ULTRASONIC TESTING OF LARGE BLOCKS FOR PRESTRESSED CAST IRON PRESSURE VESSELS

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Summary.

Ultrasonic tests were made on plate specimen and large blocks of perlit cast iron with lamellar graphite. Aims of the investigations were the control of material properties, the flaw detection and flaw classification. The material properties were classified by sound velocity and attenuation measurements. Flaw detection and flaw size estimation methods were modified with regard to the acoustic properties, the microstructure and the reflectivity of typical flaws in castings. Special localisation and flaw size estimation techniques are discussed.

1. Introduction.

One of the main problems in quality assurance of prestressed cast iron pressure vessels is the nondestructive testing of the cast iron blocks. The material of these components is a perlit cast iron with lamellar graphite and guaranteed tensile and compressive strength of 200 $^{N}/_{mm^2}$ and 800 $^{N}/_{mm^2}$ respectively (Type SKM U 84, Fa. Siempelkamp, Krefeld, Germany). Some important characteristics of the material are

1. optimum relation between high compressive strength and tensile strength values,
2. sufficient material properties up to 350 °C,
3. optimum radiation protection characteristics.

Due to the design condition and the material properties nondestructive test methods were estimated with the result, that ultrasonic testing might be the most suitable.
The task of the ultrasonic test methods are

1. control of material properties,
2. detection and classification of inhomogenities in the components with the aim to guarantee a high quality level for all components.

The performance of the test and the reliability of the test results are in a high manner influenced by

1. the design and the geometry of the components,
2. the surfaces of the components, especially the coupling conditions of the probes at the surfaces,
3. the microstructure of the material.

2. Test equipment.

Comparatively to steel the testability of grey cast iron is restricted by the attenuation of ultrasonic waves, due to the high scattering effect of lamellar graphite, especially in materials with lower tensile strength. The restriction means low test frequencies (in the range of 0.5 or 1.0 MHz), a low signal to noise ratio ($^{S}/_{N}$ - value) and insufficient resolution of small defects or defects at a large distance from the probe.

Initial work was concentrated on optimisation of the test equipment. Common used test equipment was not able to fulfill all requirements. The adaption and application of a new developed narrowband emitter-system (1) with facilities of continous frequency variation, variation of pulse duration and pulse spectrum had the following result:

1. An increase in signal/noise ratio (about 15 dB).
2. Optimisation of test frequencies (in the range of 0.5 MHz and 1.2 MHz), according to the microstructure and the wall thicknesses.

The continous frequency variation in combination with an optimised pulse spectrum allowed the testing with small attenuation and optimum signal/noise ratio. On the other hand new techniques of differentiating between attenuation and defect influence on the signal amplitude seemed to be possible.

All above techniques shall be discussed with regard to material porperty control and defect detection in the following part more in detail.

3. Ultrasonic control of material properties.

Chemical composition and solidification procedure characterise the microstructure and determine the mechanical and acoustic properties of the material. The relation between mechanical properties (module of elasticity, tensile strength etc.) and acoustic properties (sound velocity and sound attenuation) has been described by many other authors (2,3 et al.). Only between elastic moduli and sound velocity there exists a direct physical relation. Other relations, for example between sound velocity and tensile strength, sound attenuation and microstructure, are limited to equivalent materials, alternating with melting performance, gas content, overheating and others. Therefore the facilities are restricted to measurements, which compare the component with a standard of wellknown properties. Investigating cast iron of type SKM U 84 the best classification could be made by measuring sound velocity and the signal/noise ratio. Attenuation measurements at constant frequencies were not able to characterise the material in a sufficient manner, due to the influence of local differences in sound velocity, leading to a deformation of the wave front and to errors in attenuation measurement. Better results were obtained by measuring the attenuation as function of the frequency. The local distortions can be detected by variation of test frequency, fig. 1. The curve type "A" shows the attenuation values as function of the frequency for different materials, the curve type "B" shows the disturbation effect caused by the deformation of the wave front and the influence of defects respectively.

4. Flaw detection and classification.

Common used techniques are

- measurement of flaw position,
- flaw size estimation according to the echoe height,
- flaw size estimation with help of scanning techniques.

Measurements on large blocks, fig. 2, with internal flaws had the result, that the above direct methods of flaw detection had to be adapted to the specific properties of the components and to be complemented by a suitable indirect method, controlling the behaviour of the backwall echoes at different frequencies.

4.1. Flaw detection.

Flaw detection in castings is sometimes difficult, caused by the unfavourable reflectivity characteristic of the typical defects with a porous structure. The simplest form of flaw detection is scanning the surface with a normal probe. This is the common used technique of testing castings like the investigated components. But using inclined shear wave probes too it was found, that the latter technique was significantly more sensitive. A lot of inhomogenities were detected only with shear waves. But the unfavourable reflection characteristic made it necessary to control all signals with a minimum level of 6 dB over the noise level. This high sensitivity in combination with a scanning technique allowed a localisation of the area of inhomogenities. The reason for the better detectibility of shear wave techniques might be the specific reflectivity behaviour of the flaw in the presence of shear waves and on the other hand the typical dynamic behaviour of the echoes, when the probe is moved over the flaw.

4.2. Flaw size estimation.

Flaw size estimation is one of the main problems in ultrasonic testing. Two techniques are currently used, one on the basis of the amplitude of the ultrasonic signal, the other by determining the external points of the defects.

The signal amplitude alternates with flaw geometry, its orientation and reflectivity characteristic, the distance between flaw and search unit, the influence of the coupling surface and the attenuation of the material.

In testing practice, to obtain a comparision of indications from natural flaws, artificial reference flaws are employed in the form of cylindrical holes, flat bottom holes, grooves and edges. One of the most convenient methods is the flaw size estimation with help of the DGS-diagram, comparing the flaw echoe with a disk. A special problem in handling the DGS-diagram is the compensation of coupling and attenuation influences.

In the case of testing cast iron with great coupling differences and high attenuation losses the sensitivity set was modified using the structural noise as reference level. It was found that the variation of the noise level is more influenced by coupling differences, less by the attenuation. On the other hand the signal amplitude is dependent on both significantly. The noise level changed with distance according to the relation

$EH \sim {}^{1}/_{s}$, with EH = echoe height and s = sound path.

Measuring noise level and attenuation at different points it is possible to construct the reference curve in the DGS-diagram, fig. 3. The flaw size estimation can be performed than by measuring the difference between noise level and signal amplitude.

In addition the DGS-diagram was modified for testing with different frequencies without changing the probe, fig. 4. The multiple frequency reflectivity diagram (MFR-diagram) allows a flaw size estimation in the same way as the DGS-diagram, including additional information about the reflectivity characteristic, the attenuation influence and others.
The DGS-diagram and the MFR-diagram are applicable only in the presence of small defects. The size of large defects can be measured by scanning methods, e.g. the 6 dB drop, fig. 5 and 6. As demonstrated in sect. 4.1. the external points of a flaw can be localised by shear wave techniques better. The appropriate reference level is the noise level too, especially for flaws with unfavourable reflectivity behaviour.

5. Acceptance criteria.

Acceptance criteria are material properties (in relation to a standard), size and quantitiy of indications, specified as function of the quality requirement for each component. They must be worked out in detail on the basis of these investigations according to the results of stress analysis.

6. Acknowledgements.

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7. Literature.

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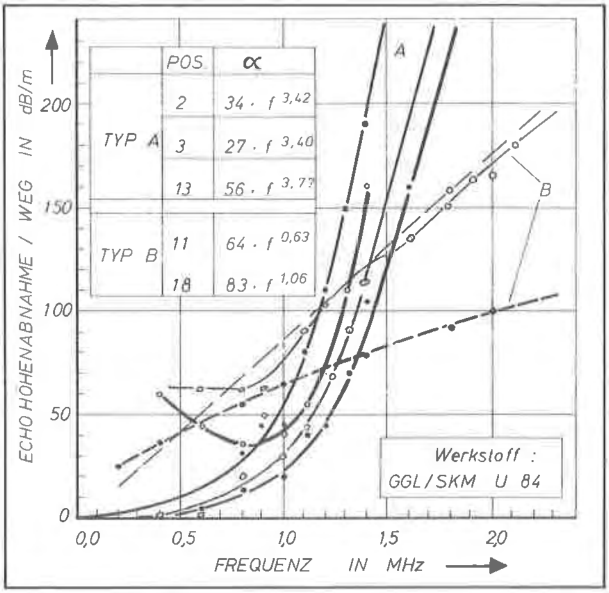


	POS	α
TYP A	2	$34 \cdot f^{3,42}$
	3	$27 \cdot f^{3,40}$
	13	$56 \cdot f^{3,77}$
TYP B	11	$64 \cdot f^{0,63}$
	18	$83 \cdot f^{1,06}$

Fig. 1: Attenuation of sound waves as function of frequency (Type A).
Influence of wave front deformation and defects respectively (Type B)

Fig. 2: Blocks of SKM U 84 with internal flaws for ultrasonic testing

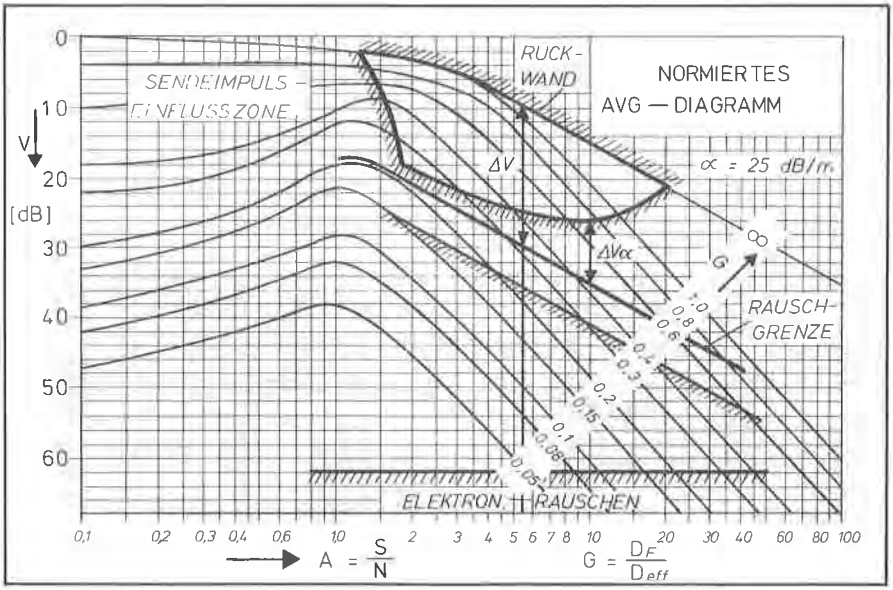


Fig. 3: DGS-diagram for ultrasonic flaw size estimation

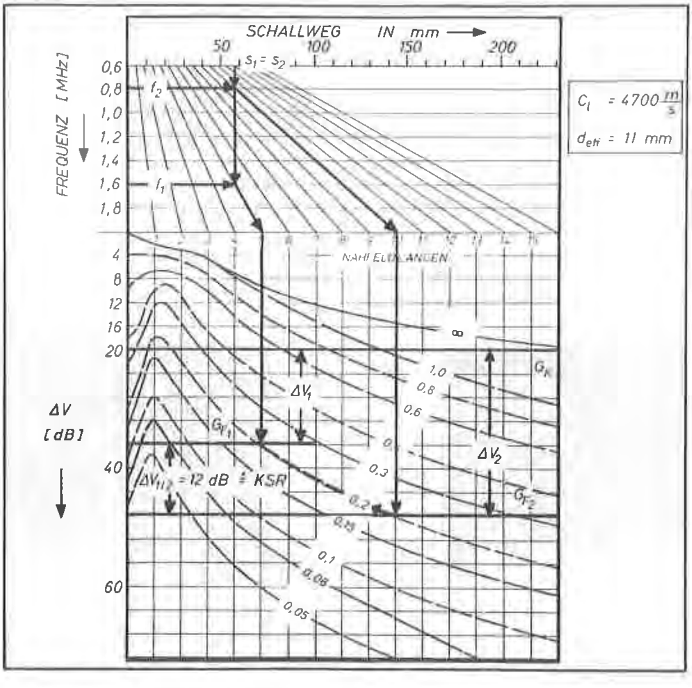


Fig. 4: MFR-diagram for flaw size estimation at different frequencies

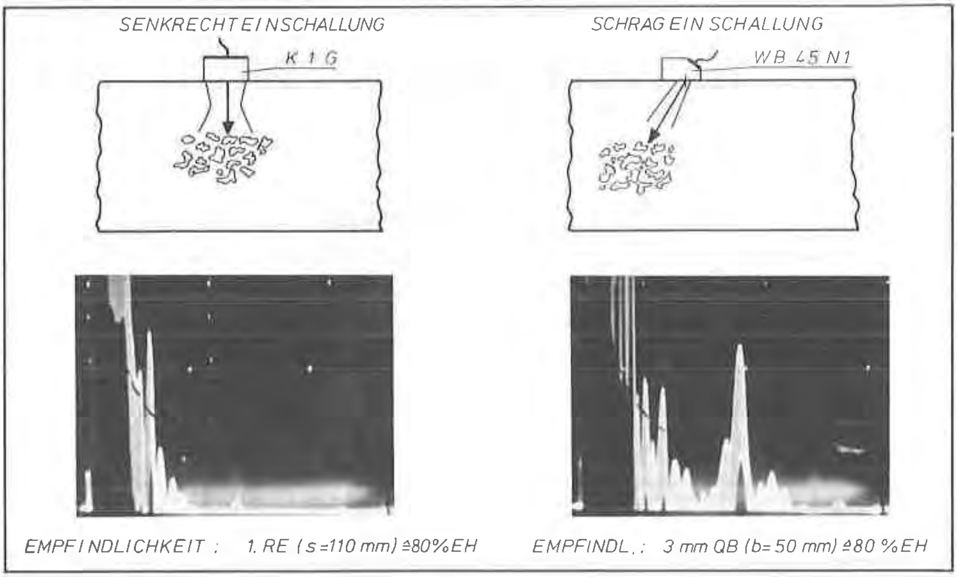
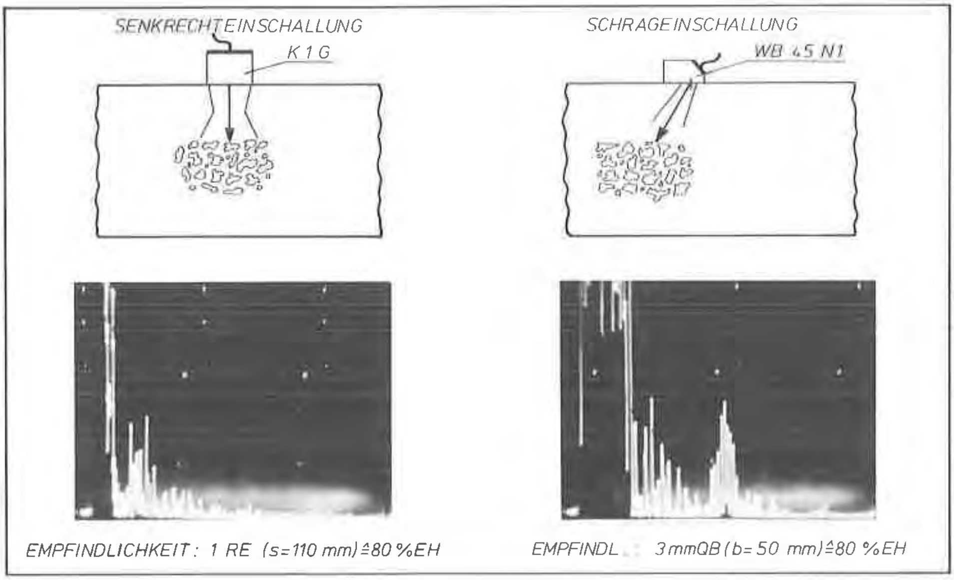


Fig. 5: Comparison of tests with normal and oblique search units (broadband system)



Gif. 6: Comparison of tests with normal and oblique search units (narrowband system)