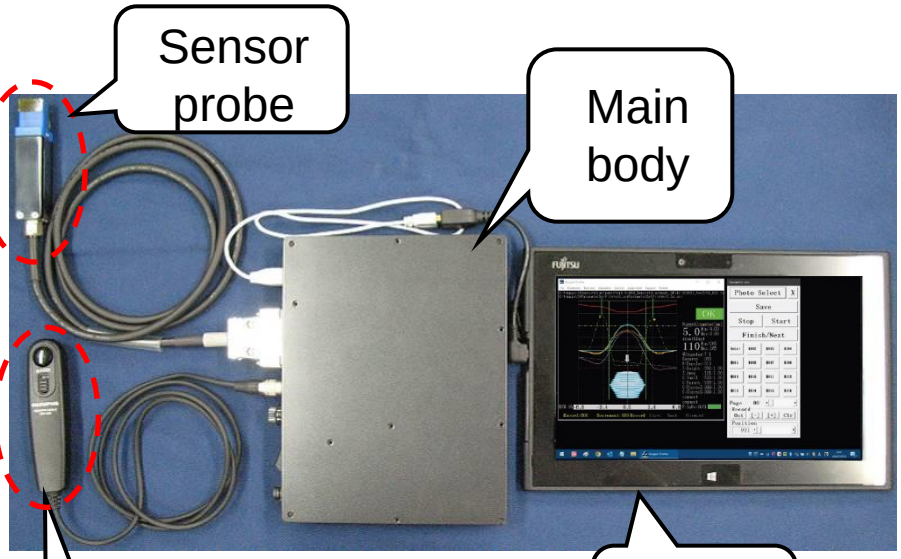


6 . Equipment composition

This equipment is composed of the following four parts.
-Main body (including PC) : hardware control, function of preparation of exciting voltage pattern.
-Tablet PC : data analysis and man machine IF functions.
-Sensor probe : generating magnetic flux and data acquisition functions.
-Handy switch : trigger function of inspection data recording.



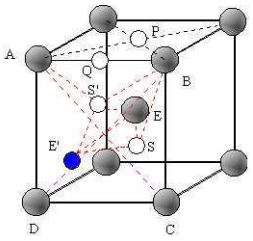
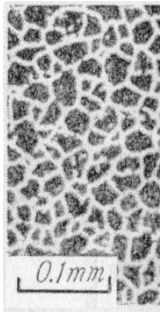
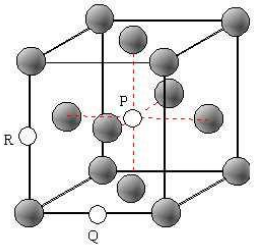
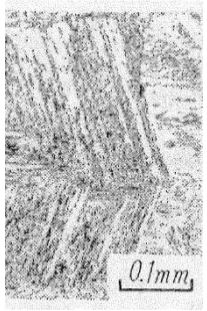
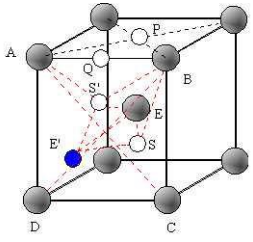
Array sensor for detection (Qty.16)



7. Change in steel materials

Important

7.1. Change in phase by steel material temperature

Item	Ferrite phase	Austenite	Martensitic phase
SEM image and crystal structure	 	 	 
Charac-teristics	• Room-temperature crystal structure • Body-centered cubic lattice crystal structure • Soft • Ferromagnetic (strongly attracted by a magnet) = **Low magnetic resistance**	• High-temperature crystal structure • Face-centered cubic lattice crystal structure • Excellent toughness and ductility • Non-magnetic (not attracted by a magnet)	• Dense needle crystal structure • Body-centered cubic lattice crystal structure • Hard but brittle • Paramagnetic (weakly attracted by a magnet) ＝**High magnetic resistance**

Current

Temperature **rise**

Water current

Temperature **quench**

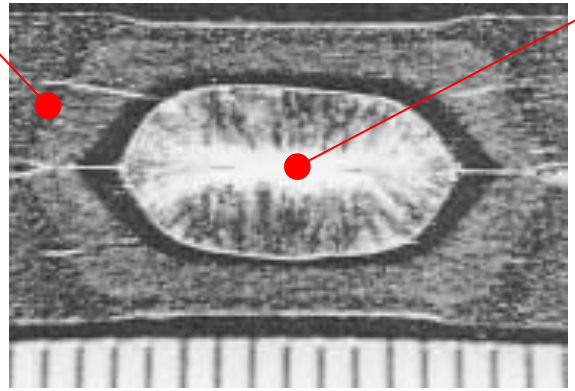


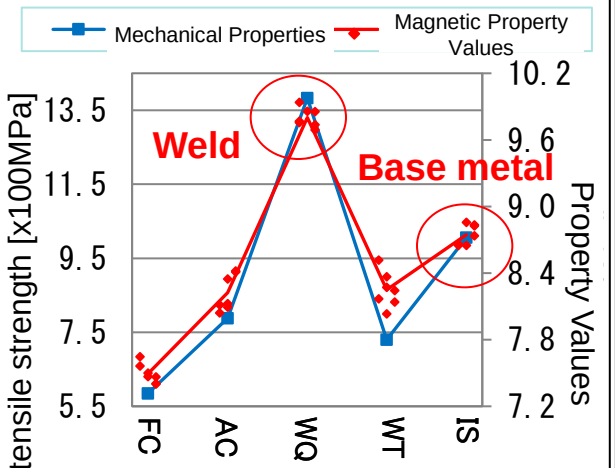
Figure: Photo of weld cross section

7.2. Change in magnetic properties accompanied by quenching steel materials

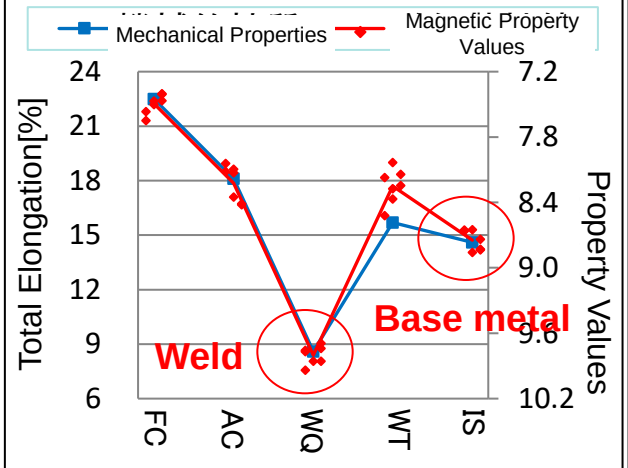
Important

Table 7.1: A list of heat-treated specimens

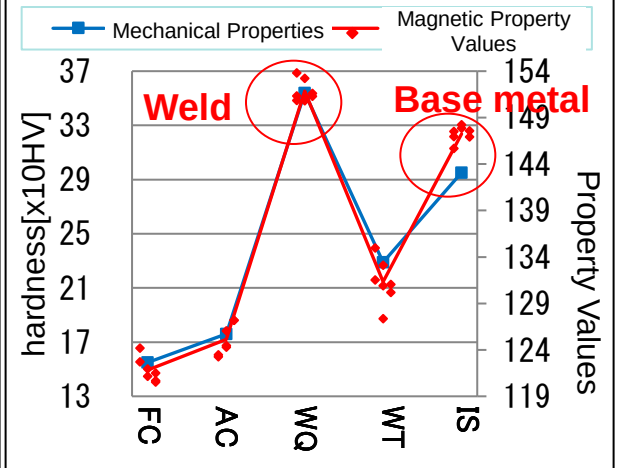
Name	Description of Process	Tensile Strength[MPa]	Total Elongation[%]	Hardness [HV]
FC	1000°C (5 minutes) + **furnace cooling**	585	22.5	155
AC	1000°C (5 minutes) + **air cooling**	788	18.1	176
WQ	1000°C (5 minutes) + **water cooling**	1383	8.6	354
WT	1000°C (5 minutes) + **water cooling + 600°C (15 minutes) + air cooling**	730	15.7	229
IS	**No treatment** (intact)	1006	14.6	295



7.1: The relationship between tensile strength and property values



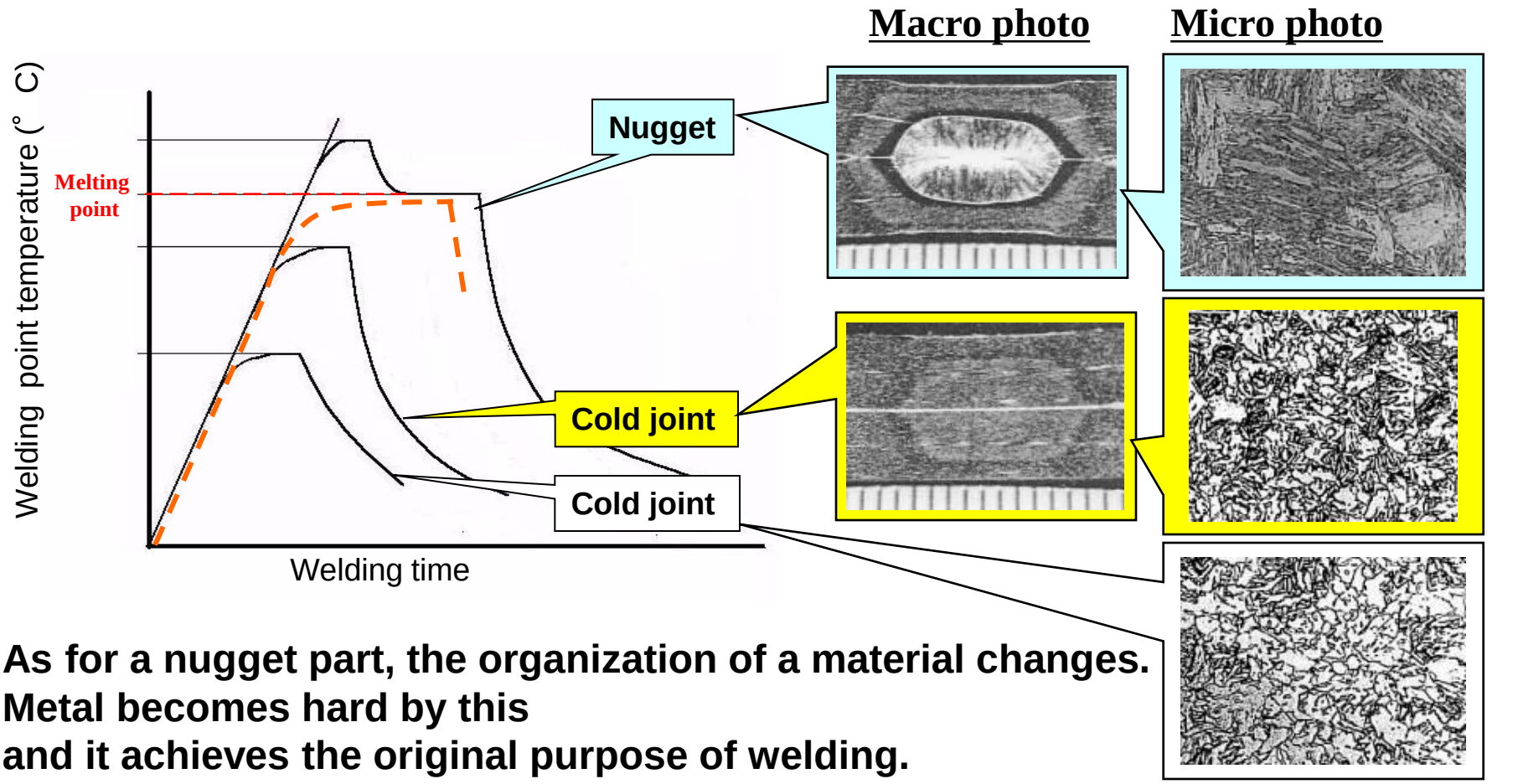
7.2: The relationship between total elongation and property values



7.3: The relationship between hardness and property values

There is a high correlation between [mechanical property (blue)] and [magnetic property (red)].

8 . Macro photos of nugget and cold-joint



As for a nugget part, the organization of a material changes.
Metal becomes hard by this
and it achieves the original purpose of welding.

⇒Nugget parts decrease in magnetic permeability (the amount of emergence of magnetic flux density) due to the martensitic transformation (transition, carbon over-saturation, etc.) in the structure.

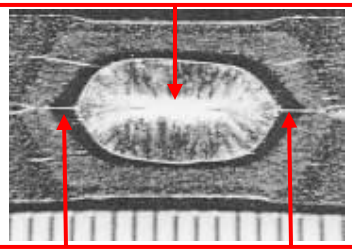
This equipment is inspecting magnetically using this characteristic.

9.Inspection theory outline and sensor structure

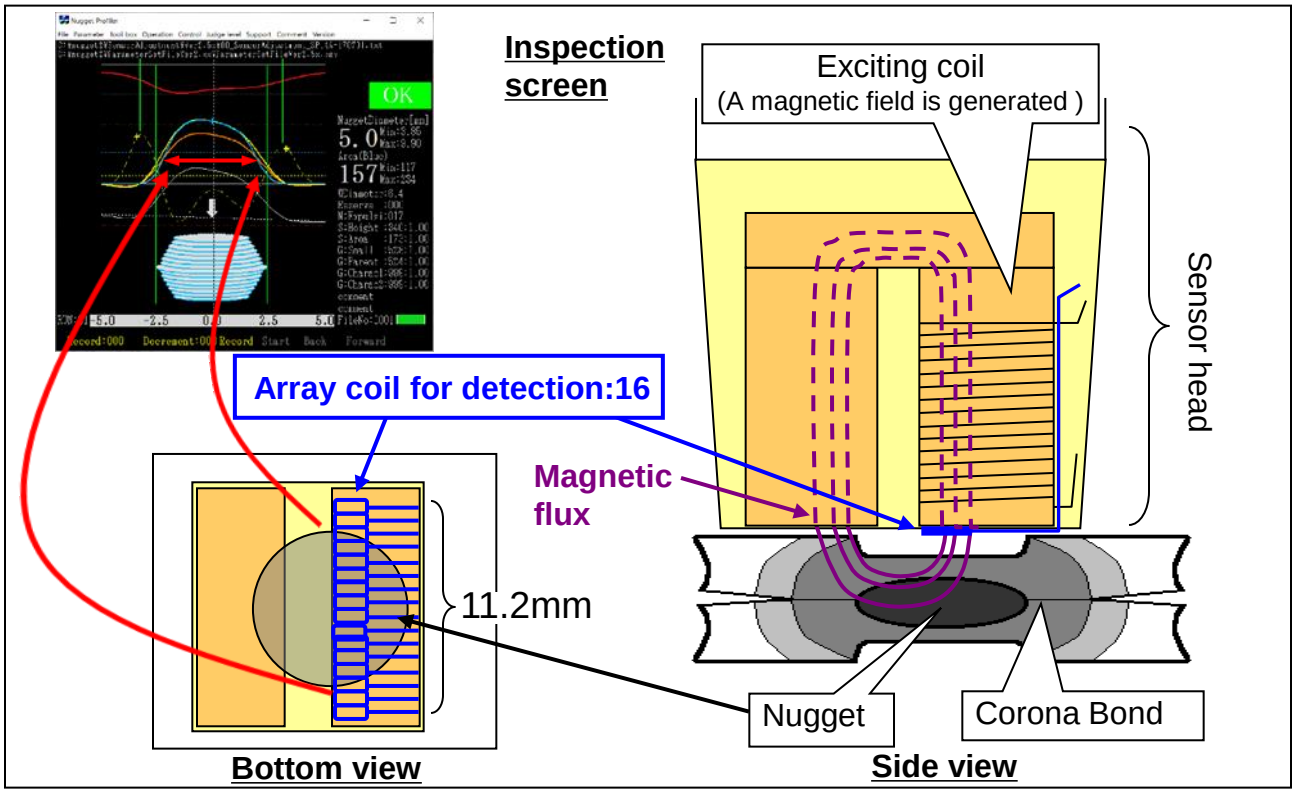
Know-how

The magnetic sensor contains two types of coils:
(1) Exciting coil: Serves as an electromagnet, which produces magnetism.
(2) Sensing coil: Converts produced magnetic flux into electrical signals, which are then sent to the device.
It obtains difference in magnetic resistance between the weld and base metal using 16 detection coils and plots it on a waveform chart.

[Nugget]
Magnetic resistance = High



[Nugget circumference]
Magnetic resistance = Low



Coil requires welded part (indentation) + two pieces on left and right side (base metal part)

10 Comparison of welding

Important

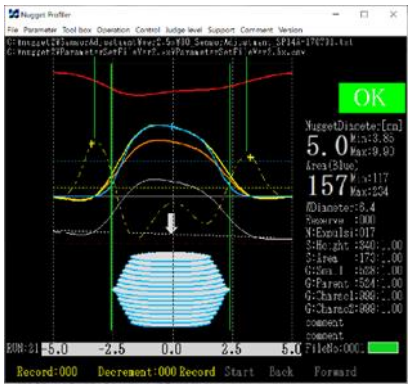
10.1 Comparison of welding quality and inspection result values

The red circle between the two sheets in the figure below indicates the part whose magnetic permeability has actually become low.
The inspection results show that the obtained curve varies depending on the welding quality.
Therefore, it is required to control not only the diameter but also the curve size.

Good

Part whose magnetic permeability has become low

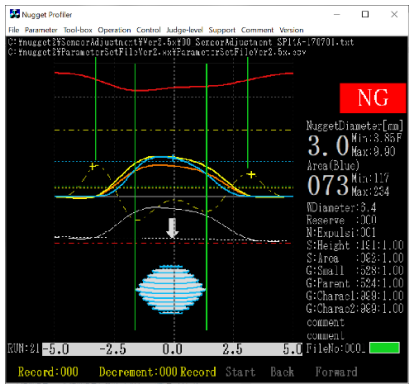
Inspection diameter: 5.0 mm
Curve area: 130



The curve height becomes lower.

A little too thin

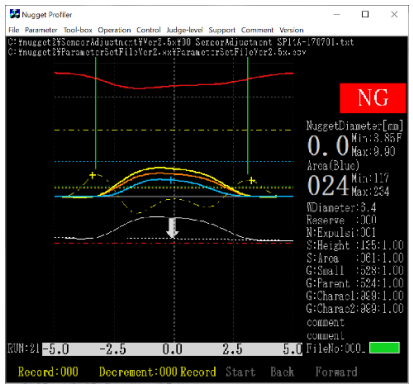
Inspection diameter: 3.7 mm
Curve area: 57



The curve height becomes lower.

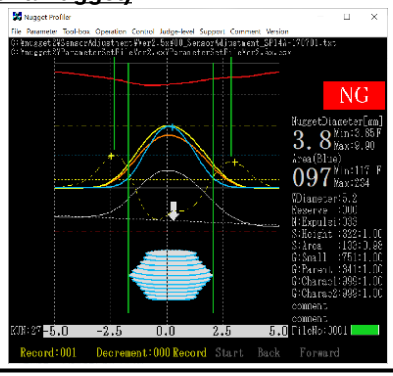
Cold-joint

Inspection diameter: 0.0 mm
Curve area: 00



The curve width becomes narrower.

A little too small diameter (with a nugget)



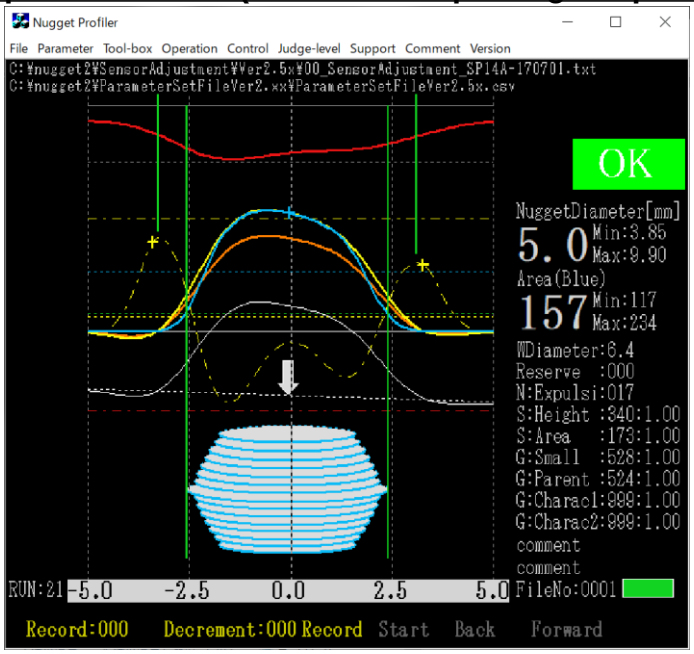
10.2 Determination of pressure welds and nuggets

Based on the detected values obtained in the previous page, the analysis result (inspection wave form) is shown below in inspecting the NG product (cold-joint) and OK product (nugget).
The "difference" at the bottom of the table below is the analysis result. This is the difference value between the yellow wave and orange wave.

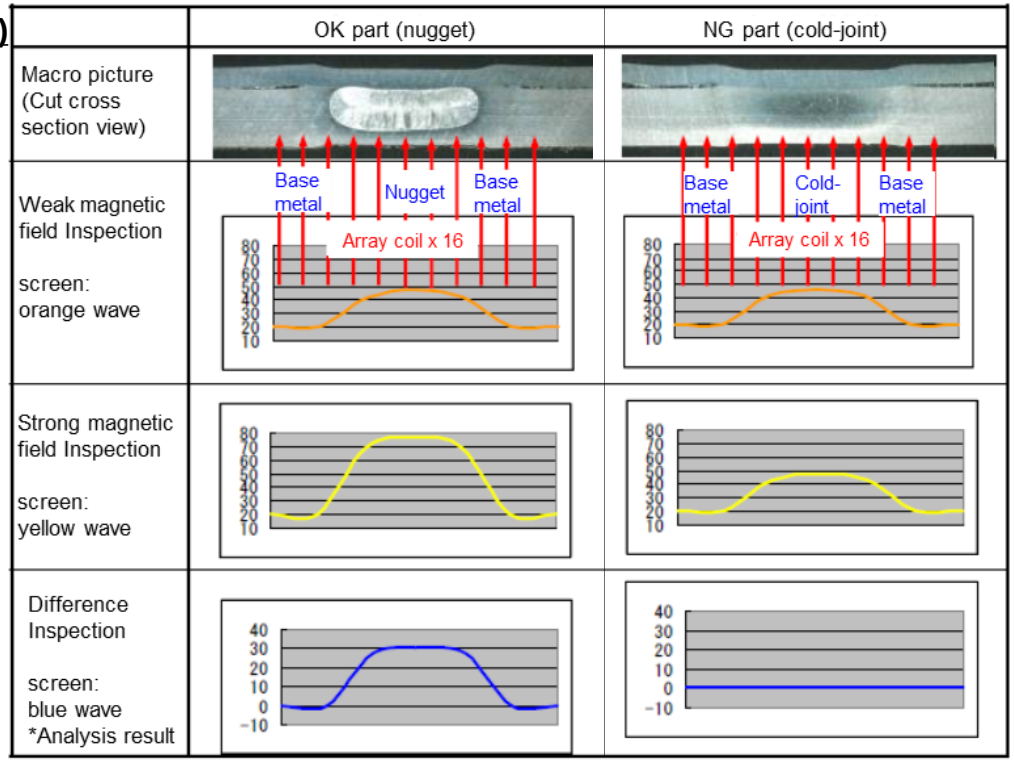
- In case of inspecting NG product => The form of blue wave (Difference) is flat or low crest.
- In case of inspecting OK product => The form of blue wave (Difference) is high crest.

* The height of blue wave and the judgment of OK/NG product are set in parameter based on the destruction test.

Inspection screen (in case of inspecting OK product)

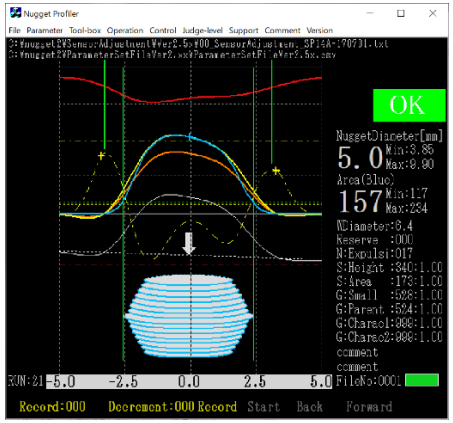
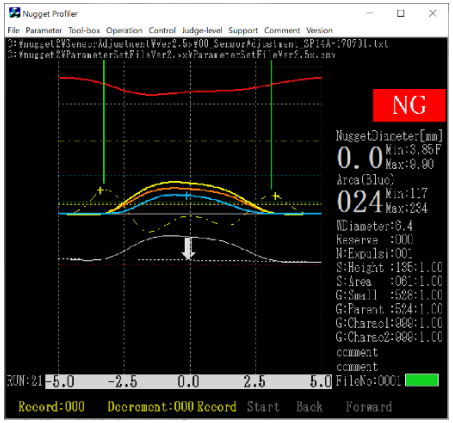


* The red line estimates the surface shape.



Important

○Comparison of OK and NG products

Item	OK	NG
Macro photo		
Status	Melt solidification	Cold joint
Change	Enough change(Martensitic phase)	Inadequate change
magnetic resistance	Slightly low	Low
Inspection waveform	 High	 Low

○Items with changing magnetic resistance

Item	S/N	Strong magnetic field	Weak magnetic field
Shape change (bending, pressing, etc.)	Noise	Acquisition	Acquisition
Pressurization (during spot welding)	Noise	Acquisition	Acquisition
Heating (no change in structure)	Noise	Acquisition	Acquisition
Organizational change	Signal	Acquisition	Non-acquisition

11. Data analyzing method

11.1. Data acquisition method

Important

The magnetic sensor contains two types of coils:

(1) Exciting coil: Serves as an electromagnet, which produces magnetism.

(2) Sensing coil: Converts produced magnetic flux into electrical signals, which are then sent to the device.

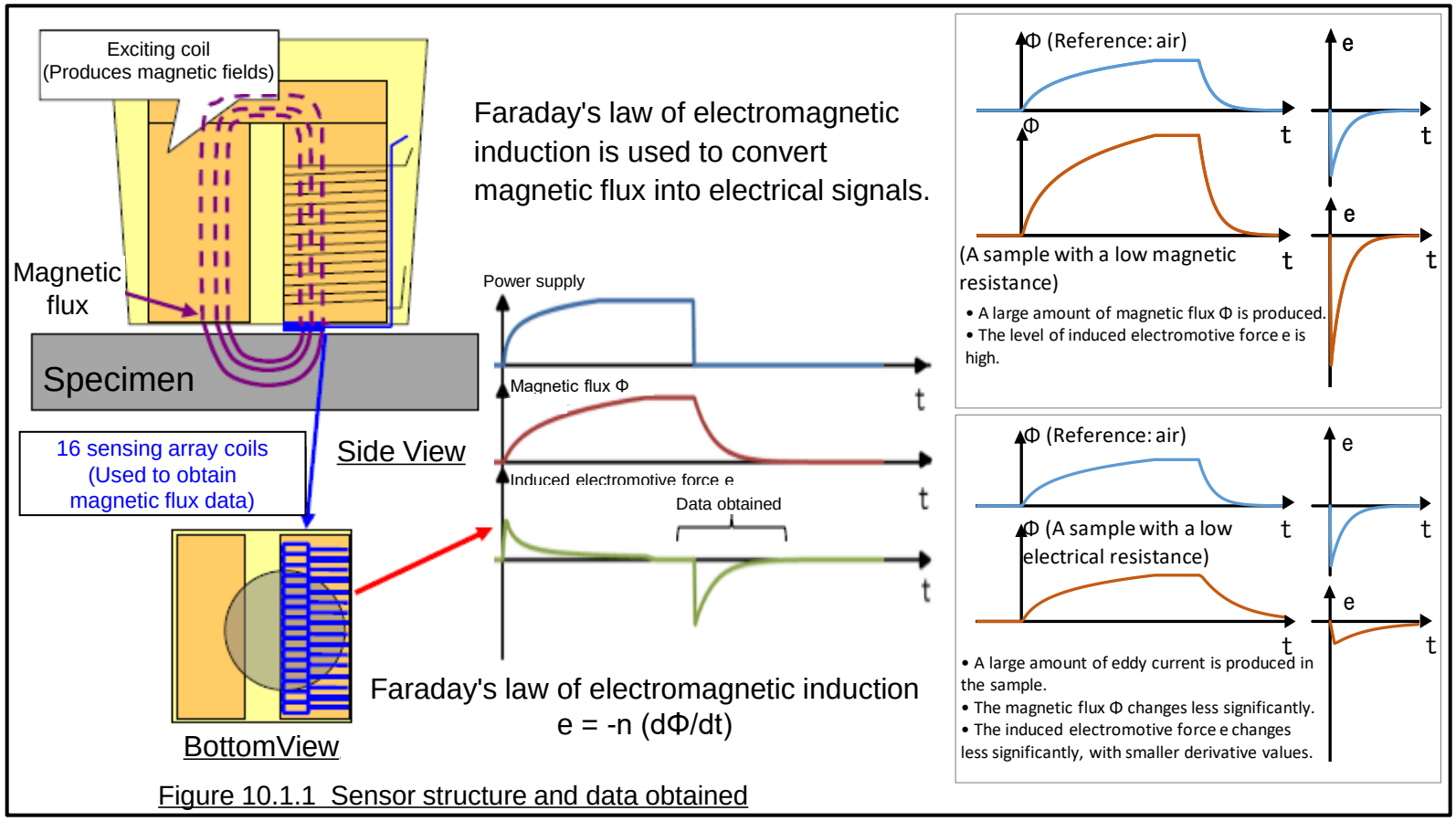


Figure 10.1.1 Sensor structure and data obtained

11.2. Summary of sensor

The magnetic sensor, which is the main component of Seam Seeker,
is energized by direct current blocking
(a patented Nippon Kouatsu proprietary technique).
This technique is capable of inducing
a much larger electromotive force compared
to the conventional alternating current (sine wave) method,
providing the following advantages:

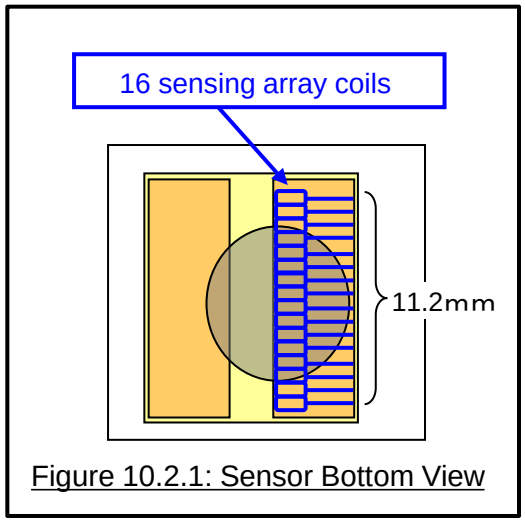


Figure 10.2.1: Sensor Bottom View

1. High performance: Changes in the steel microstructure characteristics
(tensile strength, total elongation and hardness) can be detected.
2. Smaller size: 16 array sensors are provided within a space of approximately 11 mm.

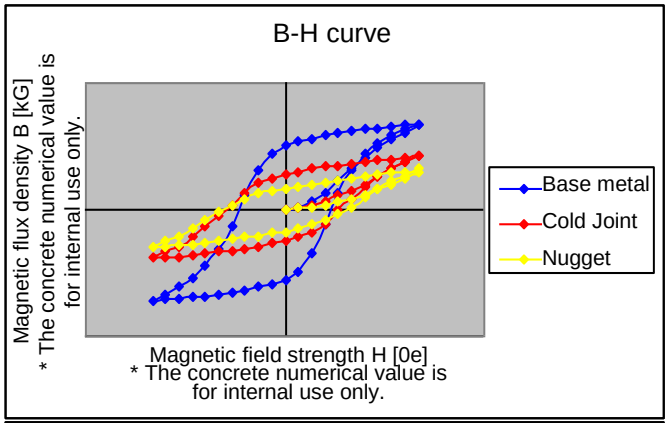
12 . Inspection theory

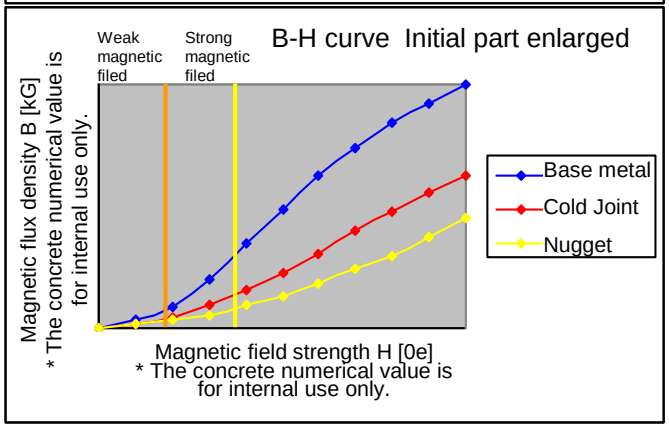
12 . 1 . Acquired signal

Generally, it is known that when steel is hardened, the magnetism characteristics are changed.
The figure is called as "B-H curve," showing the generated flux amount to the magnetic field strength.
The generated magnetic flux density B is determined depending on the material's magnetic permeability.
As shown in the figure, the magnetic permeability varies among the base metal, cold-joint, and nugget.
=> A welding area is detectable
by acquiring the magnetic flux density B.

To estimate the magnetic flux density B, acquisition is performed by changing the magnetic flux Φ to electric signal e.
(Faraday's law of electromagnetic induction)

(1) The magnetic flux density B is generated
by the magnetic field H.
$B=\mu H$ μ : magnetic permeability [H/m]
(2) The relation between the magnetic flux density B
and magnetic flux Φ is shown as the following equation.
$B=\varphi/S$ S : area where magnetic flux penetrates vertically
(3) The inspection acquired signal e of this equipment is shown
as the following equation.
$e=-N\times d\Phi/dt$ N : the number of turns of array coil
(The above equation is
Faraday's law of electromagnetic induction.)





Horizontal axis : The magnetic field strength H is decided by the amount of current which flows into a magnetization coil.
Vertical axis : The magnetic flux density B is acquired with a detection array coil.

12 . 2 . Analysis method 1

The amount of current sent to the exciting coil can control the magnetic field strength. Therefore, the signals are acquired in two patterns, at the weak magnetic field (hereinafter referred to as "weak magnetic field") and at the strong magnetic field (hereinafter referred to as "strong magnetic field"), then judge the presence/absence of nugget and calculate the nugget diameter index.

The reason why the two patterns magnetic field strength are used is that B-H curve is non-linear.

-Weak magnetic field : To the base metal, NG product (cold-joint) and OK product (nugget) have similar characteristics.

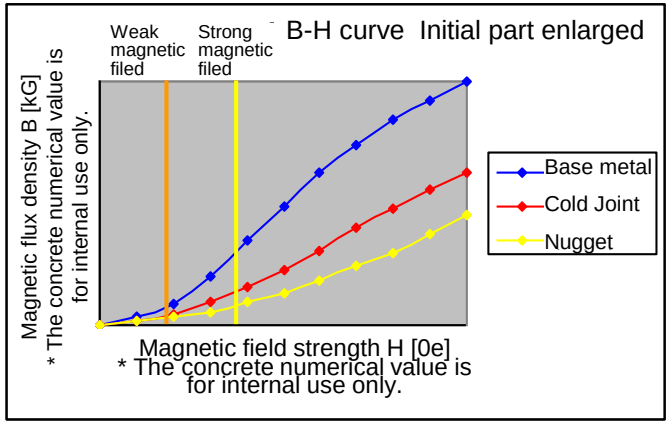
- Strong magnetic field : To the base metal, OK product is much away from the base metal than NG product.

*Analysis waveform can be obtained by the relative values from the base metal.

Compared with the magnetic flux density of base metal, the more the magnetic flux density of welding part (cold-joint, nugget) is away, the higher the crest is.

Therefore, when the strong magnetic field is observed based on the weak magnetic field, it is judged OK product (nugget) when the product is much away from the base metal characteristics.

This shows the blue waves in the inspection screen calculated from the difference between yellow wave and orange wave.



Inspection part	Weak magnetic field			Strong magnetic field		
	Magnetic flux density	Inverse number x 100	Gain adjustment (base metal = 20) * Detected value	Magnetic flux density	Inverse number x 100	Gain adjustment (base metal = 20) * Detected value
Base metal	7	100/7=14. 3	14. 3×20/14. 3=20. 0	3 1	100/31=3. 26	3. 26×20/3. 26=20. 0
Cold-joint	3	100/3=33. 3	33. 3×20/14. 3=46. 7	1 3	100/13=7. 69	7. 69×20/3. 26=47. 2
Nugget	3	100/3=33. 3	33. 3×20/14. 3=46. 7	8	100/ 8=12. 5	12. 5×20/3. 26=76. 7

*Since the upper table is shown in the following page by a diagram, please refer to it.

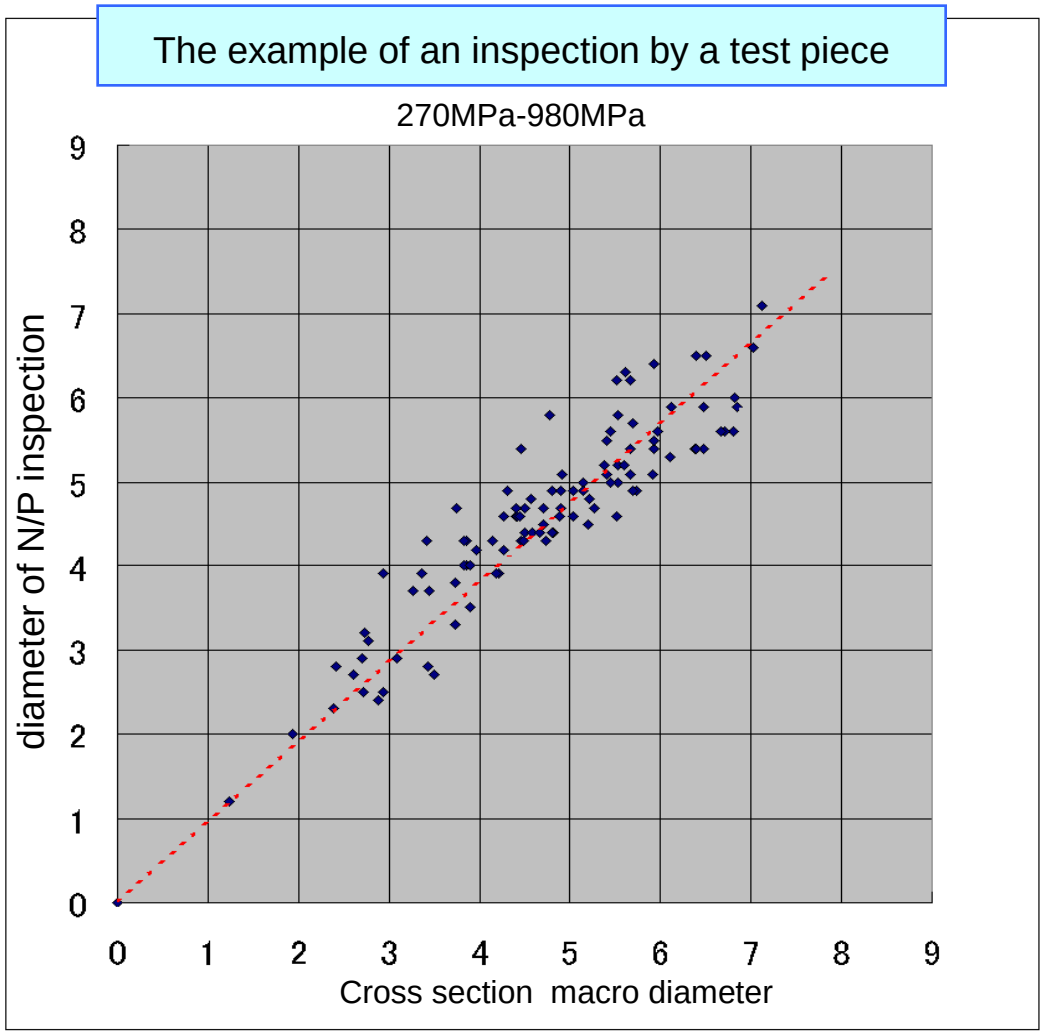
13 . Comparison with other inspection methods

	Nugget profiler	Ultrasonic type	Driver check (DC) chisel test
The contents of detection	The amount of change of metallographic structure	Distance to the changing point of acoustic impedance	Mechanical strength
A thing to be examined	Only iron	Iron, Nonferrous metal	Iron, Nonferrous metal
Area which can be inspected.	○ The part which does not have a convex around an inspection side (Contact area size is 18x10mm)	◎ : Single type ○ : Array type	△ Area where tool cannot be inserted is impossible.
Quantification of a nugget	○	× : Single type △ : Array type	×
Distinction with Cold-joint	○ (comparison of a value in fixed quantity)	△	○
Damage to the test object	None	Wiping of water and oil is required. =>Metal corrosion	A bend occurs. Tapping-back is necessary. =>Metal fatigue
Inspection of three sheets	△ (Inspection from surface and back side)	○	△ (Inspection from surface and back side)
Application to High-tension steel	○	○	△(Those with a possibility of cracking a welding part.)
Inspection time	○	△	◎
Traceability	○	○	×

14 . Comparison with driver check

	Conventional inspection Driver check	Suggestion Nugget profiler
Inspection result	2 values *Regardless of the welding diameter, whether it is sticky or not.	Trend *Indication of weld diameter fluctuation is displayed compared with standard product **. *It's not for measuring welding diameter. (large and small is compared) (**destructive test item: quality assured item)
Inspection type	Damaged inspection target. Quasi destruction test	There is no damage to the inspection target. Nondestructive inspection (can be inspected with shipping products)
Inspection record	No record remains. Did the inspection actually be done? What is the result of the test? These records do not remain.	Automatic output of electronic files. Results including inspection date and time are automatically saved.
Quality management	Since there is no record, it can not be managed.	Check the stability at the same point. Leading to confirmation that the manufacturing process is unstable.
Expand target	It is impossible to inspect a high tensile steel. There are many places where tools can not use.	High tensile strength steel can also be inspected.
burden	It is noisy. Burden on one's wrist.	Training is necessary.
Cost	High tensile steel sheet is discarded.	There is a possibility of extending the destruction test interval in the future.
Future	—	Possibility of automatic inspection by robot

15 . Correlation between the estimated nugget diameter and destruction test method



The diameter of NP inspection (diameter of an inspection of this equipment) is targeting the diameter of macro.

The size relation of the diameter of welding is the following.

macro < tear off (broken) < twist (broken)

Note: Since the breaking diameter includes the corona bond (see page 10), it is greater than the actual macro diameter.

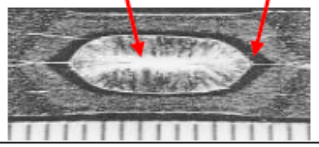
16 . Equipment specifications

Model		NPH03A	NPH03B
Dimensions(excluding protrusions)		230(w)×195(D)×50(H)mm	285(w)×205(D)×70(H)mm
Weight		1.91kg	2.32kg
PC(Display size)		Surface Go 10inch	TOUGHPAD 10inch
Welding inspection part	Inspection welding diameter	3 mm to 7 mm [Indentation diameter 8mm or less; Effective sensor width: 11 mm]	
		(The equipment may support the ranges other than the above. Please inquire us.)	
	Specimen sheet thickness (Thickness of one inspection side)	0.7 to 2.3 mm (The equipment may support the ranges other than the left. Please inquire us.)	
	Materials	Ultra high tensile strength steel plate High tensile strength steel plate Mild steel plate (Two mild steel plates are handled individually.)	
	Specimen sheet surface treatment	No treatment, electrogalvanizing, hot-dip galvanizing (As for the aluminizing. please inquire us.)	
	Number of specimen mating sheets	Two sheets, three sheets (Inspection from both sides are necessary.)	
	Sensor edge material	FR	
PC	Data storage	XLS form	
	Setting of inspection condition	Set in the inspection screen. (The setting contents can be stored in the file.)	
	Judgment method	OK/NG judgment, The diameter of a presumed nugget, Growth degree	
	Option	Navigation mode, Inspection record management	
	OS	Windows10	
Operation temperature range		5°C to 40°C (41°F to 104°F)	
Operation humidity range		Up to 80%RH (No condensation occurs.)	
Power supply		Two kinds of power supplies selectable. (1) AC85V to 240V, 0.5A (2) Battery (8 size AA Ni-MH battery)	

Please note that the product specifications are subject to change without notice for improvement.

17.Support documentation: The factor which has on magnetic resistance

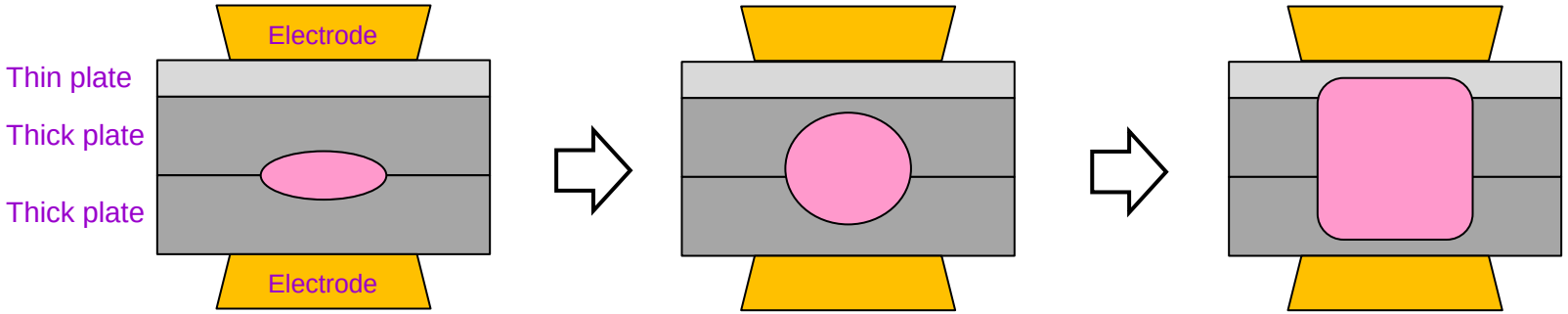
Know-how

Factor affecting		S/N	Description	Countermeasure against noise
Metal density		S: Signal	Metal density changes when a metal is crystallized by welding. Metal density becomes thick at the nugget (molten coagulation) part. Since density of the nugget part becomes thick, surrounding metal density becomes thin by just that much. <<Conclusion>> It can be determined that the clearer a difference of metal density becomes, the better quality the nugget is formed. Nugget (molten coagulation) part] Metal density = Dense Magnetic resistance = High Permeability = Low [Nugget peripheral part] Metal density = Coarse Magnetic resistance = Low Permeability = High 	-
Base metal	Contained metal	N: Noise	Metal type and content used for base metal material and thickness of steel plate.	With regards to the five items to the left, since base metal circumstances and shape are the same at the same welding position, problems can be resolved by setting parameters at every welding points The parameters set at every dots are automatically read by using the navigation mode (refer to supplementary 2).
	Surface plating	N	Type and thickness of plating of surface of steel plate	
	Stress	N	Mechanical stress applied to steel plate such as cutting, beating, bending, rolling makes magnetic resistance vary (press work). Metal may be residually magnetized.	
	Special processing	N	Hot stamping material, etc.	
Shape	Sensor contact	N	The degree of sensor contact differs depending on the shape of steel plate. No problem if the sensor is in the same contact circumstance.	
	Surface dent	N	Amount of dent on the surface of welded part. Dent is also referred to as indentation. The more an amount of dent, the higher magnetic resistance becomes.	Since an amount of dent depends on the welding requirements (pressurization, current, cycle), the welding requirements are equivalent at the same welding position. In addition, when the amount of dent decreases, it can be determined that welding itself gets close to defect.

18. Supplement: Welding three plates

Know-how

When welding three plates, a nugget is formed as follows:



Process of nugget formation when welding three steel plates
- A nugget is first formed between thick plates, and then reaches to an area between thin and thick plates.
- Between high-strength steel plates, and then between soft steel and high-strength steel plates

→The nugget formation starts from an area with high electric resistance.

Source:
Literature in weld engineering
Volume 35 (2017) No. 1, etc.

○Electric resistance depending on steel plate thickness and type

	Low resistance		High resistance
Steel plate thickness (Length)	Thin	→	Thick
Steel plate type	Soft steel (Low carbon content)	→	High-strength steel (Low carbon content)

$$R = \rho \frac{l}{A}$$

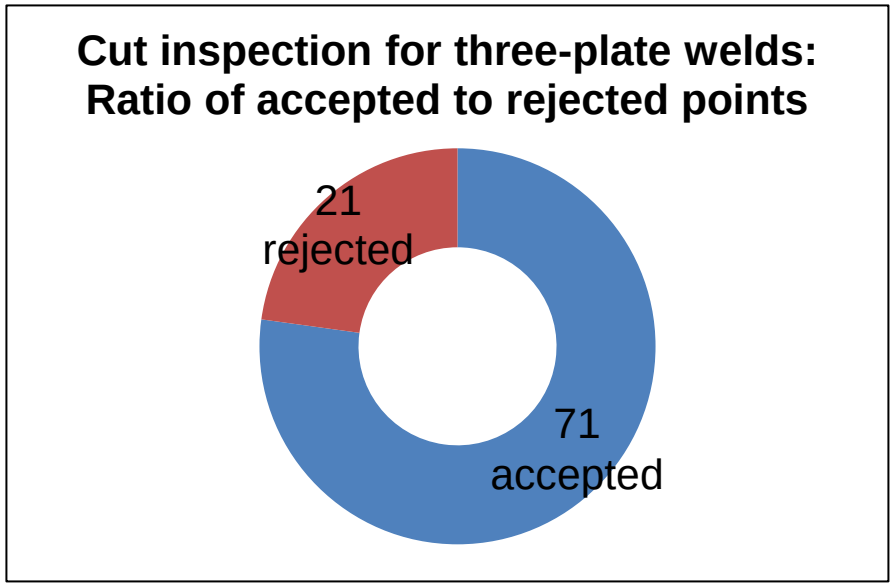
R = Electric resistance
ρ = Electric resistivity
l = Length
A = Sectional area

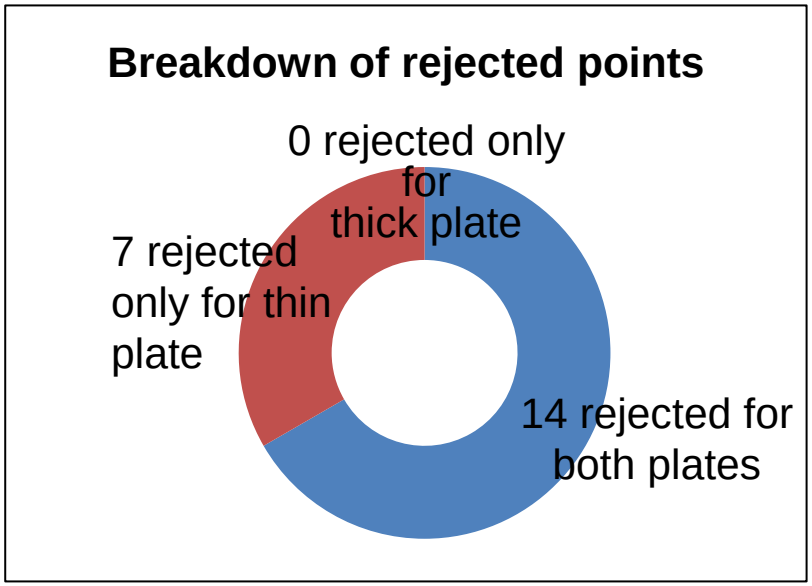
Steel type	Electric resistance (μΩ・cm)
Carbon steel (with 0.1% C: equivalent to S10C) …	14.2
Carbon steel (with 0.2% C: equivalent to S20C) …	16.9
Carbon steel (with 0.4% C: equivalent to S40C) …	

18. Supplement: Welding three plates

Know-how

We cut and inspected 92 three-plate weld points to check the welding status.





Cut inspection:

A cut inspection is a method to break a sample actually and measure the weld system.