Automatic Verification of Induction Hardening Using Eddy Current and Preventive Multi-Frequency Testing

By ARNOLD HORSCH
ibg Prüfcomputer GmbH, Ebermannstadt, Germany

Increasing quality demands, new product liability regulations, as well as international market networks force manufacturers to take special measures encompassing the field of material testing. Nowadays, specified tolerances are extremely small. Therefore processes have to include the conducting of 100% material, structure and hardening tests on a fast, reliable and simple basis. The technology applied must be the latest state of art, it must comply with maximum safety requirements and be very economical.

Eddy current testing, especially Preventive Multi-Frequency Testing (PMFT) is applicable for a large range of uses. It has been successfully introduced worldwide to test all kinds of material, including the determining of microstructure and hardening characteristics. There are numerous applications for such a system.

Today, every company carries out spot checks during manufacturing, in order to guarantee the quality of products. Within the framework of control one of the most important problems is to ensure repeatability of quality. Quality control faces major problems within this area; these might start with supply of the material or products [1].

Parts properties; that is structure, hardness or case depth, which are determined by the induction hardening process, are subject to variation. To determine correct heat treatment, the test method must be non-destructive; thus, eddy current testing is applicable.

Computer-based multi-frequency eddy current test stations with 8 to 32 testing frequencies and up to 16 test positions has greatly increased the efficiency of this testing method. Its field of application ranges from structure, hardening and case depth inspection to material mix inspection. One of the most outstanding advantages of modern eddy current test systems using PMFT is their capability to detect unexpected defects.

Table I Application Examples of Material Testing by Means of Eddy Current Preventive Multi-Frequency Testing (PMFT)

Component	Parameters to be tested
Bearing parts	case depth, structure and hardness pattern
Axle components	case depth, structure and hardness pattern
Pinion pins and axles	case depth, structure and hardness pattern
Linear guide components	case depth, structure and grinder burn
Steering racks and the like	case depth, structure and hardness pattern

Table II Possible Hardening Errors During Induction Hardening

Which parameter was incorrect?	In which way was it incorrect?	What are the effects of this?
Austeniting temperature	too high	Overhardening, incorrect structure martensite + residual austenite
	too low	Underhardening, incorrect structure martensite + bainite + ferrite
Austeniting time	too long	Overhardening, case too high, incorrect structure martensite + residual austenite
	too short	Underhardening, shallow case, incorrect structure martensite + bainite + ferrite
Quenching	too fast	Incorrect structure martensite + residual austenite
	too slow	Incorrect structure martensite + bainite + ferrite
	formation of vapor bubbles	soft spots not defined
Annealing temperature	too high	hardness too low
	too low	hardness too high
Annealing time	too short	hardness too low
	too long	hardness to high
Rate of feed	too slow	shallow case, misplaced case, austeniting time too short
	too fast	case too high, misplaced case, austeniting time too long
Damaged inductor	undefined	undefined
Malpositioning	undefined	unsymmetrical hardening pattern, overheating, melting

Table I gives a few application examples of non-destructive material testing for verification of induction hardening by means of eddy current multi-frequency technology.

Why 100% Testing?

Variation in product usually is in accord with statistical analysis and can be predicted or estimated. For this reason it is sufficient to make a certain number of spot checks in order to conclude the general nature of the quality from the test data.

Problems develop if during manufacturing some occurrences arise which are not subject to standard statistical distribution. First, one needs to know what may happen unexpectedly. Table II lists possible hardening errors.[2,3]

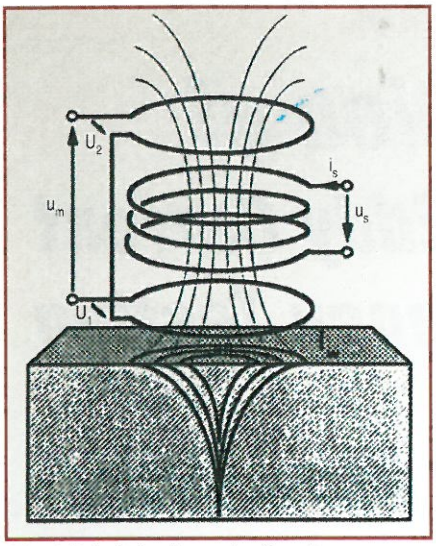

Fig. 1 Principle of a probe function.

Modern process monitoring systems, which should be available for all new machinery, allow detection of some of these errors while they develop. These errors may occur as isolated or in combination with others. If several minor deviations accumulate, the process monitoring system does not immediately respond, while defective parts are being produced. Simple methods like hardness inspection cannot be used for reliable determination of the error. Spot checks will fail if the error occurs for a short time between two spot checks.

Generally, spot checks are only capable of detecting slow changes in the process. Unpredictable errors occurring for a short time are unlikely to be detected by spot checks. Thus, inspection using eddy current test method must be used if 100% of all defective parts are to be found.

How Does Eddy Current Testing Work?

Basically, the test installation consists of a coil with a sending and a receiving winding. The two windings are only loosely coupled. In the empty coil, a low voltage is induced in the receiving winding by the magnetic field of the sending winding.

If a test part approaches the coil system, the coupling factor between the sending and the receiving winding changes (see Fig. 1). This change is mainly determined by electrical and magnetic conductivity (permeability) of the test part. These two electromagnetic properties are strongly influenced by the microstructure of the test part. If the part is too hard, permeability is different than for an annealed part.

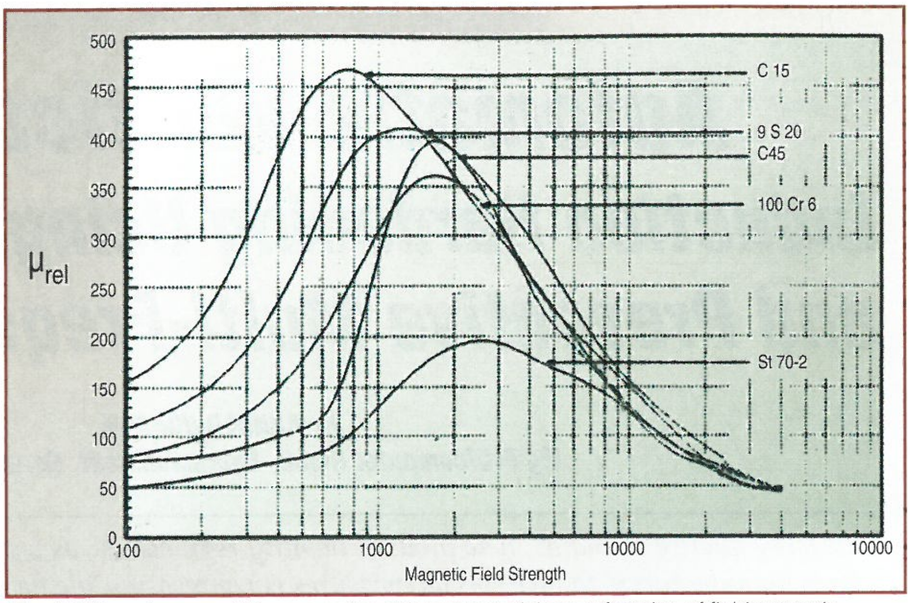

Fig. 2 Different permeability curves for different materials as a function of field strength.

What Is Permeability?

The variable of ferromagnetic materials decisive for eddy current testing is permeability. Permeability actually means relative permeability, a number without any dimension, which indicates how much better a certain material can conduct electric flux lines in comparison to air. Air has the value of 1. A steel which can be magnetized has a value between 10 to a few 1,000.

The correlation between permeability and field strength is not at all linear. In case of a very small field strength, permeability is low (starting permeability). With an increasing field strength permeability increases to a maximum value, whereupon it decreases subsequently to a smaller value. The reason can be seen in the dislocation of the Bloch wall as well as in the direction of the "Magnetic Weiss's Domain."

Every structure and every material has a characteristic permeability. This means that parts with different heat treatments and different microstructures exhibit different permeability. Fig. 2 shows the different permeability curves for different materials[4].

If testing is done at frequencies where eg. C45 and 100 Cr6 have the same permeability, the two materials cannot be separated or distinguished. This may happen if material mix between 100 Cr6 and St70 is expected and the eddy current instrument is optimally set to cause this result.

Why Preventive Multi-Frequency Testing (PMFT)?

Eddy current testing is the most economical and most reliable method for 100% inspection. The method is not new, but there is still some discomfort with it due to bad experience with old monofrequency systems which were used in the past.

Test results obtained from these monofrequency systems can be used with restrictions only.

Monofrequency Test

Monofrequency systems commonly use a group of OK parts and a group of NOT GOOD parts, eg. improper case depth, to set the instrument for the test task. With this situation many influencing factors are not considered.

Considering all errors listed in Table II, it becomes clear that one cannot have master parts with all possible defects to set the instrument. There is not a complete set of defective parts covering all defects possible for every part; furthermore, artificial defects are never as effective as real defect, and it is very difficult to simulate improper heat treatment to create such defects.

Monofrequency test instruments are usually not very new and use 50Hz for excitation of eddy currents (see Fig. 3). With some of them, one can switch from one frequency to another, but in all cases, only one single frequency is used for testing.

Evaluation of test results is done in different ways, but usually it is only unidimensional. Some test instruments provide multidimensional evaluation of test results.

Test speed for the monofrequency method is usually not very high because electronics used for evaluation are rather slow.

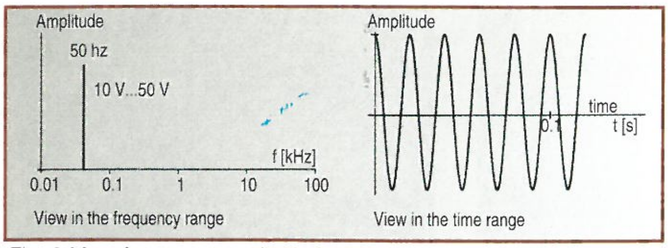

Fig. 3 Monofrequency method of testing.

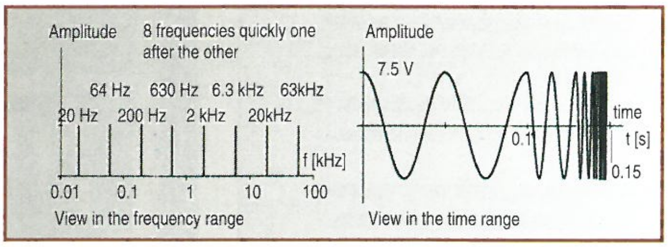

Fig. 4 Preventive multi-frequency method of testing.

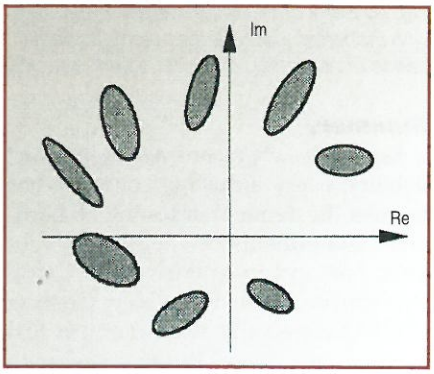

Fig. 5 (above) Diagram representing the need to satisfy all tolerance fields (parameters).

Fig. 6 (right) Eddyliner®P multifrequency eddy current test instrument using PMFT.

Preventive Multi-Frequency Testing

Modern eddy current test instruments based on the Preventive Multi-Frequency Test method, Fig. 4, operate in a completely different manner. Based on the experience that different defects cause different signals in eddy current test instruments, a large number of test frequencies is used now. Only OK parts are used to set the test instrument.

Apart from the large number of frequencies, it is important that a broad frequency range is covered, ie. the ratio between the lowest and the highest test frequency should be 1:1000 or higher to guarantee reliable testing.

Due to use of new electronic components it was possible to reduce test time considerably. From a time point of view, it does not matter whether two or eight frequencies are used for testing (because testing is done faster), and it is now possible to really test preventively. This means that all information contained in a material can be 'read.'

Another advantage is the multidimensional evaluation of modern test systems. A separate tolerance field is generated for every test frequency (see figure). Only when all tolerance fields are satisfied can one assume that the part is OK. If a part is not OK in only one tolerance field, the part is classified NOT GOOD. Any change in the low, middle or upper frequency range is displayed clearly.

Economic Significance

Apart from the aforementioned criteria for test reliability, cost for a test system influences the decision of which method will be used. Considered are these factors: expenditure for test station, test instrument, auxiliaries, etc.; expenditure for staff necessary for testing and evaluation; expenditure for various nonproductive times, eg. interruption of manufacturing for verification; scrap due to delayed adjustments in the manufacturing process and customer complaint.

Cost for equipment and staff can easily be estimated. Cost for organization and scrap are very difficult to calculate.

The eddy current test instrument (eddyliner®P) and preventive multi-frequency testing, Fig. 6, make it possible to lower the costs of serial tests significantly. Destructive tests are essentially reduced to machine readjustments, destructive inspections and testing NOT GOOD parts. With respect to series testing, reduction of test scrap and time saving are dramatic (see Fig. 7).

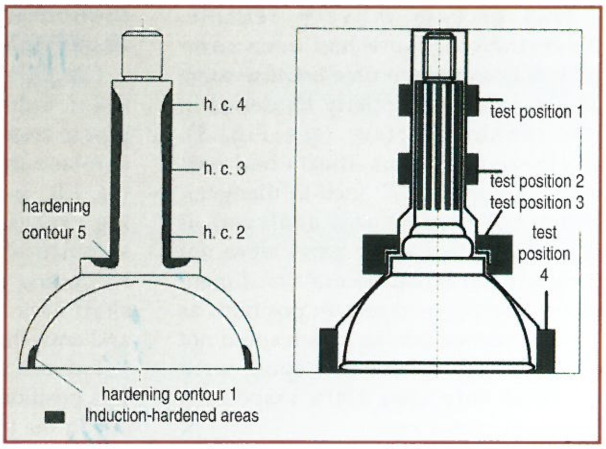

Fig. 7 Test positions for destructive inspection of case depth. Due to the specific shape of the inductor, testing requires more expenditure than for non-destructive testing.

Application Examples

Two standard examples illustrate the potential provided by eddy current testing by Preventive Multifrequency testing (PMFT) with an eddy current test instrument (eddyliner®P).

Induction-Hardened Water Pump Shafts

Water pump shafts are induction-hardened by a coil in a continuous process. The shafts are pushed through the inductor by means of a driving wheel.

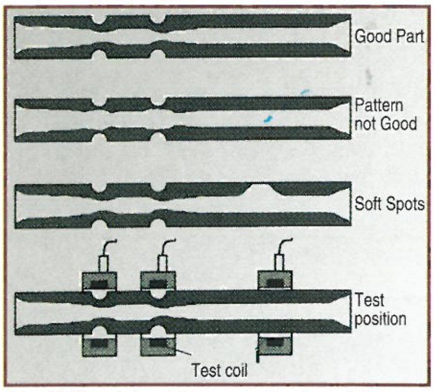

Fig. 8 Possible defects and test positions on water pump shafts in order to control induction hardening results.

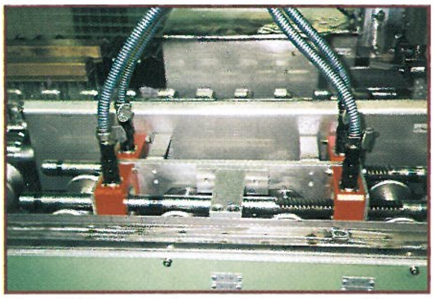

Fig. 11 Two steering racks in test position.

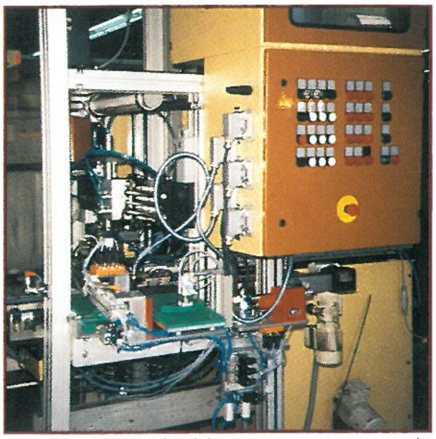

Fig. 9 Integrated eddy current test system in feed to grinding machine.

This process is very reliable. Nevertheless, there had been complaints from time to time because some shafts were not properly hardened in the running surface (see Fig. 8). Furthermore, some shafts had soft spots of approx. 1/2 inch in diameter. When the process was analyzed, it turned out that these parts were not properly hardened because of dimensional tolerances at certain positions as well as malpositioning which could not be specified. These soft spots were detected only after 100% inspection had been introduced.

To remedy these problems would have been possible by extensive and cost-intensive changes in the process. Since this did not promise 100% success, 100% eddy current testing was the ideal solution.

After one year of operation, it showed that the error rate was less than 0.1%. Complaints sue to improper hardening are no longer an issue.

Due to the eddy current test system, only one test station is needed for several induction hardeners. The multi-position test instrument (eddyliner®P3) was used (see Fig. 9). Total test time for all 3 relevant test positions is less than one second. Cycle rate of the system is more than 3 parts/sec.

Automatic Verification of Induction Hardening on Steering Racks

The eddy current test system for control in induction hardening of areas of power steering racks is integrated in a two-lane machine (HWG Inductoheat, Fig. 10). In an interlinked manufacturing process, parts have to be tested automatically for correct hardness and hardening depth in the tooth and the shaft area after induction hardening and annealing.

Two test parts are tested separately at two positions each, one in the shaft and one in the tooth area for hardening pattern, hardening depth, hardness and material mix (see Figs. 11 and 12). At every test position, testing is done with eight test frequencies ranging from 25Hz to 25kHz. If, for example, on lane 1 a defect occurs, this part is sorted out. The eddy current test instrument is interlinked with the system control. This allows stopping of the system if several NOT GOOD parts are sorted out in a certain period of time so that scrap is reduced to a minimum.

Cycle time of the test instrument is much less than cycle time of the hardening machine. The concept of integration of this entire system for this application is an optimum, economical solution.

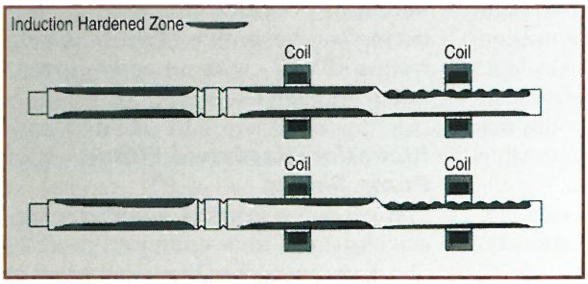

Fig. 12 Two-lane testing with test positions in shaft and toothed area.

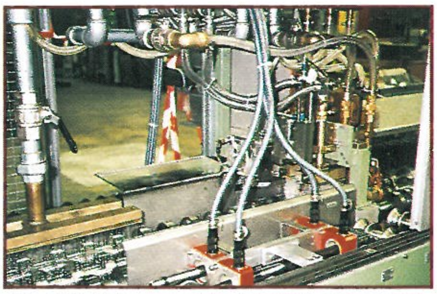

Fig. 10 Eddy current test system integrated with induction machine for automatic verification of hardening of power steering racks.

Summary

Especially when considering product liability, every industrial company has to meet the demand of testing all hardened components by means of a reliable, fast and inexpensive 100% test. Preventive Multi-Frequency Testing (PMFT) especially with modern test systems (eddyliner® P) integrated with induction hardening, is a real alternative to destructive systems. It is possible to operate these systems as inline testing machines or as automatic monitoring systems with 100% reliability and without any problems.

A single-frequency test must be considered as being unreliable. Only a multi-frequency test, which adheres to the described marginal conditions, resembles a reliable method within the field of eddy current testing.

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For further information please contact:

ibg NDT Systems Corp.
20793 Farmington Road, Suite 8
Farmington Hills, MI 48336
Tel. (810) 478-9490
Fax (810) 478-9491