Novel nondestructive testing applications in old automotive engine

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Abstract. Some new methods and equipments of nondestructive testing used for old automotive engine were presented, including ultrasonic testing, metal magnetic memory testing and eddy current testing. The importance of nondestructive testing in the process of quality control for old engine was pointed out. Technologies and equipments of nondestructive testing for the typical old engine components were introduced. Meanwhile, the demand of special standard for nondestructive testing was raised, which was the difficulty in nondestructive testing for the old engine.

Keywords: automotive engine, metal magnetic memory testing, ultrasonic testing, eddy current testing, nondestructive testing

1. Introduction
Remanufacturing engineering is an effective way to upgrade the life of old equipment, complying with the strategy of sustainable development in China. The goal of remanufacturing engineering is to make the processed waste products to meet or exceed the performance of new products. If the residual life prediction was not done for the old service parts before remanufacturing, huge waste will be caused, at the same time, the remanufactured component is not safe, which will not only bring losses to the users, but also bring losses to remanufacturing enterprises. Therefore, it is very important to predict the residual life of old components for remanufacturing engineering [1].

How to make remanufacturing productions widely applied in the development of society and increase the confidence of users are very important. Theoretically, remanufacturing production should be regarded as new one, so the quality and performance need to be ruled by the standard of new one. Series of quality monitoring methods were used in the process of producing new production, such as testing and judgment of components, should be widely applied in remanufacturing in order to meet the request.

It should be emphasized that the effect of nondestructive testing in remanufacturing component is very important as the same as the new component. The application of nondestructive testing technology mainly undertakes two tasks, which are quality testing and special performance testing. However, it is absolutely different between remanufacturing one and new one because of the particularity of remanufacturing production. There are some defects only in the old components before remanufacturing resulted by abnormal stress and dissociation of material structure after long time service. Therefore, series of nondestructive testing methods must be studied and improved.
the remanufacturing testing standards should be strictly and appropriately established, the advanced testing equipments need to be developed and used [2]. In the paper, some novel nondestructive testing methods and equipments used for old automotive engine are presented.

2. Methods and Results

Nondestructive testing technology was taken as a branch subject previously, but it has been regarded as an important technology because of many accidents appearing with the development of society. Nowadays, it becomes a synthetical subject, which has much development potential. Qualitative and quantitative detecting could not be completed by only one method, which needs multiple testing methods. Modern nondestructive testing includes ultrasonic testing, magnetic particle testing, penetrant testing, eddy current testing and X-ray testing, et. al. Every method has its own character [3]. For example, as a widely used method, ultrasonic testing can nondestructively estimate metal, non-metal and composite components, but it also has shortages, for instance, it is difficult to detect surface defects and the parts with rough surface. X-ray testing has high cost and is harmful to operator. Eddy current testing is very fast, which cannot contact samples and use couplant s, but it can only detect surface or near surface flaws of conducting material. Therefore, every method has goodness and badness. Only one method can not exactly estimate damage degree and life. Generally, there is complementarity for series of testing methods. If the methods could be integrated into a synthetical equipment, which becomes a novel integrated nondestructive testing method, the quality assurance of remanufacturing productions will be extremely developed [4-6].

In order to change the situation of nondestructive testing applied in remanufacturing engineering and improve the industrialized process of remanufacturing, the following typical remanufacturing engine components were firstly pointed out.

Firstly, cylinder body, which is the main part of engine, must be detected before remanufacturing. It is very easy to induce cracking and stress concentrations in the inner wall of cylinder body, which is affected by alternating temperature and fatigue loads, shown in figure 1.

![Figure 1. Automotive cylinder and the superficial cracking](image)

A: automotive cylinder B: cracking.

A new method composed of eddy current testing and metal magnetic memory testing was applied. Four probe of eddy current testing and metal magnetic memory testing were installed in a probe block at intervals of 90 degrees. The probe block can move up and down, and can also rotate. According to this, not only inside and outside defects of cylinder are detected, but also the stress concentration will be tested. The equipment and testing result are shown in figure 2.

Secondly, the vulnerable area of crankshaft is corner between journal and shaft arm, called R angle, where there may be cracking, presented in figure 3. And the journal is also easy to be worn. In references [7], ultrasonic testing method was used to detect the inner defects of the crankshaft. But there is a hole in the old crankshaft, which was processed in service. Conventional ultrasonic testing method is not suitable, which can easily cause missed and false results.
Ultrasonic detection for R corners of crankshaft is very easy to cause missed detection using ordinary probe. In order to avoid the R angle on the ultrasonic obstacle, the double oblique probe with single crystal is invented. A lateral angle is added to the common oblique probe in the double oblique probe, which can effectively avoid the barrier on the ultrasonic oil hole and the R angle, the detection of the shaft neck and R angle of internal defects can be realized. The detecting instrument is digital ultrasonic testing instrument named XZU-1. Considering the complexity of the R angle of the concave shape, the corresponding probe calibration testing block is made for double oblique probe, shown in figure 4.

The manual testing methods for crankshaft is shown in figure 5. The angle $\beta$ and $\beta'$ can be tested by the probe calibration testing block. Then location of the defect P can be calculated by Eq. 1, Eq. 2. and Eq. 3. It is shown that this detection method can effectively detect the crankshaft internal and R corner defects, judging whether the crankshaft is suitable for remanufacturing.

$$PN = EP \times \sin \beta'$$  \hspace{1cm} (1)
$$MP = QN = EN \times \sin \beta = EP \times \cos \beta' \times \sin \beta$$  \hspace{1cm} (2)
$$EQ = EN \times \cos \beta = EP \times \cos \beta' \times \cos \beta$$  \hspace{1cm} (3)
Thirdly, a valve is presented in figure 6. The small types are used in the motors of cars and the large ones are used in diesel engines of ships or locomotives. For the detection of the welding line in the shaft, it is proposed that a normal probe is used in the direct coupling mode on the front of the valve shaft, shown in figure 6.

The diameter of the transducer is matched to the shaft diameter. The acoustically absorbent protection layer (coupling membrane) reduces coupling deviations caused by standard hard-faced probes. Indications from the weld zone are evaluated, which extend above the noise level caused by coarse grain structure formation, the results are shown in figure 7.

There is also cracking in the valve fillet caused by fatigue. An automated detection method of valve fillet is realized by eddy current testing. The EPB1.CE/EPB1.JO testing probe automatically moves from the vertical position to the horizontal position in the range of 90 degree, at the same time, the valve does circular motion in order to realize inspecting the base arc end surface and near surface defects of the valve, the method and equipment are shown in figure 8.
Figure 8. Eddy current testing method and equipment for valve fillet
A: schematic diagram of method B: equipment.

Shown in figure 9, the cracking with width of 0.5 mm and depth of 1 mm on the surface or nearby of the fillet can be detected, which is suitable for the requirements of the old valve detection before remanufacturing.

Figure 9. Eddy current testing result of valve fillet.

3. Discussions
The demand of equipment remanufacturing engineering promotes the development of nondestructive testing technology, meanwhile, development of nondestructive testing technology can better ensure the quality of equipment remanufacturing products and promote the development of equipment remanufacturing industry, which are complementary relationship [8,9]. Several years ago, many persons put forward the breadth of nondestructive testing field. With the improvement of nondestructive testing technique and the development of national science, nondestructive testing becomes very important for new materials, new energy, environment and public security and other areas of particular concern in the country's applied research. On the premise of building a resource conserving and environment-friendly society, nondestructive testing is very in line with the requirements of equipment remanufacturing engineering. Nondestructive testing technology could be widely applied, although there are many basic theoretical problems remaining to be solved. The more importance is how to use other disciplines of knowledge and technology to develop nondestructive testing technology and instrument to solve practical engineering project as far as possible.

Because of the particularity of remanufacturing production, the nondestructive standard is different from the standard for new production. But the nondestructive testing methods for remanufacturing production are short at present. It should be founded on base of real data in practical process according
to different characters, which is a long time task. It is very difficult to set up a special nondestructive testing standard for remanufacturing engineering. Such as collecting remanufacturing production samples, founding technology standard and the changing rules of defects after many times applications. These works are the key, and also difficult for nondestructive testing of remanufacturing engine. Modified or innovative methods should be made, and lots of experimental testings need to be done for extra project.

4. Conclusions

Some novel methods and equipments of nondestructive testing used for old automotive engine are presented in this paper, including ultrasonic testing, metal magnetic memory testing and eddy current testing. The testing results meet the requirements of the remanufacturing engine. It should be pointed out that nondestructive testing technology is in constant development, it must be continuously explored in the application and research of practical remanufacturing engineering. It is believed that nondestructive testing technology could be widely applied in the manufacturing fields with the development of science and technology, such as the field of computer and new materials.

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