Typical Internal Defects Characterization in Castings Based on Rapid Total Focusing Method

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Abstract: The quality of castings directly affects their service life, and it is crucial to evaluate their quality by means of non-destructive testing (NDT). The total focusing method (TFM) has gained a lot of applications in many fields because of its higher sensitivity and visualisation of results. In order to achieve the application of this technology in casting quality inspection, this paper optimises both imaging speed and imaging quality. Firstly, by training the deep learning model, the complex calculation of high-resolution images is skipped, and high-resolution images are generated directly from low-resolution images to achieve fast characterisation of defects inside the castings by deep learning. And the characterisation results are compared with the DR inspection results to achieve fast and high-quality characterisation of typical defects inside the castings, which provides the basis for the application of this technology in casting quality inspection.

Keywords: castings; ultrasonic testing; TFM; deep learning

1 Introduction

Casting as the basic industry of manufacturing is widely used, with the development of technology, the structure is more complex, the working environment requires more stringent castings have become the focus of research and development. Such as aircraft engines in the magazine, hydraulic turbine runner, etc., the casting process is complex. In the casting process, due to stress concentration and other issues, it is inevitable to produce a variety of defects, affecting the quality of castings, which in turn reduces the service life of castings.

In the field of nondestructive testing, ultrasonic testing is often used in the detection of internal defects in castings because of its fast detection speed, low cost and other advantages. With the development of ultrasound technology, phased array ultrasound technology has a higher sensitivity, but also can achieve the visualisation of the detection results. The total focusing method (TFM) ultrasound detection is the use of a number of array elements containing a phased array ultrasound probe successive emission of ultrasound waves, to be detected in the area of detection, each array element and then successively receive these ultrasound data (FMC), and according to the TFM imaging algorithms through the post-processing of data by the way of the ultrasound detection technology. Compared with conventional phased array ultrasound, TFM ultrasound inspection can be post-processing algorithms to focus on any position (pixel point) of the imaging area, and thus can obtain higher detection sensitivity and resolution, while intuitive imaging can better characterise the defects in the inspection area.

At present, the TFM inspection technology has been widely used in bolt and weld inspection, but there are few applications in castings. The quality of TFM imaging directly depends on the number of pixel points, but each pixel points amplitude needs to be calculated by the TFM, and the more pixel points, the longer the algorithm calculation time. In addition, coarse grains inside the casting, poor surface condition, etc. will affect the effect of focusing imaging. Therefore, if the TFM is to be applied in casting inspection, it is necessary to solve the problems of imaging speed and imaging quality, i.e., to achieve rapid characterisation of typical defects inside the casting.

At present, the optimisation of the imaging time for the confocal algorithm is divided into several aspects. First, the wave number imaging algorithm can avoid the calculation of the ultrasonic propagation path in the algorithm, which can improve the imaging speed to a certain extent, but the calculation needs to be processed for three-dimensional data, and the memory load is too large, which makes it difficult to be applied in portable ultrasonic phased array equipment. Simplification of the FMC is also commonly used to speed up the method, such as triangular matrix, sparse matrix, etc., to reduce the data can improve the imaging speed, but a large number of experiments have also shown that the reduction of data for a specific detection need, the reduction of data will reduce the quality of the imaging, and it is difficult to meet the high quality of the detection needs. With the development of computer hardware, accelerated imaging methods through the use of GPUs, DSPs and FPGAs have been applied to TFM imaging, and powerful hardware can nearly shorten the imaging time of TFM. However, the cost of hardware is difficult to match with the development of increasing detection needs. In summary, many of the current methods have certain limitations for higher resolution TFM images. With the development of artificial intelligence, deep learning is widely used in the fields of data classification and image processing. Homin Song et.al combine simulation data and test data as a database to train deep learning models to achieve super-resolution imaging, but the results are only verified in the test, and are not applied in the actual industrial inspection [1].

In summary, this paper proposes a method based on deep learning to achieve fast high-resolution TFM imaging, for cast steel parts, cast titanium parts and other castings for the FMC acquisition, the construction of low-resolution images and high-resolution image pairs as a database, to achieve fast high-resolution imaging. And in this way, the typical defects inside the castings are characterised, and the results are compared with the DR inspection results, so as to realise the accurate characterisation of the defects inside the castings by TFM. It provides a theoretical basis for the application of total focus technology in casting inspection.

2 Experimental procedure

The research idea of this paper is shown in Fig. 1. Firstly, the FMC containing defects are acquired, and the traditional TFM is used to generate images with different resolutions (from low resolution to high resolution). Then the low resolution image and the high resolution images as a set of image pairs, which is used to train the deep learning model. Finally, the low resolution image is calculated by the traditional focusing algorithm, and then the high resolution image is generated by the trained deep learning model to achieve fast focusing high-resolution imaging. In this paper, a 32-array phased array probe is used for data acquisition of cast steel and titanium parts containing typical defects such as porosity and porosity, with a confocal imaging area of 40 mm × 50 mm. after fast high-resolution imaging is achieved, a phased array probe equipped with an encoder is used to perform a confocal B-scan and C-scan on the casting and the C-scan image is compared with the DR image, so as to realise the characterisation of the casting's typical defects.

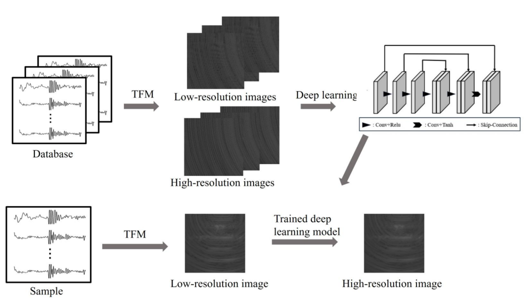

Figure 1 Technical route

3 Result and discussion

(1) Database and model

The same FMC were calculated using the TFM for64×64 pixel, 128×128 pixel, 256×256 pixel, 512×512 pixel, and 1024×1024 pixel, respectively. It can be found that the low-resolution imaging time is only 0.04 s, and when the resolution reaches 512×512 pixel, the single picture imaging time is 7.28 s, which is already difficult to meet the needs of industrial inspection.

In addition, as shown in Table 1 for the similarity between different resolution images, were selected PSNR, SSIM, Lpips three parameters (in order to ensure that the image size is the same, the low-resolution image using linear interpolation with 1024 × 1024 pixel for comparison). It can be found that as the resolution increases, the higher the similarity with the 1024×1024 pixel image, indicating the availability of the database.

Table 1. Comparison of image similarity at different resolutions

	64*64	128*128	256*256	512*512	1024*1024
Time(s)	0.04	0.12	0.62	7.28	28.63
PSNR	33.49	35.25	38.52	42.62	/
SSIM	0.8646	0.8719	0.9194	0.9646	/
Lpips	0.6257	0.5108	0.3228	0.1788	/

(2) Characterization of typical defects inside castings

In order to advance the application of TFM in casting inspection, the technology was used to characterise internal defects in castings. A 64-array probe with a mechanical encoder is used to sweep the casting, showing both the TFM B-scan and the TFM C-scan. As shown in Fig. 2, comparing the detection results with the DR results, typical defects such as shrinkage and porosity can be clearly distinguished in the C-scan. Moreover, the depth of defects can be determined in the B-scan, which cannot be achieved by DR.

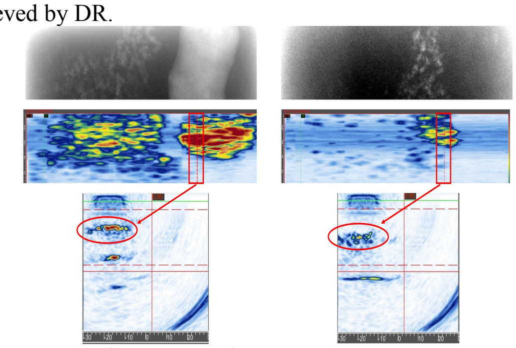

Figure 2 Comparison of DR and TFM detection results

4 Conclusion

In this paper, we construct a database containing images of different resolutions by means of deep learning to optimise the generation time of high-resolution images generated by the traditional TFM, which, compared with the 1024×1024 pixel generated by the TFM, can reach PSNR of about 39, SSIM of about 90, and the imaging time using the deep learning model is only 0.05s, which significantly improves the imaging speed. After realising the fast imaging, TFM B-scan and C-scan inspections were carried out on the castings, and the typical defects such as shrinkage and porosity in the castings were similar to the results of the DR inspection, and the TFM can provide the depth of the defects, which provides a solid theoretical basis for the application of the technology on the castings.

Reference

[1] Song H M, Yang Y C. Super-resolution visualization of subwavelength defects via deep learning-enhanced ultrasonic beamforming: A proof-of-principle study. NDT and E International, 2020, 116: 102344.